OXFORD INSIGHT SCIENCE

AUSTRALIAN CURRICULUM FOR NSW

STAGE 5 **10**

JENNY ZHANG
SUSAN FILAN
SAMANTHA HOPLEY
RIC MORANTE
JEFF STANGER
CRAIG TILLEY

OXFORD

OXFORD

INSIGHT SCIENCE

AUSTRALIAN CURRICULUM FOR NSW

STAGE 5

10

JENNY ZHANG
SUSAN FILAN
SAMANTHA HOPLEY
RIC MORANTE
JEFF STANGER
CRAIG TILLEY

OXFORD
UNIVERSITY PRESS
AUSTRALIA & NEW ZEALAND

OXFORD
UNIVERSITY PRESS

Oxford University Press is a department of the University of Oxford. It furthers the University's objective of excellence in research, scholarship, and education by publishing worldwide. Oxford is a registered trademark of Oxford University Press in the UK and in certain other countries.

Published in Australia by
Oxford University Press
253 Normanby Road, South Melbourne, Victoria 3205, Australia

First published 2015

National Library of Australia Cataloguing-in-Publication data

Oxford Insight Science 10 student book / Jenny Zhang, Susan Filan, Samantha Hopley, Ric Morante, Jeff Stanger, Craig Tilley

ISBN 978 019 557757 0 (pbk plus obook/assess)

For secondary school age.
Science–Australia–Textbooks
507

Edited by Monica Schaak, Brigid Brignell and Catherine Greenwood
Illustrations by Alan Laver, Ian Laver
Typeset by Aisling Gallagher
Indexed by Mary Russell
Proofread by Liz Ward
Printed by Sheck Wah Tong

CONTENTS

CORRELATION TO THE NSW SYLLABUS FOR THE AUSTRALIAN CURRICULUM: SCIENCE STAGE 5

	Stage 5 outcomes		Insight Science 9						Insight Science 10							
		A student:	1 Inside the Atom	2 The Periodic Table	3 Understanding and Managing Ecosystems	4 Body Systems and Responses	5 Plate Tectonics	6 Energy on the Move	1 Genetics and Biotechnology	2 Evolution	3 Chemical Reactions	4 Using Chemistry	5 Objects in Motion	6 The Universe	7 Global Systems	8 Independent Research Project
Working Scientifically Skills	SC5-4WS	develops questions or hypotheses to be investigated scientifically	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	SC5-5WS	produces a plan to investigate identified questions, hypotheses or problems, individually and collaboratively		•	•	•	•	•	•	•		•	•	•	•	•
	SC5-6WS	undertakes first-hand investigations to collect valid and reliable data and information, individually and collaboratively	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	SC5-7WS	processes, analyses and evaluates data from a first-hand investigation and secondary sources to develop evidence-based arguments and conclusions	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	SC5-8WS	applies scientific understanding and critical thinking skills to suggest possible solutions to identified problems	•	•	•	•			•	•	•	•	•	•	•	•
	SC5-9WS	presents science ideas and evidence for a particular purpose and to a specific audience, using appropriate scientific language, conventions and representations	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Physical World	SC5-10PW	applies models, theories and laws to explain situations involving energy, force and motion						•					•			
	SC5-11PW	explains how scientific understanding about energy conservation, transfers and transformations is applied in systems						•					•			
	PW1	*Energy transfer through different mediums can be explained using wave and particle models. (ACSSU182)*						•								
	PW2	*The motion of objects can be described and predicted using the laws of physics. (ACSSU229)*											•			
	PW3	*Scientific understanding of current electricity has resulted in technological developments designed to improve the efficiency in generation and use of electricity.*						•								
	PW4	*Energy conservation in a system can be explained by describing energy transfers and transformations. (ACSSU190)*						•					•			

			Insight Science 9						Insight Science 10							
		A student:	1	2	3	4	5	6	1	2	3	4	5	6	7	8
Earth and Space	SC5-12ES	describes changing ideas about the structure of the Earth and the universe to illustrate how models, theories and laws are refined over time by the scientific community					●							●	●	
	SC5-13ES	explains how scientific knowledge about global patterns of geological activity and interactions involving global systems can be used to inform decisions related to contemporary issues					●								●	
	ES1	*Scientific understanding, including models and theories, are contestable and are refined over time through a process of review by the scientific community. (ACSHE157, ACSHE191)*												●		
	ES2	*The theory of plate tectonics explains global patterns of geological activity and continental movement. (ACSSU180)*					●									
	ES3	*People use scientific knowledge to evaluate claims, explanations or predictions in relation to interactions involving the atmosphere, biosphere, hydrosphere and lithosphere. (ACSHE160, ACSHE194)*													●	
Living World	SC5-14LW	analyses interactions between components and processes within biological systems			●	●			●	●						
	SC5-15LW	explains how biological understanding has advanced through scientific discoveries, technological developments and the needs of society			●	●			●	●						
	LW1	*Multicellular organisms rely on coordinated and interdependent internal systems to respond to changes in their environment. (ACSSU175)*				●										
	LW2	*Conserving and maintaining the quality and sustainability of the environment requires scientific understanding of interactions within, the cycling of matter and the flow of energy through ecosystems.*			●											
	LW3	*Advances in scientific understanding often rely on developments in technology, and technological advances are often linked to scientific discoveries. (ACSHE158, ACSHE192)*							●							
	LW4	*The theory of evolution by natural selection explains the diversity of living things and is supported by a range of scientific evidence. (ACSSU185)*								●						
Chemical World	*SC5-16CW*	explains how models, theories and laws about matter have been refined as new scientific evidence becomes available	●	●												
	SC5-17CW	discusses the importance of chemical reactions in the production of a range of substances, and the influence of society on the development of new materials									●	●				
	CW1	*Scientific understanding changes and is refined over time through a process of review by the scientific community.*	●													
	CW2	*The atomic structure and properties of elements are used to organise them in the periodic table. (ACSSU186)*		●												
	CW3	*Chemical reactions involve rearranging atoms to form new substances; during a chemical reaction mass is not created or destroyed. (ACSSU178)*									●					
	CW4	*Different types of chemical reactions are used to produce a range of products and can occur at different rates and involve energy transfer. (ACSSU187)*										●				

WHAT IS INSIGHT SCIENCE?

Oxford Insight Science is a comprehensive and flexible suite of resources designed specifically to address the NSW Syllabus for the Australian Curriculum: Science. Engaging content and activities for a range of abilities enable students to develop deep understanding of science concepts and transferable scientific skills, which promote scientifically literate citizenship.

FOUR STRANDS OF SCIENCE

Knowledge and Understanding of Science has been classified into four main strands of content and ideas. Within each strand, core concepts build on the previous year as students progress through the stages.

Physical World

Forces, motion, energy transfers and transformations, and the contribution of scientific and technological development to solving problems

Earth and Space

The Earth and its place in the solar system, the development of models and theories, resource use and management, and geological activity

Living World

Structure and function of living things, classification, interactions between living things and their environment, and the advancement of biological understanding through technological development

Chemical World

Properties of matter and arrangement of particles, relating properties to uses, chemical reactions produce new substances, and the refinement of models, theories and laws with new scientific evidence

WORKING SCIENTIFICALLY

Knowledge and understanding of scientific ideas is gained through the application of scientific skills. The development of these key skills enables students to transfer them to new situations and, through inquiry, discover new ideas for themselves. The use of scientific skills promotes deeper understanding of and greater engagement with content.

The Working Scientifically skills of the NSW Syllabus are scaffolded and integrated throughout all experiments and activities within the *Oxford Insight Science* series:

Questioning and predicting

Identifying problems, and developing predictions and testable hypotheses

Planning investigations

Collaboratively and individually develop plans to investigate questions, problems and hypotheses

Conducting investigations

Collaboratively and individually follow instructions to safely conduct investigations and collect valid and reliable data

Processing and analysing data and information

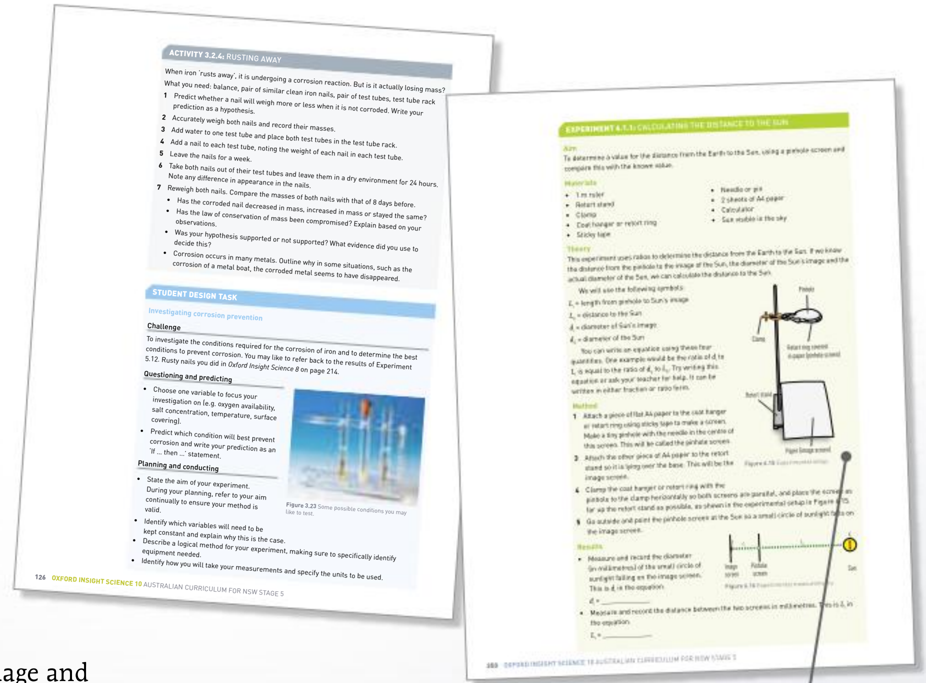
Process and analyse first- and second-hand data to identify trends and relationships and to draw conclusions based on evidence

Problem solving

Develop and use appropriate strategies to produce plausible solutions for problems

Communicating

Present science ideas in a manner, language and presentation type appropriate for a specific purpose or audience


ACTIVITY 3.2.4: RUSTING AWAY

When iron 'rusts away', it is undergoing a corrosion reaction. But is it actually losing mass?
What you need: balance, pair of similar clean iron nails, pair of test tubes, test tube rack

1 Predict whether a nail will weigh more or less when it is not corroded. Write your prediction as a hypothesis.
2 Accurately weigh both nails and record their masses.
3 Add water to one test tube and place both test tubes in the test tube rack.
4 Add a nail to each test tube, noting the weight of each nail in each test tube.
5 Leave the nails for a week.
6 Take both nails out of their test tubes and leave them in a dry environment for 24 hours. Note any difference in appearance in the nails.
7 Reweigh both nails. Compare the masses of both nails with that of 8 days before.
- Has the corroded nail decreased in mass, increased in mass or stayed the same?
- Has the law of conservation of mass been compromised? Explain based on your observations.
- Was your hypothesis supported or not supported? What evidence did you use to decide this?
- Corrosion occurs in many metals. Outline why in some situations, such as the corrosion of a metal boat, the corroded metal seems to have disappeared.

STUDENT DESIGN TASK

Investigating corrosion prevention

Challenge

To investigate the conditions required for the corrosion of iron and to determine the best conditions to prevent corrosion. You may like to refer back to the results of Experiment 5.12. Rusty nails you did in *Oxford Insight Science 8* on page 214.

Questioning and predicting

- Choose one variable to focus your investigation on (e.g. oxygen availability, salt concentration, temperature, surface covering).
- Predict which condition will best prevent corrosion and write your prediction as an 'If ... then ...' statement.

Planning and conducting

- State the aim of your experiment. During your planning, refer to your aim continually to ensure your method is valid.
- Identify which variables will need to be kept constant and explain why this is the case.
- Describe a logical method for your experiment, making sure to specifically identify equipment needed.
- Identify how you will take your measurements and specify the units to be used.

Figure 3.23 Some possible conditions you may like to test.

126 OXFORD INSIGHT SCIENCE 10 AUSTRALIAN CURRICULUM FOR NSW STAGE 5

EXPERIMENT 4.1.1: CALCULATING THE DISTANCE TO THE SUN

Step-by-step instructional diagrams model correct scientific skills and techniques in experiments

ENGAGING LEARNING

Each Student Book chapter is designed to visually and creatively engage students with beautiful artwork, photographs, case studies, source material and in-depth coverage of each topic being studied. Supported by numerous experiments and activities suitable for classrooms and different learning styles, all students have the opportunity to engage with science and their own learning.

Spectacular and current photography bring science to life.

Question blocks throughout the text for constant review of knowledge and concepts.

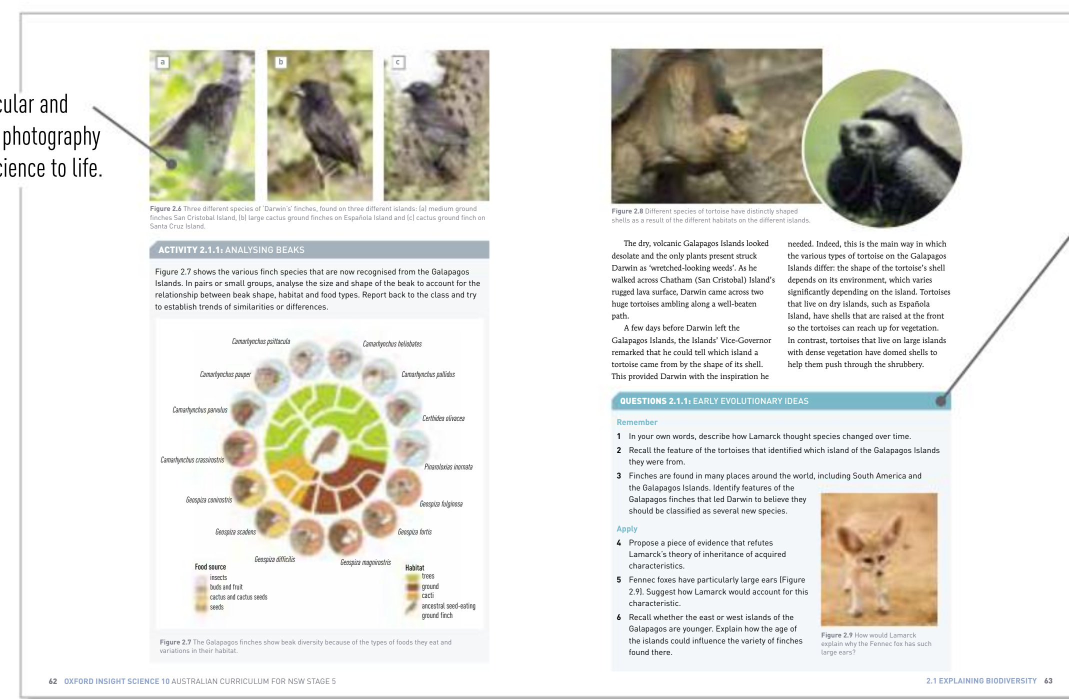


Figure 2.6 Three different species of 'Darwin's' finches, found on three different islands: (a) medium ground finches San Cristobal Island, (b) large cactus ground finches on Española Island and (c) cactus ground finch on Santa Cruz Island.

ACTIVITY 2.1.1: ANALYSING BEAKS

Figure 2.7 shows the various finch species that are now recognised from the Galapagos Islands. In pairs or small groups, analyse the size and shape of the beak to account for the relationship between beak shape, habitat and food types. Report back to the class and try to establish trends of similarities or differences.

Figure 2.7 The Galapagos finches show beak diversity because of the types of foods they eat and variations in their habitat.

Figure 2.8 Different species of tortoise have distinctly shaped shells as a result of the different habitats on the different islands.

The dry, volcanic Galapagos Islands looked desolate and the only plants present struck Darwin as 'wretched-looking weeds'. As he walked across Chatham (San Cristobal) Island's rugged lava surface, Darwin came across two huge tortoises ambling along a well-beaten path.

A few days before Darwin left the Galapagos Islands, the Islands' Vice-Governor remarked that he could tell which island a tortoise came from by the shape of its shell. This provided Darwin with the inspiration he needed. Indeed, this is the main way in which the various types of tortoise on the Galapagos Islands differ: the shape of the tortoise's shell depends on its environment, which varies significantly depending on the island. Tortoises that live on dry islands, such as Española Island, have shells that are raised at the front so the tortoises can reach up for vegetation. In contrast, tortoises that live on large islands with dense vegetation have domed shells to help them push through the shrubbery.

QUESTIONS 2.1.1: EARLY EVOLUTIONARY IDEAS

Remember

1 In your own words, describe how Lamarck thought species changed over time.
2 Recall the feature of the tortoises that identified which island of the Galapagos Islands they were from.
3 Finches are found in many places around the world, including South America and the Galapagos Islands. Identify features of the Galapagos finches that led Darwin to believe they should be classified as several new species.

Apply

4 Propose a piece of evidence that refutes Lamarck's theory of inheritance of acquired characteristics.
5 Fennec foxes have particularly large ears (Figure 2.9). Suggest how Lamarck would account for this characteristic.
6 Recall whether the east or west islands of the Galapagos are younger. Explain how the age of the islands could influence the variety of finches found there.

Figure 2.9 How would Lamarck explain why the Fennec fox has such large ears?

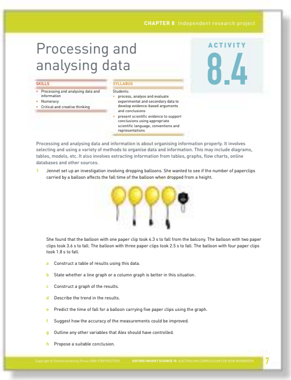
62 OXFORD INSIGHT SCIENCE 10 AUSTRALIAN CURRICULUM FOR NSW STAGE 5

2.1 EXPLAINING BIODIVERSITY 63

INTEGRATED TEACHING AND LEARNING SUPPORT

obook + assess

Access to Oxford's electronic book format — the obook — is included with this Student Book and offers online and offline access to the complete Student Book in an easy-to-read format for any screen size, with multimedia links, interactive learning objects, videos, note-taking tools and dynamic question blocks. Oxford's obook is compatible with laptops, iPads, tablets and IWBs. assess provides 24/7 online assessment designed to support individual student progression and learning.


Processing and analysing data

ACTIVITY 8.4

Workbook

Oxford Insight Science is supported by a Workbook for each of the years 7–10. The Workbooks provide extra practice of key skills and encourage an inquiry-based approach to learning — perfect for use in class or for homework.

obook + assess teacher

obook and assess teacher includes all content from the Student Book with a huge range of teaching support for mixed ability classes:

- Comprehensive syllabus mapping and customisable teaching programs.
- Hundreds of teaching strategies, additional activities and lesson planning tips.
- Checkpoint worksheets, differentiated to suit different abilities and learning styles.
- Advice on addressing common misconceptions.
- Support for Student Book experiments, student-designed investigations and activities, including risk assessment templates.
- Suggested answers to all Student Book and Workbook questions.
- Ability to assign reading and extras to students or classes.
- Access to a testbank (of unseen questions), auto-marking assessments and class progress and results.

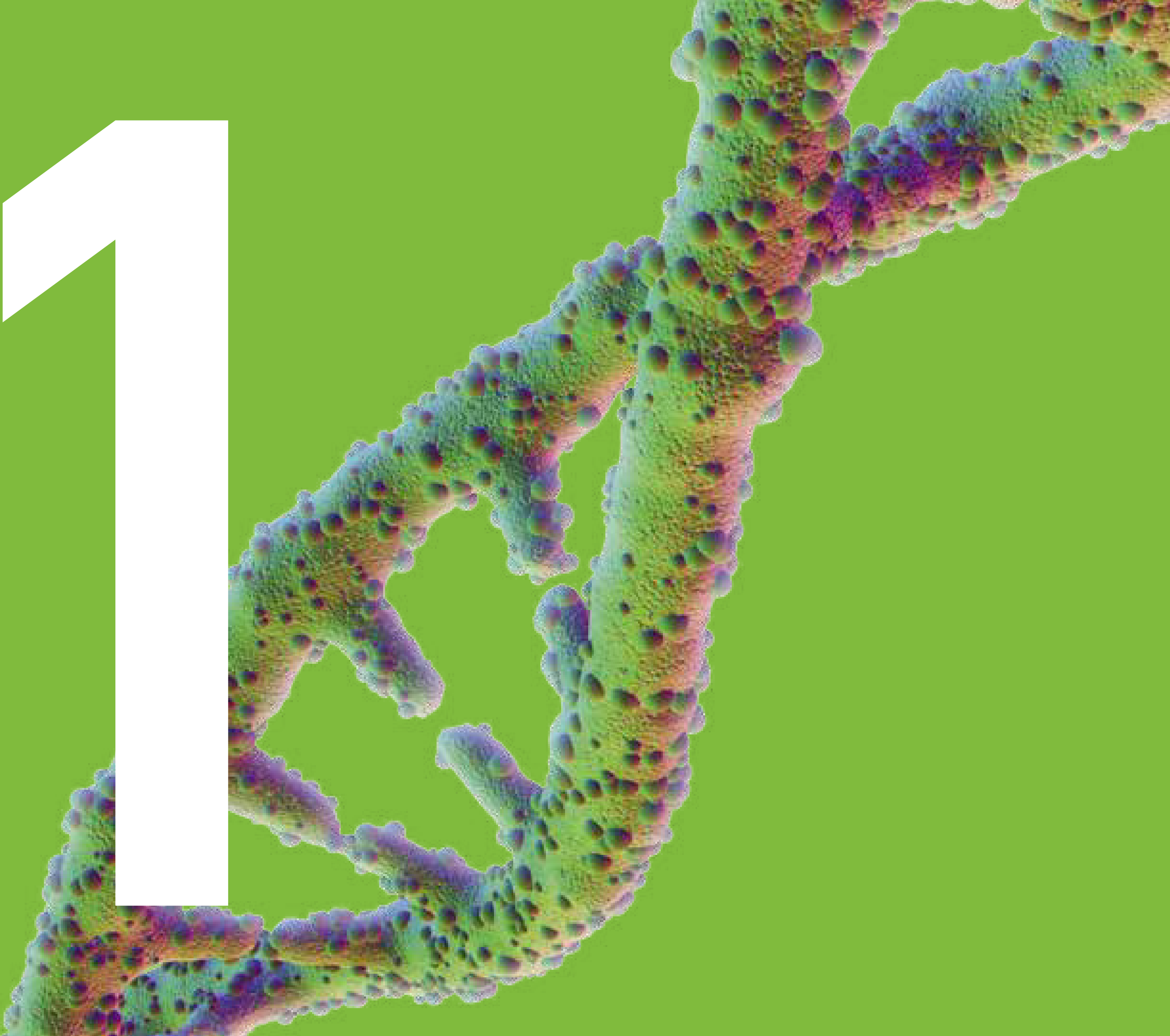
ANSWERING SCIENCE QUESTIONS

In the senior sciences, questions asked in examinations are often phrased as statements, which begin with a verb such as 'identify' or 'justify'. While not all questions are structured in this way, it is important to learn how to respond to these types of questions. In this book, many of the questions start with these verbs. The table below gives a quick guideline to the level of response and the types of information required for **some** of the verbs that you are likely to come across.

← Increasing in complexity

Verb	Explanation
Recall	Usually based on a simple fact or theory. Requires you to remember ideas or facts and present them.
Identify	Can be completed in a sentence or two. Recognise the content and name certain features.
Define	Identify the main qualities and/or state the meaning.
Outline	Give the main features of something in general terms.
Calculate	Use calculations to determine information from facts or figures.
Deduce	Make conclusions based on information given.
Account	Give reasons for the statement/s made.
Predict	Suggest what may happen. This usually needs to be based on the information available.
Describe	Give features and characteristics.
Distinguish	Note how things are different.
Compare	Show how things are different and similar.
Contrast	Show how things are different. Contrast is often used with compare in order to look at both similarities and differences.
Interpret	Usually refers to figures, diagrams or graphs. Find meaning of the trends, or draw meaning from the diagrams.
Propose	Usually used in conjunction with other verbs, 'propose' typically requires you to put forward an action.
Explain	Give reasons for the statement/s made relating cause and effect. Generally, you will need to link ideas and statements by looking at the relationship between them.
Analyse	Identify the key components of the context and explain the relationship/s between them. Relate cause and effect and relate this to implications.
Justify	Support a statement, argument or conclusion based on your understanding and/or scientific knowledge. This usually requires you to explain your reasoning in order to justify a statement.
Discuss	Provide points for and against a particular issue. This usually requires you to use evidence from given information as well as your background understanding.
Assess	Based on the information given, and through thorough discussion, make a judgement regarding the content. A question beginning with the verb 'assess' is typically an extended response requiring a high level of succinctness and depth in the answer. Ensure you include a judgement statement based on the evidence you provide.
Evaluate	Similar to an assess question, an evaluate question requires you to make a judgement. The key difference is that evaluations require a judgement based on a given criteria and require you to make a statement regarding the value of the context.

1



GENETICS AND BIOTECHNOLOGY

Over hundreds of millions of years, an incredibly diverse range of living things has evolved on the Earth. This variety enables each organism to occupy a slightly different niche in the environment. Variation in the physical make-up and behaviour between organisms is controlled by an amazing molecule called DNA.

DNA AND THE GENETIC CODE 1.1

DNA is often called the blueprint of an organism and contains all the information required to produce a functioning cell. DNA is a long, chain-like molecule made up of just four units repeated in varying orders. The sequence of these units forms the genetic code, which provides the instructions for making proteins. DNA is passed from parents to offspring via gametes that fuse together to form unique combinations.

Students:

- » identify that genetic information is coded in lengths of DNA called genes, which are joined together as chromosomes
- » outline the Watson–Crick model of DNA, and how it applies to replication and mutation
- » relate the structure and function of human reproductive organs

GENETIC INHERITANCE 1.2

About 100 years before the genetic code of DNA was identified, Gregor Mendel discovered that genes and their different combinations are inherited by offspring from their parents. He determined that the phenotype, or physical manifestation, of an individual is dependent on the combination of alleles and that some alleles, are dominant over others. The patterns of inheritance established by Mendel still hold true today.

Students:

- » identify that heritable characteristics are controlled by the transmission of genes and chromosomes

GENE TECHNOLOGY 1.3

Technologies such as genetic sequencing enable geneticists to locate and identify mutations, and to insert new genes into faulty DNA to repair it. Useful genes from one species can be inserted into the DNA of a different species to create transgenic organisms with particular characteristics that benefit humans. The scope and applications of gene technology is vast, but just because we have the technology, it does not necessarily mean we should always use it. Many gene technologies involve ethical issues that must be considered.

Students:

- » describe how developments in genetic technology have advanced medical understanding
- » discuss some ethical advantages and disadvantages of biotechnology
- » assess the role of computers in DNA sequencing and analysis (additional content)
- » research the applications of bioinformatics (additional content)

1.1 DNA AND THE GENETIC CODE

In 1953, James Watson and Francis Crick were the first scientists to determine the structure of DNA. This molecule is contained within the cells of all living organisms and it controls all the characteristics of life. The structure of human DNA is now well understood. However, genetic research continues so that we can understand the genomes of other species, how genes from different organisms can interact, and how this information can be used to improve our lives and health.

THE STRUCTURE OF DNA

Deoxyribonucleic acid (DNA) exists within all living cells and is like a blueprint for every structure and function in an organism. It contains a code unique to the individual that can be passed to offspring, generation after generation. The DNA molecules of all living things on the Earth have the same general structure, but each species has its own unique DNA that defines the species. There are also slight differences in the DNA between individuals within a species, which is why we are all unique. Understanding the structure of DNA enables us to explain not only the similarities that exist between and within species, but also the differences.

Watson and Crick

James Watson and Francis Crick (Figure 1.1) worked together at the University of Cambridge in the United Kingdom during the early 1950s. Watson was a young chemist from the United States and Crick was a physicist from the United Kingdom. As a team they unravelled the secret of the DNA structure; however, they performed no experiments themselves. Instead, their talent lay in interpreting secondary data – the experimental results of others.

There was a lot of information available about DNA when Watson and Crick began their investigation. This information included the following:

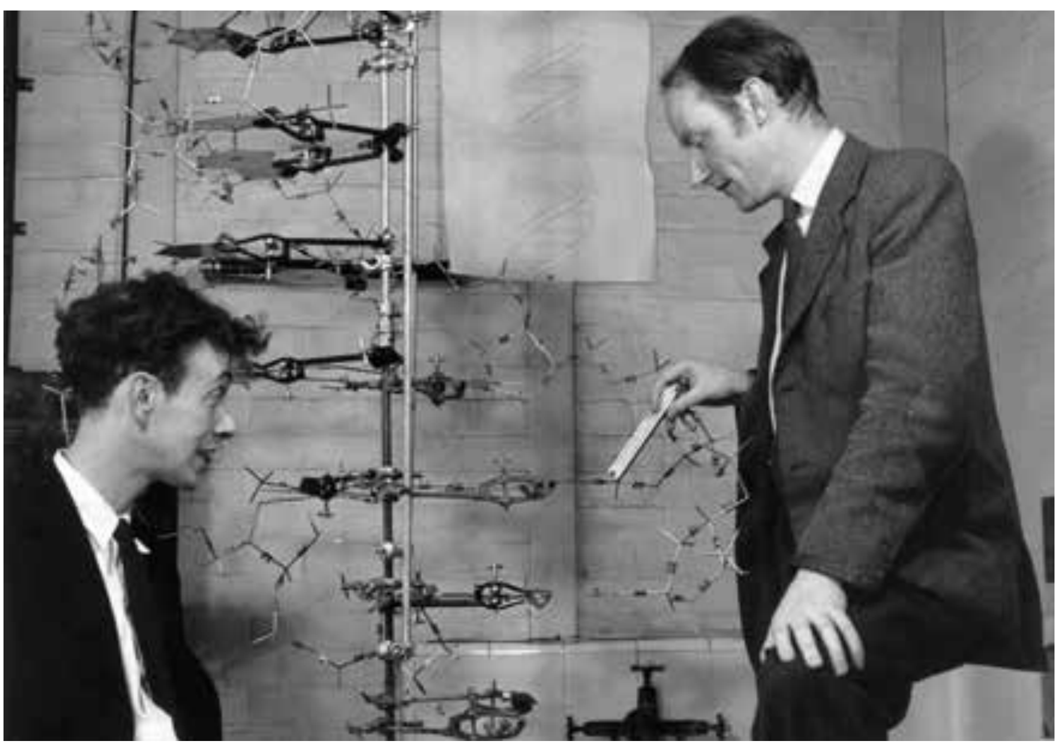


Figure 1.1 Watson and Crick working on their model of DNA. Note the diagram on the wall.

- DNA was known to be a large, long, thin molecule composed of units called nucleotides containing the nitrogenous bases adenine (A), guanine (G), cytosine (C) and thymine (T).
- Russian biochemist Phoebus Levene thought the four bases were arranged in a fixed, repeating pattern.
- American biochemist Linus Pauling's work on proteins led him to believe that DNA had a helical or spiral structure.
- X-ray crystallography pictures of DNA (Figure 1.2b) from the laboratories of Maurice Wilkins and Rosalind Franklin of King's College, London, showed markings that almost certainly indicated the turns of a giant helix.
- American biochemist Erwin Chargaff's data indicated that the amount of adenine equalled the amount of thymine, and that the amount of guanine equalled the amount of cytosine.

Watson and Crick tried to put all this information together and build a model of the structure of DNA. In February 1953 they completed their model, which established the now familiar structure of DNA – the **double helix**.

a

b

Figure 1.2 (a) Rosalind Franklin and (b) the X-ray crystallography that she took of DNA.

LITERACY BUILDER

An incredible woman

Rosalind Elise Franklin – Pioneer molecular biologist (born 25 July 1920, died 16 April 1958)

There is probably no other woman scientist with as much controversy surrounding her life and work as Rosalind Franklin. Franklin was responsible for much of the research and discovery work that led to the understanding of the structure of deoxyribonucleic acid, DNA. The story of DNA is a tale of competition and intrigue, told one way in James Watson's book, *The Double Helix*, and in quite another in Anne Sayre's study, *Rosalind Franklin and DNA*. In 1962, only James Watson, Francis Crick and Maurice Wilkins received the Nobel Prize for the double-helix model of DNA, four years after Franklin's death at age 37 from ovarian cancer.

Figure 1.3 Rosalind Franklin hard at work.

Franklin excelled at science and attended one of the few girls' schools in London that taught physics and chemistry. When she was 15, she decided to become a scientist. Her father was decidedly against higher education for women and wanted Rosalind to be a social worker. Ultimately he relented, and in 1938 she enrolled at Newnham College, Cambridge, graduating in 1941. She held a graduate fellowship for a year, but quit in 1942 to work at the British Coal Utilization Research Association, where she made fundamental studies of carbon and graphite microstructures. This work was the basis of her doctorate in physical chemistry, which she earned from Cambridge University in 1945.

She then spent three years (1947–1950) in Paris at the Laboratoire Central des Services Chimiques de L'Etat, where she learned X-ray diffraction techniques. In 1951, she returned to England as a research associate in John Randall's laboratory at King's College, London.

There she crossed paths with Maurice Wilkins. She and Wilkins led separate research groups and had separate projects, although both were concerned with DNA. Randall gave Franklin responsibility for her own DNA project. Wilkins was away at the time, and when he returned he misunderstood her role, behaving as though she were a technical assistant. Both scientists were actually peers. His mistake, acknowledged but never overcome, was not surprising given the climate for women at the university then. Only men were allowed in the university dining rooms, and after hours Franklin's colleagues went to men-only pubs.

But Franklin persisted on the DNA project. J. D. Bernal called her X-ray photographs of DNA, 'the most beautiful X-ray photographs of any substance ever taken'. Between 1951 and 1953 Rosalind Franklin came very close to solving the DNA structure. Crick and Watson beat her to publication, in part because of the friction between Wilkins and herself. At one point, Wilkins showed Watson one of Franklin's crystallographic portraits of DNA. When he saw the picture, the solution became apparent to him, and the results went into an article in *Nature* almost immediately. Franklin's work did appear as a supporting article in the same issue of the journal.

A debate about the amount of credit due to Franklin continues. What is clear is that she did have a meaningful role in discovering the structure of DNA and that she was a scientist of the first rank. Franklin moved to J. D. Bernal's lab at Birkbeck College, where she did very fruitful work on the tobacco mosaic virus. She also began work on the polio virus. In the summer of 1956, Rosalind Franklin became ill with cancer. She died less than two years later.

Questions

1 Discuss (in groups and then as a whole class) the controversy surrounding Rosalind Franklin's role in the discovery of DNA, and her impact on science.

2 Is the language in the article intended for the general public or the scientific community? Explain your answer.

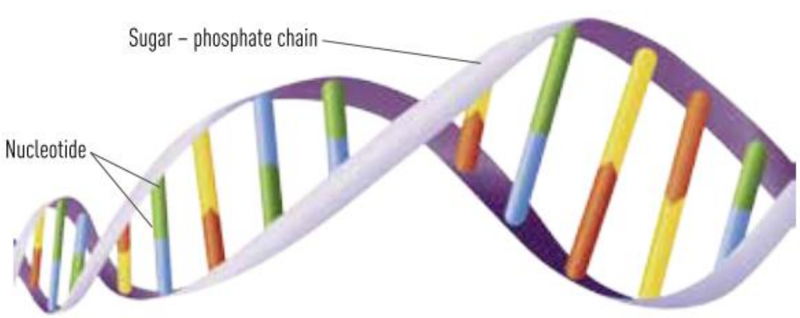


Figure 1.4 The double helix is composed of two sugar–phosphate chains joined together by complementary pairs of nucleotides.

The double helix

DNA is a type of nucleic acid. **Nucleic acids** are specific types of chemical, like proteins, lipids or carbohydrates. There are two main types of nucleic acids: DNA and RNA (ribonucleic acid). Nucleic acids are polymers, which are chemical structures made up of repeating units (nucleotides in this case). The **Watson–Crick model** of DNA as a double-helix structure can be likened to a ladder twisted into a spiral.

NUCLEOTIDES

A nucleotide is the basic unit of nucleic acids. Nucleotides are complex molecules made up of three components:

- a nitrogenous **base**
- a five-carbon sugar
- a phosphate group.

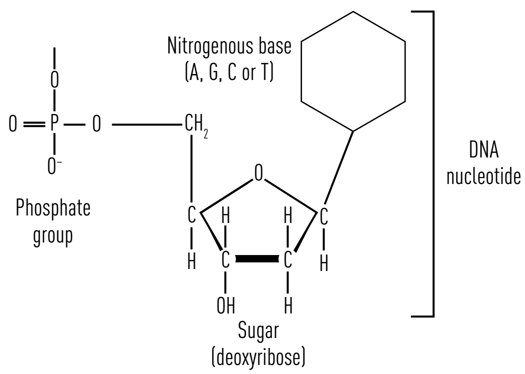


Figure 1.5 The structure of a DNA nucleotide.

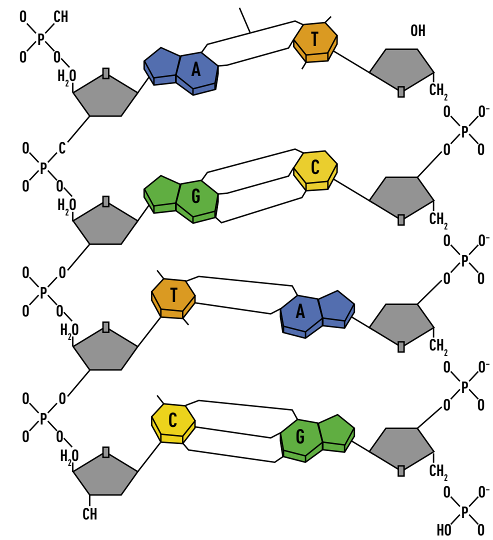
DNA contains the sugar deoxyribose and the four bases adenine (A), guanine (G), cytosine (C) and thymine (T).

Nucleotides are joined together by their sugar and phosphate groups. This forms a **sugar–phosphate backbone**. The bases are attached to the sugars and are at right angles to the sugar–phosphate backbone, like the rungs in a ladder. Any number of nucleotides can join together, in any order, to form the nucleic acid polymer, or polynucleotide chain.

One of the greatest achievements of Watson and Crick was their realisation that bases on one polynucleotide strand are bonded to bases on the other strand, with A always bonding with T, and G always bonding with C. The implications of the results of Chargaff's research, with DNA containing similar percentages of A and T, and C and G, were suddenly obvious. These base pairs are called complementary bases or complementary base pairs.

Two polynucleotide chains, or strands, are attracted to each other due to the chemical nature of the complementary bases. This is important for the easy 'unzipping' of the ladder during replication. A large base (adenine or guanine) is always bonded to a small base (thymine or cytosine) because this gives a consistent amount of space between the strands.

The two chains then wind into a double helix.



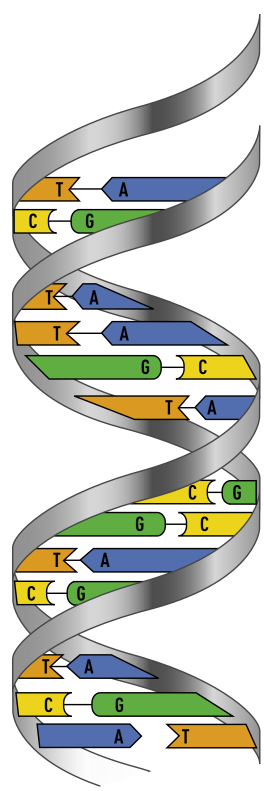


Figure 1.6 Two polynucleotide strands held together with hydrogen bonds between complementary base pairs.

RNA is a single-stranded polynucleotide with a similar sugar–phosphate backbone to that of DNA. However, RNA contains the sugar ribose and the four bases adenine (A), guanine (G), cytosine (C) and uracil (U). RNA plays a key role in protein synthesis.

ACTIVITY 1.1.1: MODELLING DNA

What you need: coloured card, scissors, sticky tape, paper clips

Use the materials provided, or other craft materials available, to construct an accurate representation of the DNA double helix. Features that must be represented are pairing between the complementary bases, the structure of the sugar–phosphate backbone and the hydrogen bonding between strands.

Genes and chromosomes

DNA is located in the nucleus of organisms, where it looks a little like a tangled pile of cotton threads. Theoretically, the polynucleotide strands can be infinitely long, but they actually form specific lengths called **chromosomes**. The number of chromosomes per cell and the length of each chromosome vary between species. However, the number of chromosomes is not necessarily an indication of organism complexity. Table 1.1 shows the number of chromosomes of a variety of different organisms.

Table 1.1 Chromosome numbers in various organisms.

Organism	Number of pairs of chromosomes	Total number of chromosomes
Drosophila (fruit fly)	4	8
Kangaroo	6	12
Amoeba	6	12
Pea	7	14
Yeast	16	32
Cat	19	38
Human	23	46
Dingo	39	78
Shrimp	127	254
Fern	600	1200

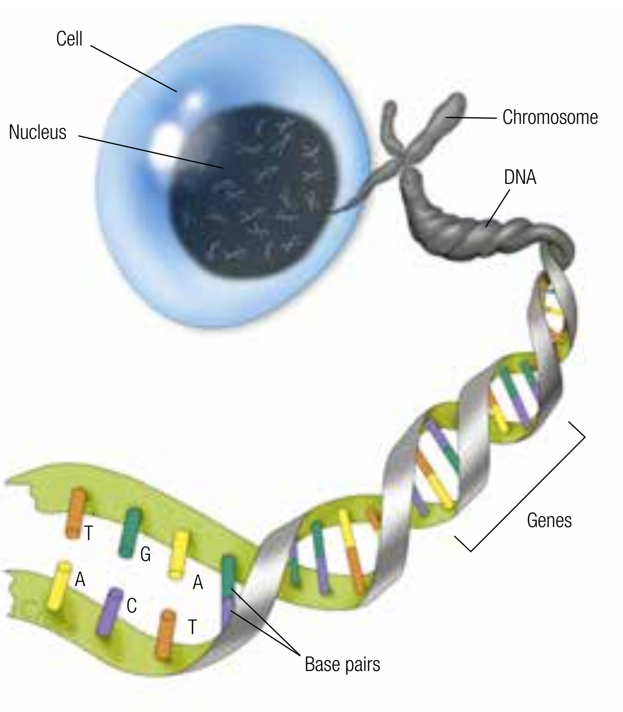


Figure 1.7 The relationship between DNA, genes and chromosomes.

The number of chromosomes per species is always an even number because chromosomes exist in **homologous pairs**. During sexual reproduction, each parent provides one set of chromosomes. The chromosomes are paired according to their length, which is determined by the genes they carry. A **gene** is a length of DNA that has a specific sequence of base pairs and codes for a particular characteristic. For example, a gene may have the information for making the melanin (a pigment that gives colour to your skin), for making insulin, or even for determining shape of your hairline. A single chromosome may have hundreds or even thousands of genes.

Chromosomes can be extracted from a cell, stained and photographed through a digital microscope. The image is called a **karyotype** and is used to identify chromosomal abnormalities.

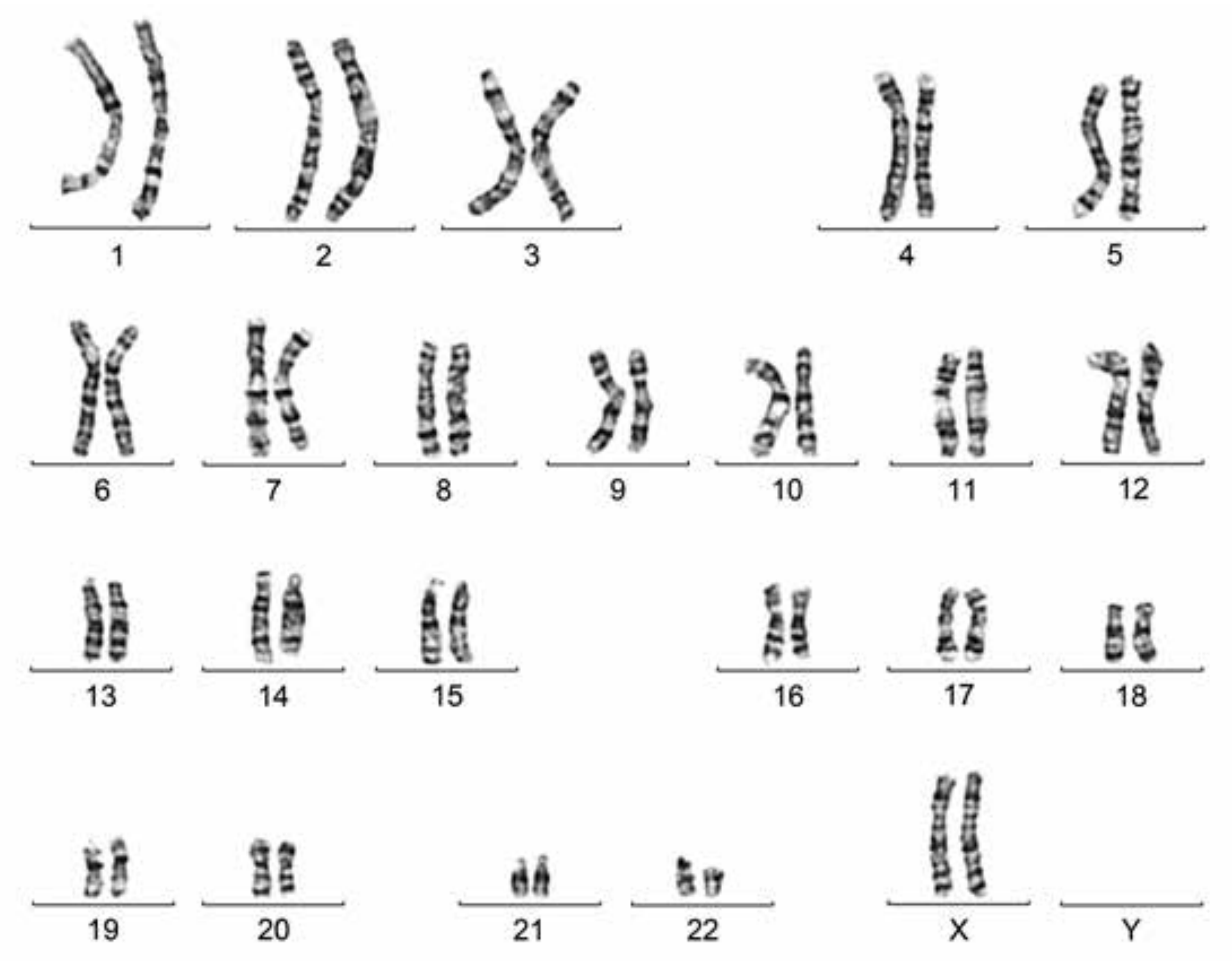


Figure 1.8 A karyotype of a female human.

EXPERIMENT 1.1.1: EXTRACTING DNA

Aim

To extract and observe DNA from cells.

Part A

Materials

- 100 g dried peas or frozen peas (thaw first)
- 200 mL water
- 6 g table salt
- 20 mL dishwashing liquid
- 1 g meat tenderiser
- Blender
- 1L beaker
- Sieve
- Stirring rod or spoon
- Timer

Method

1. Dissolve the salt in the water.
2. Combine the peas and salty water in the blender. Mix for 15 seconds to form a lumpy liquid in which the peas are only just broken up. Do not overblend.
3. Pour the contents through a sieve into the 1L beaker. Discard the pulp in the sieve.
4. Add the dishwashing liquid to the filtrate and stir gently to avoid making bubbles. Stir for 8 minutes.
5. Add the meat tenderiser and continue to stir gently for another 2 minutes. This mixture is the source of DNA needed for Part B of the experiment.

Part B

WARNING

> Ethanol is flammable. Keep well away from naked flames.

Materials

- Test tubes and test tube holder
- Ice-cold ethanol
- Skewer or glass stirring rod
- Microscope
- Clean microscope slides and cover slips
- Methylene blue stain

Method

1. Pour 15 mL of the DNA source (pea filtrate from Part A) into a test tube.
2. Dribble 15 mL ice-cold ethanol down the side of the test tube – there should be equal amounts of filtrate and ethanol in the test tube.
3. Leave the test tube to separate into layers. This will take at least 10 minutes. The alcohol will eventually settle on top of the watery pea mixture. DNA is less dense than water and should float up into the alcohol layer, leaving the other cellular components behind.
4. When the mixture has separated completely, use a stirring rod to gently twirl and twist the DNA to collect it from the alcohol layer. DNA looks white.
5. Gently spread a small amount of the DNA sample onto a glass slide. Add 1 drop of methylene blue stain to the DNA sample. Place the cover slip on the edge of the methylene blue and allow it to fall into place. This should eliminate any air bubbles.
6. Look at your sample under ×10 magnification. Once focused, you can then try the higher magnifications using the fine focus knob. You will not see the double-helix strands, but you should see clumps of DNA material that may look like a tangled mass of strands.

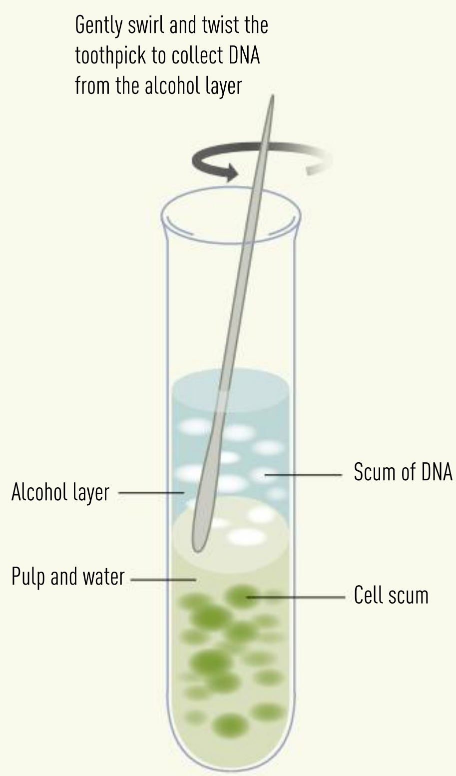


Figure 1.9 Procedure for collecting DNA from the alcohol layer.

Results

Present your results as a labelled diagram, with several short statements or labels explaining your observations.

Discussion

1 Briefly describe the appearance of the DNA.
2 Do you think human DNA will look the same as the DNA from peas?
3 In homes, dishwashing liquid is used to degrease fat from dishes. Meat tenderiser works to break down some of the proteins in meat. Alcohol can be used to dehydrate or dry moisture. With this in mind, suggest the role of each additive in the DNA extraction.
4 What materials remain in the watery layer? Justify your answer.
5 Describe any problems you encountered and suggest ways to improve your experimental technique.

Conclusion

Summarise the outcomes of this experiment.

QUESTIONS 1.1.1: THE STRUCTURE OF DNA

Remember

1 Describe the structure of a nucleotide and recall the names of the four bases of DNA.
2 Describe how nucleotides join to form polynucleotides.
3 Identify the part(s) of DNA that remain constant and the part(s) that are variable.
4 Identify the differences between DNA and RNA.
5 Identify the type of bond that holds the two polynucleotide chains together.

Apply

6 Explain how the order of the bases on one polynucleotide chain determines the order of the bases on the other chain.
7 Explain the relationship between DNA, chromosomes and genes.
8 In your own words, describe the double-helix structure of DNA using the ladder analogy, or one of your own.

Create

9 Draw an annotated timeline showing the major contributors and their contributions to the discovery of the structure of DNA.

REPLICATION AND CELL DIVISION

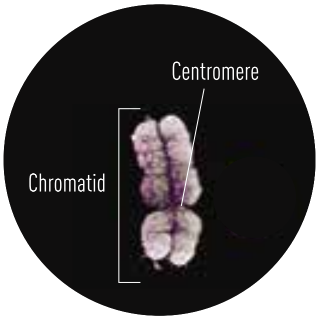


Figure 1.10 After replication, the doubled chromosome is made up of two sister chromatids joined at the centromere.

The genes that make up chromosomes hold the code for every characteristic of an organism. A full set of these blueprints is present in almost every cell of a multicellular organism. The few exceptions include red blood cells, which do not have a nucleus, and gametes (sperm and ova), which only have one set of chromosomes rather than pairs.

Two forms of cell division create new cells in a multicellular organism: mitosis and meiosis. The process and purpose of these two types of division are different, but they both begin by copying the cell's DNA so each new cell contains the correct number of chromosomes.

Replication of DNA

Watson and Crick determined that, because of the double-stranded structure of DNA and complementary base pairing, DNA could make copies of itself with a process called **replication**.

With the aid of several specific enzymes, the hydrogen bonds between bases are broken in sections so that the strands separate and expose the bases. Spare nucleotides that are floating around in the nucleus are added in a complementary sequence to the exposed strands until two full new strands have been completed.

Replication is the first stage of both mitosis and meiosis, and every chromosome is replicated. After replication, the doubled chromosomes are still attached at a point called the centromere and the chromosomes often look like an 'X'. Chromosomes are commonly drawn like this because it is the stage at which they are most easily visible under a microscope. Each strand of the doubled chromosome is called a chromatid.

Key things to remember about replication:

- Before replication: single chromosome = 1 molecule of DNA (double-stranded double helix) = 1 copy of every chromosome
- After replication: doubled chromosome = 2 molecules of DNA = 2 chromatids joined at the centromere = 2 copies of every chromosome

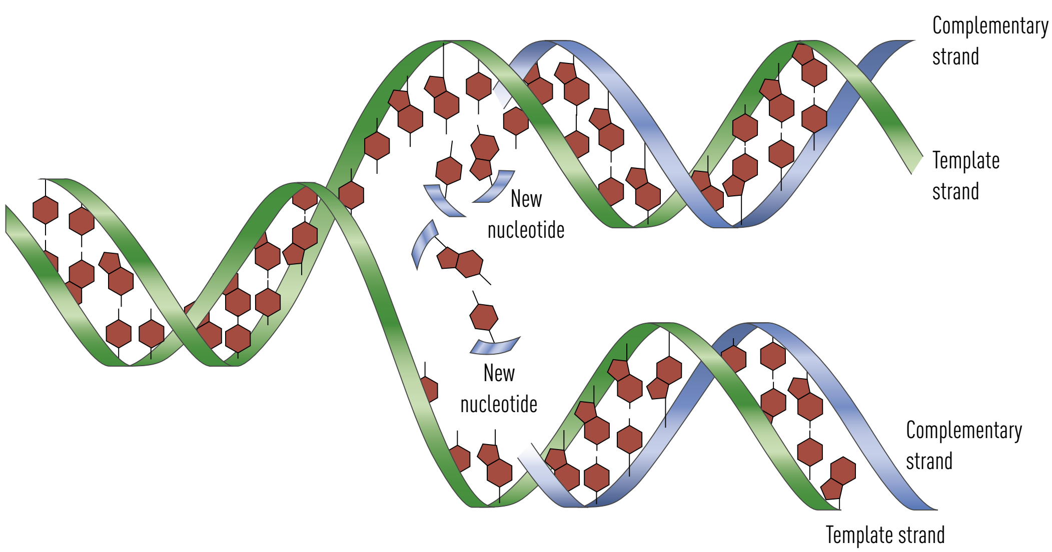


Figure 1.11 DNA replication. The double helix unwinds and each original polynucleotide strand acts as a template for new nucleotides to bond by complementary base pairing. Two double helices (molecules of DNA) that are identical to the original molecule are formed.

ACTIVITY 1.1.2: REPLICATING THE TEMPLATE STRAND

A section of the DNA template sequence of a gene is shown below.

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

1 Identify what the letters A, C, G and T stand for.
2 Identify which bases are complementary.
3 Write down the complementary sequence for this template strand.

Mitosis

The nuclei of **somatic** (body) human cells contain 46 chromosomes arranged into 22 homologous pairs and one pair of sex chromosomes, which determine the gender of the individual. We can also say that the somatic cells are **diploid** (two sets of chromosomes in homologous pairs). One member of each pair has come from the female parent and the other from the male parent via the gametes.

Mitosis is the process of replicating exact copies of somatic cells. Mitosis was first introduced on page 118 of *Oxford Insight Science 7* and is discussed further on page 62 of *Oxford Insight Science 8*. You may recall that mitosis is the cell division used for growth and repair in multicellular organisms, and is a form of asexual reproduction (binary fission) in unicellular organisms. In mitosis, the original parent cell divides once into two identical daughter cells. Every cell in your body, except gametes (the sex cells), is produced by mitosis.

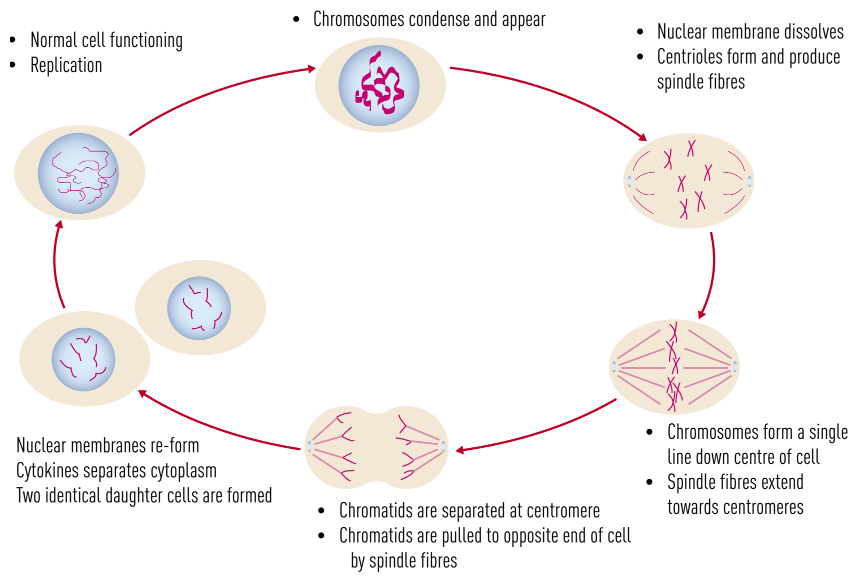


Figure 1.12 The stages of mitosis.

ACTIVITY 1.1.3: MITOSIS IN ACTION

What you need: prepared microscope slide(s) showing a tissue in the process of growth and development, light microscope

1. View a prepared slide under the microscope at the greatest magnification possible. In your field of view, identify the cells that are in the resting phase and those that are undergoing the other phases of mitosis.
2. Estimate the proportion of cells undergoing mitosis compared with those in the resting phase. Express this as a percentage and record it in your workbook.
3. Sketch at least four cells undergoing different stages of cell division. Remember the conventions for drawing biological images under the microscope. Clearly label all the components within the cell that you can identify correctly.
   - DNA is visible under the microscope during the resting phase but not as individual chromosomes. Find out what DNA is called in this less tightly wound form.
   - What might be an advantage for DNA being tightly wound during mitosis?
   - Describe the possible consequences for a cell if there are errors during the process of DNA replication.
   - Find out the length of time it takes for a typical cell (e.g. a skin cell) to undergo the process of cell division.
   - Explain the significance of mitosis for an organism.

Meiosis

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

Gametes differ from all other body cells because they contain half the number of chromosomes of body cells – they are **haploid** (one set). Human gametes have 23 individual chromosomes that are not in pairs.

Meiosis is the process by which diploid cells are converted into haploid gametes and it occurs in the gonads of multicellular, sexually reproducing organisms. In humans, it occurs in the testes in males and ovaries in females.

Meiosis is sometimes called reduction division. It involves a growth and preparation phase called interphase, and then two separate division events known as meiosis I and meiosis II. Essentially, meiosis I separates the homologous pairs of chromosomes and meiosis II separates the chromatids.

The only purpose of a gamete is to fuse or join with another gamete to make a new cell called a zygote. This fusion of gametes is called **fertilisation**. The zygote will be diploid because it contains two sets of chromosomes, one from each gamete. Therefore, the original number of chromosomes is restored again in the body cells of the new organism (offspring).

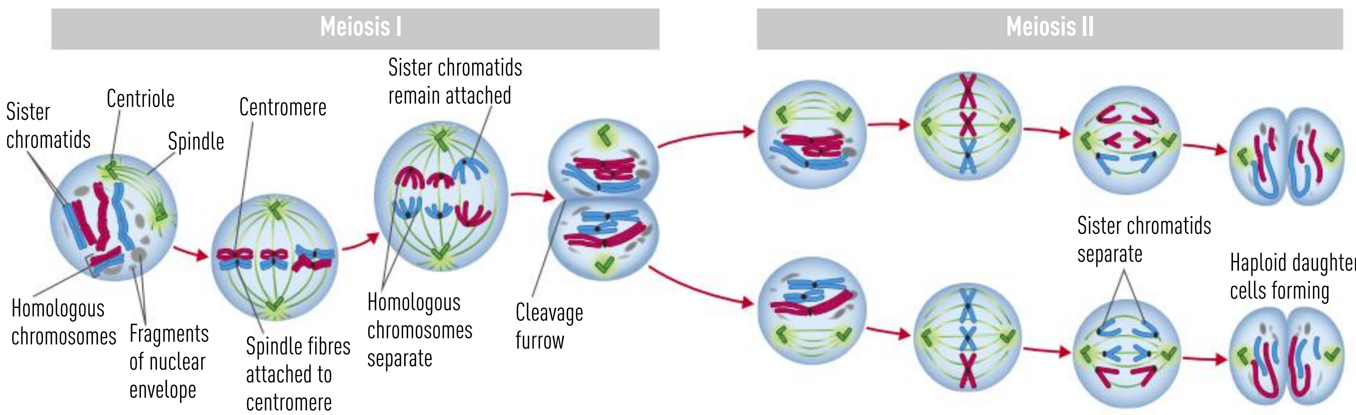


Figure 1.13 The stages of meiosis.

Sperm production

In human males, meiosis and the formation of gametes occurs in the testes (singular: **testis**), specifically inside the seminiferous tubules. In adult males, these very fine tubes may have a combined length of 300–500 metres per testis.

Spermatagonia are the starting cells of the process of sperm production, and are found in the lining of the seminiferous tubules. They divide once by mitosis to produce two diploid cells; one daughter cell remains a spermatagonium to repeat the process, and the other becomes a primary spermatocyte.

The primary spermatocyte then undergoes meiosis to produce four haploid spermatids.

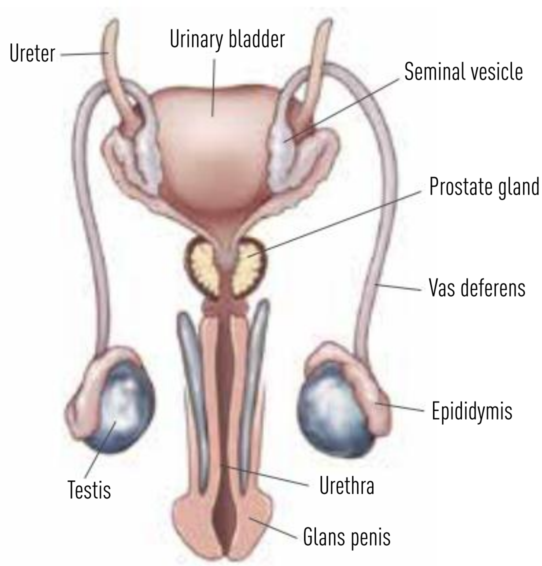


Figure 1.14 The male reproductive system in humans. The testes are the sites of meiosis.

These cells grow tails, develop into sperm cells and are released into the seminiferous tubule. The immature sperm move to the epididymis where they are stored until they mature. By the time they leave the testis and move into the vas deferens, the sperm are fully motile (able to swim by themselves) and capable of fertilising an ovum.

The production of sperm is a continuous process. Mitosis of spermatagonia ensures there are always cells that can produce new sperm.

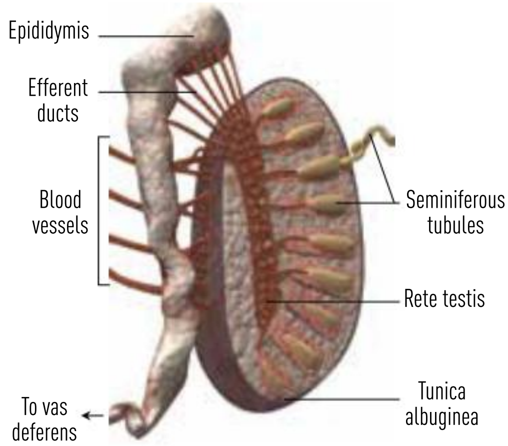


Figure 1.15 A cross-section of a human testis.

Ova production

Female gametes begin their development as primordial follicles (gamete starting cells) in the ovaries (singular: **ovary**). Unlike human males, who can produce sperm continuously, human females possess all their potential ova at birth (around 1–2 million). The primordial follicle is made up of an oocyte (the undeveloped ovum) and a protective layer of granulosa cells. Most primordial follicles never develop or mature. Because the oocyte is unable to repair itself, most die before puberty, leaving only 300 000–400 000 potential ova with around another 1000 or so dying every month after that.

If hormones trigger the primordial follicle to develop, it increases in size and grows protective layers of cells through mitosis. When the follicle is matured, the first division of meiosis takes place. However, cytokinesis divides the cells so that the vast majority of the cytoplasm ends up in the oocyte. The smaller cell dies.

During ovulation (the release of an ovum from the ovary), the mature follicle ruptures and releases the oocyte and its protective layer of cells into the fallopian tube. The second division of meiosis does not take place unless a sperm cell penetrates the protective layer and combines with the oocyte. The second division separates the chromatids of the doubled chromosomes and cytokinesis forms a tiny cell and a large ovum. Again, the smaller cell dies. The haploid ovum accepts the DNA from the sperm, fertilisation is achieved and a diploid zygote is formed.

On average, females release around 400 oocytes in their lifetime. Perhaps only one or two will be fertilised and develop into a foetus.

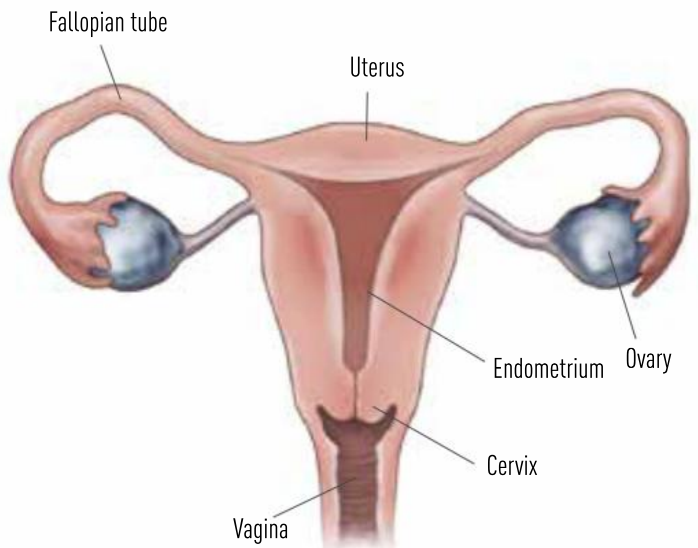


Figure 1.16 The female reproductive system in humans. The ovaries are the sites of the first division of meiosis.

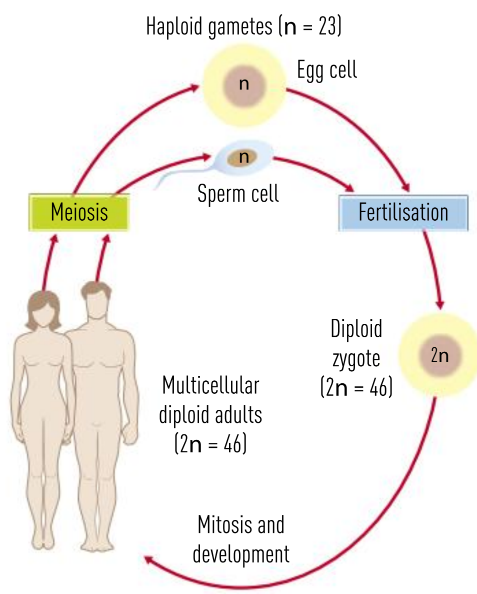


Figure 1.17 The human life cycle and how meiosis and mitosis are involved.

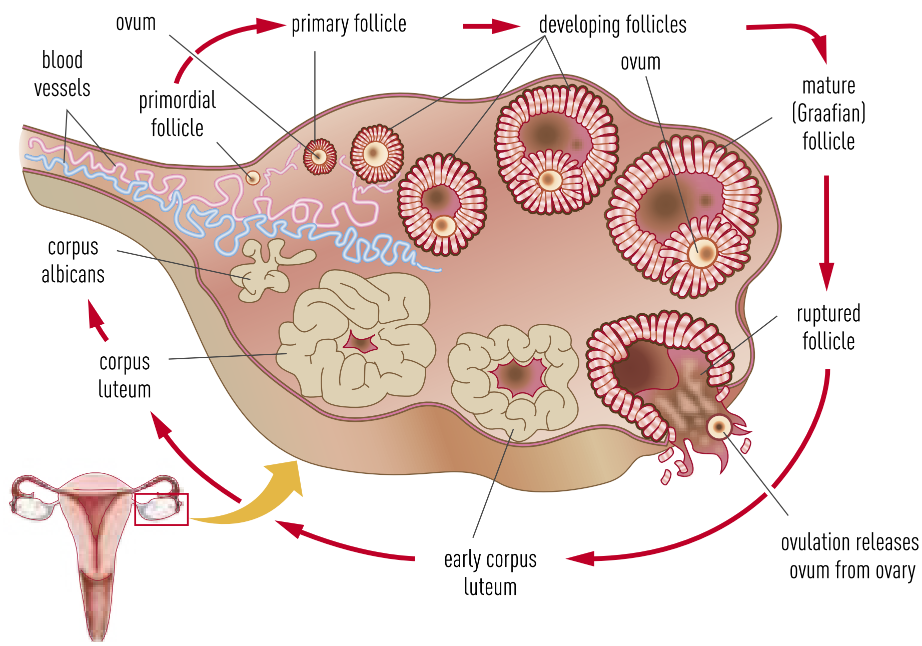


Figure 1.18 Follicular development and ovulation.

QUESTIONS 1.1.2: REPLICATION AND CELL DIVISION

Remember

1 Define the term 'DNA replication'.

2 Describe the difference between a haploid and a diploid cell. Provide an example of each.

Apply

3 Define fertilisation and explain why it is important for a species.

4 Construct a simple flow chart to demonstrate the process of DNA replication.

5 If part of a template strand of DNA reads ACTGGCATTCAG, identify the complementary base sequence.

6 Complete the following table comparing mitosis and meiosis.

	Parent cell (haploid/diploid)	Number of divisions	Number of daughter cells	Daughter cells (haploid/diploid)	Purpose(s) of division
Mitosis					
Meiosis					

7 We all commenced our lives as a single cell, a zygote, which then grew into an embryo. Identify the type of cell division involved in the growth of a zygote into an embryo.

8 Propose whether or not the offspring of sexually reproducing organisms are identical to their parents. Explain your answer.

9 Compare the production of male and female gametes in humans. You may like to use a table or graphical organiser.

10 Propose how you could identify cells viewed under the microscope as undergoing mitosis or meiosis. Justify your answer.

Create

11 Individually or in small groups, create a model or annotated poster of either a testis, or an ovary and a fallopian tube. Label your model or poster to show the key structures and the processes involved in the production of mature gametes.

MUTATION

When cells divide, exact copies of every chromosome are usually produced because of the double-stranded structure of DNA and the complementary pairing of bases. The chromosome copies are generally distributed evenly between daughter cells during the process of mitosis. However, nature is not perfect all the time. Mistakes are made during both replication and cell division. These mistakes are called **mutations**. Mutations can involve individual genes or entire chromosomes.

The genetic code

A gene mutation is a change to the sequence of bases within a gene and usually happens during replication. Most of these mutations are detected and fixed by enzymes (specialised 'helper' proteins that act as proofreaders). The impact of these mutations varies depending on the nature of the change to the genetic code.

The genetic code is the sequence of bases in a gene and provides the specific instructions for the synthesis of proteins. Some proteins are the building material for major structures and organelles within the cell, whereas others are functional proteins such as enzymes.

Proteins are polymers made up of polypeptides, which are chains of **amino acids**. There are only 20 amino acids that occur naturally in human proteins, but they can be used in millions of different combinations. Each amino acid requires a specific code, which is made up of the DNA bases A, T, C and G.

First base	Second base U: Codon (base triplet)	Amino acid	Second base C: Codon	Amino acid	Second base A: Codon	Amino acid	Second base G: Codon	Amino acid	Third base
U	UUU	Phe	UCU	Ser	UAU	Tyr	UGU	Cys	U
U	UUC		UCC		UAC		UGC		C
U	UUA	Leu	UCA		UAA	Stop	UGA	Stop	A
U	UUG		UCG		UAG	Stop	UGG	Trp	G
C	CUU	Leu	CCU	Pro	CAU	His	CGU	Arg	U
C	CUC		CCC		CAC		CGC		C
C	CUA		CCA		CAA	Gln	CGA		A
C	CUG		CCG		CAG		CGG		G
A	AUU	Ile	ACU	Thr	AAU	Asn	AGU	Ser	U
A	AUC		ACC		AAC		AGC		C
A	AUA		ACA		AAA	Lys	AGA	Arg	A
A	AUG	Met/Start	ACG		AAG		AGG		G
G	GUU	Val	GCU	Ala	GAU	Asp	GGU	Gly	U
G	GUC		GCC		GAC		GGC		C
G	GUA		GCA		GAA	Glu	GGA		A
G	GUG		GCG		GAG		GGG		G

Ala	alanine
Arg	arginine
Asn	asparagine
Asp	aspartic acid
Cys	cysteine
Gln	glutamine
Glu	glutamic acid
Gly	glycine
His	histidine
Ile	isoleuicine
Leu	leucine
Lys	lysine
Met	methionine
Phe	phenylalanine
Pro	proline
Ser	serine
Thr	threonine
Trp	tryptophan
Tyr	tyrosine
Val	valine

Figure 1.19 The entire genetic code was deciphered by 1966 and scientists now understand which amino acid is coded for by each codon. There are three stop codons and one start codon.

Protein synthesis

Protein synthesis is a multi-step process where the relevant section (the gene) of DNA is copied into RNA. The short strands of RNA leave the nucleus and go to a ribosome where they form a template for an amino acid chain.

Individual amino acids are coded for by a triplet of bases called a **codon**. The four bases can be arranged as triplets in 4 × 4 × 4 = 64 different ways. This is more than enough for 20 amino acids. Hence, there is usually more than one codon for each amino acid. The sequence of amino acids in a protein is coded for by the sequence of codons along the DNA molecule.

The codons for the amino acids are typically listed using RNA rather than DNA. All proteins start with the amino acid methionine, which is coded for by the 'start' codon AUG.

SCIENCE SKILLS

Interpreting the genetic code

A section of the RNA sequence made from a particular gene is shown below.

A U G C A G G U A C A G C G U

1 Write down the sequence of the template DNA strand.

2 Using the genetic code in Figure 1.19, write down the amino acid chain that is coded for by the above sequence.

3 What would occur if a mutation in the DNA causes the RNA codon CAG to become UAG?

Mutagens

The base sequence (order of bases) in DNA is critical. A tiny change in the sequence may alter the amino acids being coded for, which can change the protein produced and may affect the normal functioning of the organism. Although the aim of replication is to preserve the base sequence, occasional errors, or mutations, can occur. On most occasions these mutations can be corrected. Sometimes a mutation will result in a new codon that still codes for the same amino acid, or the change is not in an important part of the DNA. But on other occasions, mutations can change the protein produced, which can cause problems and can even be fatal.

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

Somatic mutations occur during mitosis of body cells. The effect is localised to that individual and may lead to an illness such as cancer. Germ-line mutations occur during meiosis and the formation of gametes. These mutations do not affect the individual, but are passed on to their children if that gamete is fertilised. Germ-line mutations are said to **heritable** because they can be passed on or 'inherited' by offspring.

Genetic mutations

Genetic mutations only affect individual genes. There are three possible outcomes of genetic mutations:

- Sequence still codes for the same amino acids (some amino acids have more than one code) so there is no change to the polypeptide.
- Sequence codes for at least one different amino acid, which alters the structure and function of the polypeptide to varying degrees.
- Sequence is changed to include an earlier stop codon, shortening the polypeptide and often significantly altering its structure and function.

Radiation

- Ionises biochemical compounds in cells, forming free radicals
- The free radicals cause damage to DNA and proteins (e.g. breakages in chromosomes)

Chemicals

- Some chemicals insert into DNA instead of bases (i.e. they substitute for bases)
- Other chemicals insert between bases, causing problems when the DNA replicates

UV light

- Causes thymine bases that are close together on a DNA polynucleotide chain to bind together, forming 'thymine dimers'. This causes problems during DNA replication

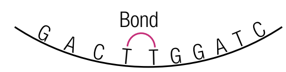


Figure 1.20 The effect of some mutagens.

ACTIVITY 1.1.4: ANALYSING MUTATIONS

A normal RNA sequence is shown below, together with a mutated sequence.

Normal sequence AUG ACG CAG AAU UGG GAU CCU ACG

Mutated sequence AUG ACA CAG AAU UGG GAU CCU ACG

Describe the outcome of the mutation on protein synthesis. You may wish to consult the genetic code in Figure 1.19.

Chromosomal mutations

Chromosomal mutations are classified according to whether they change the structure of chromosomes or alter the number of chromosomes in the cell. Chromosomal mutations are often identified by their karyotype.

ACTIVITY 1.1.5: MODELLING STRUCTURAL CHROMOSOMAL MUTATIONS

What you need: paper, coloured pencils, scissors, sticky tape or glue

1. Research the main forms of structural chromosomal mutations (deletion, duplication, translocation and inversion) and write a brief description of what each mutation involves.
2. Draw five chromosomes of different lengths and use the alphabet to indicate about five genes per chromosome. Do not use any letter more than once.
3. Cut and paste your chromosomes to represent each type of structural mutation.
4. Evaluate how well your models represent the mutations.
5. Compare your models with those of other students in the class. Are they similar or different? Assess which model best represents each mutation, and explain why you think this.

Mutations involving chromosome number

Mutations that alter chromosome numbers are usually the result of a homologous pair of chromosomes failing to separate during meiosis. In such cases, one of the daughter cells (gametes) will have too many chromosomes and the other will have too few. If an abnormal gamete is fertilised, the offspring will have either too many or too few chromosomes.

Down syndrome is the result of a person having three copies of chromosome 21 (trisomy 21).

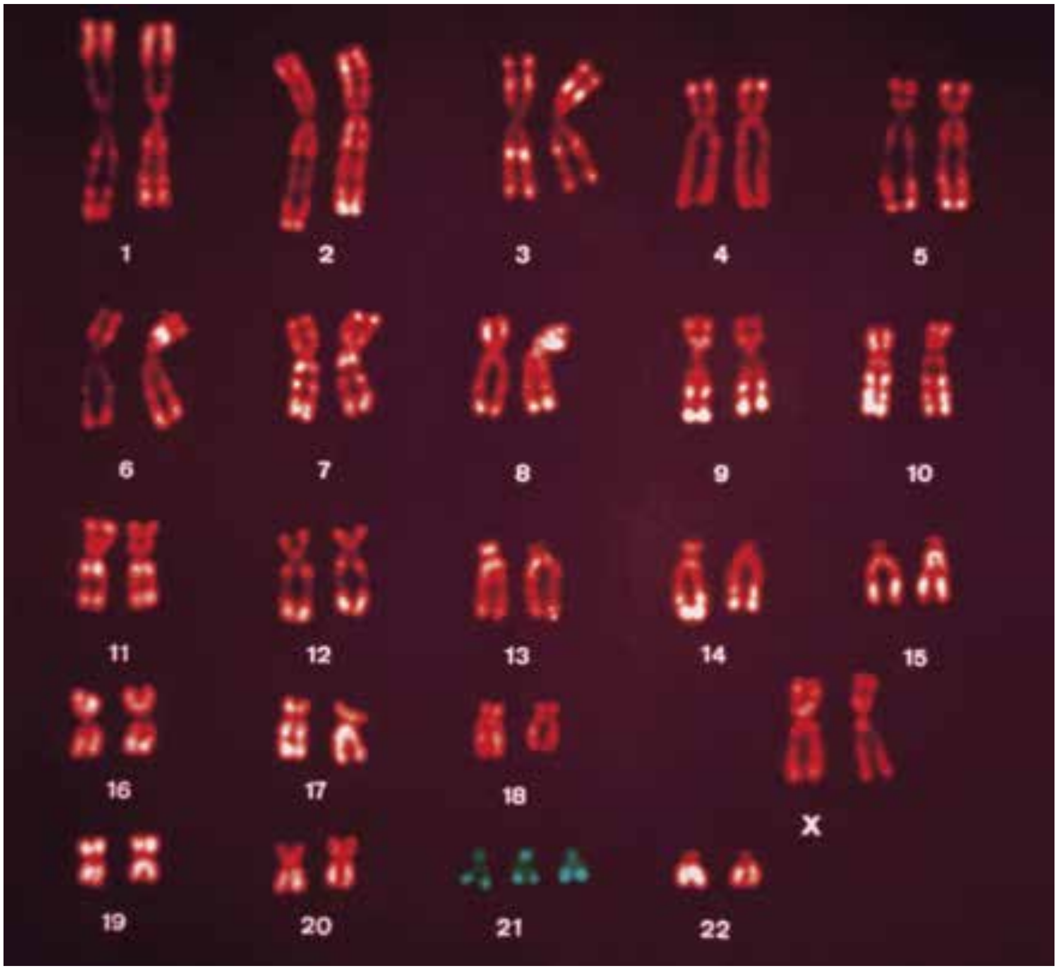


Figure 1.21 Karyotypes clearly show chromosomal mutations such as trisomy 21.

QUESTIONS 1.1.3: MUTATION

Remember

1 Define the term 'mutation'.

2 Explain what a mutagen is with reference to specific examples.

3 Identify at least two differences between replication and protein synthesis.

4 Identify the function of DNA.

Apply

5 Are all mutations heritable? Explain your answer.

Analyse and evaluate

6 Propose a reason why DNA must be copied into RNA for protein synthesis.

7 Assess whether mutations can ever be advantageous.

8 Describe how a polypeptide is like a string of beads.

DNA AND THE GENETIC CODE

1.1 CHECKPOINT

Remember

1 What do the following abbreviations stand for?
   a DNA [1 mark]
   b RNA [1 mark]
   c U [1 mark]
   d T [1 mark]

2 Name the four nucleotides found in:
   a DNA [2 marks]
   b RNA [2 marks]

3 Polynucleotides and polypeptides are both polymers.
   a Suggest what the root word 'poly' means. [1 mark]
   b Identify the units that make up each type of polymer. [2 marks]
   c Give examples of the final products of each type of polymer. [2 marks]

4 For both sperm and ova:
   a identify where each type of gamete are produced [2 marks]
   b identify where each type of gamete mature. [2 marks]

5 Identify why replication of DNA must occur before cell division. [1 mark]

Apply

6 Use the terms 'gametes' and 'fertilisation' to explain how DNA is transferred from one generation to the next. [2 marks]

7 Explain the differences between the following terms. You may like to use diagrams.
   a base and codon [1 mark]
   b diploid and haploid [1 mark]

8 If a gene contains 600 nitrogenous bases, calculate how many amino acids would be incorporated into the resulting polypeptide. [1 mark]

9 Identify the key organs of the female and male reproductive systems and relate them to their function. [4 marks]

10 Examine the original DNA sequence and its mutated version.

   Original:
   TAC GTT CGA TTC ATC GGA TTG CAT

   Mutation:
   TAC GTT CGA CAT CGG ATT GCA T

   Describe the effect of the mutation on the polypeptide produced. [2 marks]

11 You are observing a cell in the middle of meiosis. Identify how you could determine whether you are observing meiosis I or II. [1 mark]

12 Explain why it is essential for the number of chromosomes to be halved during meiosis. [1 mark]

Analyse and evaluate

13 Evaluate whether a gene or a chromosome has the most control over the structure and function of an organism. Explain your reasoning. [2 marks]

14 Trisomy 21 is most commonly the result of a chromosome mutation during ovum formation. Propose a reason why this mutation is more common in female gametes than in sperm (5–10% of trisomy 21 cases) and why it is thought that this type of mutation becomes more common as females age. [2 marks]

15 Meiosis usually results in four haploid daughter cells. Explain why only one mature ovum is produced by meiosis in human females. [2 marks]

Research

16 Research a genetic disorder. Identify the type of mutation, how common it is, how it is usually diagnosed, the common symptoms and any treatments associated with the disorder. Present your findings as an informative pamphlet or multimedia presentation. Include an appropriate bibliography of your sources. [5 marks]

TOTAL MARKS
[/42]

1.2 GENETIC INHERITANCE

Just how significant is our genetic code? Which characteristics of our make-up are determined by genes and their DNA code? The establishment of the relationship between DNA and the genes on chromosomes paved the way for a greater understanding of genetics. That, combined with the experimental genetics pioneered by Gregor Mendel, has answered many questions. Scientists now have a greater understanding of how our genes function and the influence of our environment on genetically determined characteristics.

THE FATHER OF GENETICS

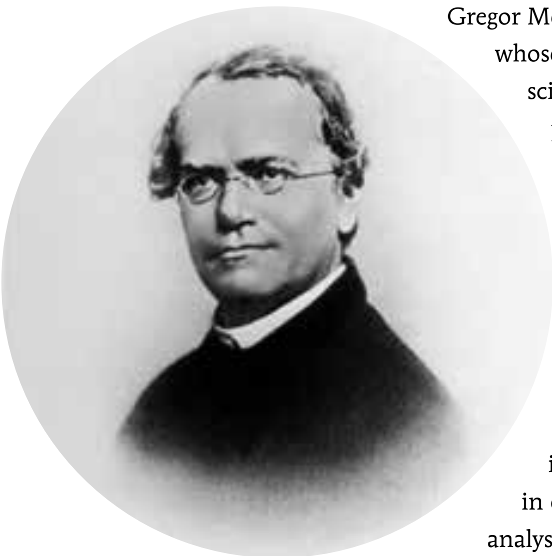


Figure 1.22 Gregor Mendel – botanist, monk and father of modern genetics.

Gregor Mendel was an Austrian monk whose hobby was performing scientific experiments on the pea plants in the monastery garden. Most of his experimental work was done in the 1850s, a few decades before the discovery of DNA and 100 years before the structure and genetic code of DNA had been identified. Mendel's success in obtaining reliable results to analyse and make predictions was because he:

- studied a large number of characteristics in the plants
- carried out a large number of crosses
- used pure breeding lines.

Most of Mendel's conclusions based on his results still hold true today, even with all the additional information we now know about genetics. Without the current technology, Mendel may not have been able to explain exactly what was going on inside the cells, but he determined the ways in which parents pass on their characteristics to their offspring. Mendel is often referred to as the father of modern genetics.

Mendel's experiments

Mendel noticed that although the pea plants in his garden were of the same species and successfully bred together to produce healthy, fertile offspring, they were not all the same. Some plants had white flowers, whereas others had purple flowers; some plants produced round peas, whereas others produced wrinkled peas; and so on. These differences between individuals of the same species are called variations. Mendel's experiments were largely to determine how these variations were passed from one generation to the next.

Mendel began by establishing pure or true-breeding lines for seven different pea plant characteristics that typically only appeared in two different forms. True-breeding organisms are genetically identical to their parents and will always produce genetically identical offspring when interbred.

Mendel would then take two true-breeding plants with different forms of the same characteristic and breed them together to determine which form the characteristic would take in the next few generations of offspring.

For example, Mendel studied the characteristic of pea seed shape: either round (spherical) or wrinkled.

1 Mendel bred two groups of true-breeding pea plants: one with round seeds and the other with wrinkled seeds. These were called the P or parental generation.

2 Mendel crossed the true-breeding plants for round seeds with the true-breeding plants for wrinkled seeds. He did this by manually transferring the pollen grains from one flower to another. The offspring were all round seeded pea plants. They were known as the F_1 or first generation.

3 Mendel then allowed the round F_1 plants to interbreed to produce an F_2 generation. In the F_2 generation, Mendel's crosses resulted in about 296 round to 103 wrinkled seeds, which is roughly ¾ round and ¼ wrinkled seeds, also expressed as a ratio of 3:1.

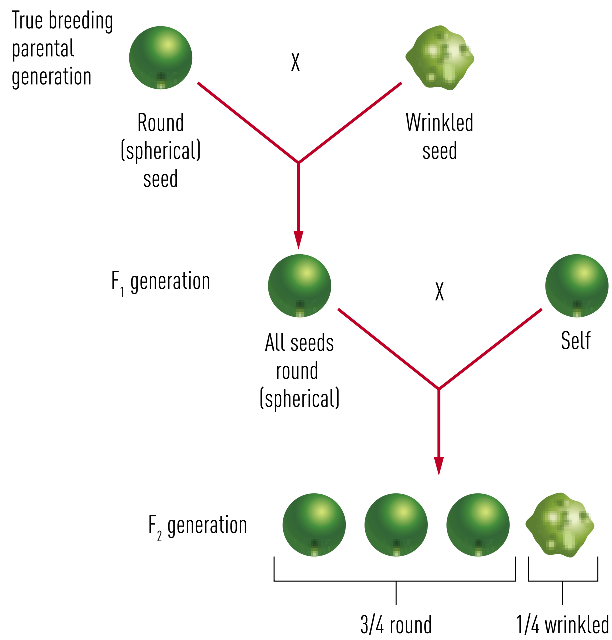


Figure 1.24 Mendel's experimental results using seed shape of pea plants.

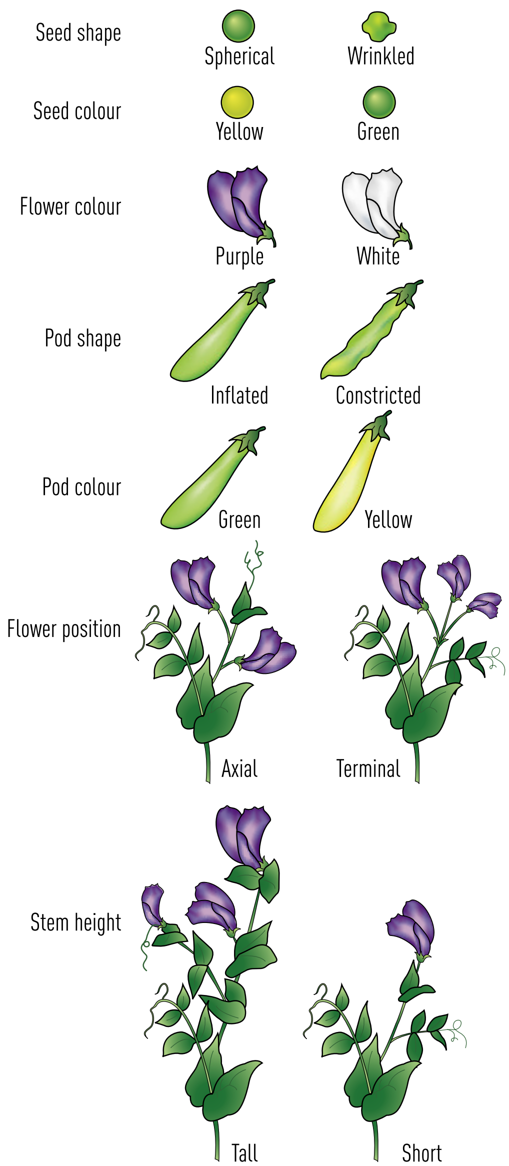


Figure 1.23 The seven traits, or characteristics, of pea plants studied by Mendel. Mendel focused on these seven pairs of traits and isolated each as a true-breeding trait before he began studying various crosses.

Basic principles of genetics

Mendel's explanations about the results of his experiments were amazingly accurate. With no microscope work and very few colleagues with whom to discuss the results, he made the following conclusions.

- There must be 'factors' inside cells that control characteristics. Mendel's 'factors' were later renamed genes.
- Two copies of each 'factor' are present in every cell and control each characteristic: one 'factor' is from the male parent and the other from the female parent.
- Each 'factor' separates from the other before fertilisation (meiosis and gamete formation) and recombines at fertilisation, but the two, factors, do not blend.
- The 'factors' that control different characteristics are passed on to the next generation independently of each other.

Without knowledge of genes, chromosomes or DNA, Mendel managed to accurately explain how such variation between individuals of the same species was possible. As knowledge and understanding of Mendel's 'factors' improved, his basic conclusions were expanded to become two of the fundamental laws of genetics.

The law of segregation

There are two copies of every gene in all sexually reproducing organisms that control each characteristic, and the same genes are grouped together on homologous pairs of chromosomes. During meiosis these homologous chromosomes segregate (separate), with one copy of each chromosome and all the genes it holds appearing in every gamete (for example, in the ovum/egg and in the sperm/pollen). These chromosomes recombine at fertilisation. They do not blend, but instead match together to form homologous pairs again.

The law of independent assortment

When the homologous pairs of chromosomes segregate, they do so independently of other pairs of chromosomes. In other words, when the chromosomes line up in their homologous pairs, the side each chromosome takes is completely random. The mother's chromosome may be on the right for one pair but on the left for a different pair.

We now know this law applies in all cases except when the genes are linked (situated on the same chromosome). Mendel, by chance, did not study any linked genes and so he did not know that genes are situated on chromosomes. We also know now it is the chromosomes that segregate rather than the individual genes as Mendel thought.

Genotypes and phenotypes

The law of segregation does not completely explain why Mendel often found that one form of the characteristic he was examining would disappear from the offspring and then reappear in subsequent generations during his crosses.

Some genes come in different forms. These different forms of the same gene are called **alleles**. In the previous example, the gene is seed shape, and the alleles are round seeds or wrinkled seeds. When a gene has more than one allele, an individual may have different combinations of those alleles. The specific combination of alleles is called the **genotype**. The genotype helps to determine the appearance of the individual, known as the **phenotype**.

A true-breeding individual has two copies of the same allele for each gene. They can only pass one form of the characteristic on to their offspring. True-breeding individuals are also described as being as **homozygous** for that trait or characteristic.

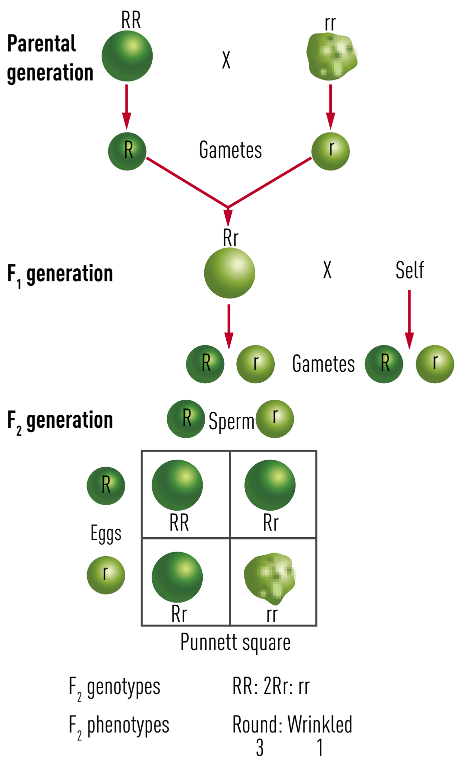
In Mendel's experiments, he crossed two different true-breeding individuals together, guaranteeing that the F_2 generation would have one copy of each allele, or would be **heterozygous** for that trait. Even though all the offspring had the two different alleles, they all showed the same phenotype. One allele was being expressed rather the other. The allele expressed in the phenotype of a heterozygous individual is said to be **dominant**, and the allele that is hidden is said to be **recessive**.

Individuals showing the dominant trait only need to have one copy of the dominant allele for it to show in the phenotype. This means individuals with the dominant trait could be heterozygous or homozygous dominant for that gene. Dominant alleles are represented by a capital letter that represents the gene.

The recessive trait is only expressed if there are no dominant alleles present. Therefore, all individuals with the recessive phenotype must be homozygous recessive for that gene. Recessive alleles are always shown by a lowercase version of the letter used for the dominant allele (Table 1.2).

Table 1.2 Genetic notation for the gene for flower colour.

Genotype	Phenotype	Description
FF	purple	homozygous dominant
Ff	purple	heterozygous
ff	white	homozygous recessive



1. Both parents are homozygous (RR and rr) and produce only one type of gamete (either all R from RR or all r from rr).

2. When a cross is made, it is the gametes that fuse. So, all the F_1 individuals will be Rr. Because spherical (round) is dominant to wrinkled, all the F_1 individuals will have spherical (round) peas.

3. When the F_1 individuals are crossed, it will be Rr crossed with Rr and both parents will produce two types of gametes, R and r. These gametes fuse to produce the F_2 generation and the genotypes of the offspring (F_2) can be obtained conveniently using a square developed by the geneticist Punnett, called a Punnett square. The gametes are placed on the Punnett square vertically and horizontally. The possible crosses, and resulting genotypes are then found by putting the gametes together. In this way, the different phenotypes and their ratios can be easily determined.

Figure 1.25 An explanation of Mendel's results in terms of genotypes, phenotypes, dominance and recessiveness. Note: Rr and rR are the same – the dominant allele is always written before the recessive regardless of whether it was supplied by the sperm or egg.

QUESTIONS 1.2.1: THE FATHER OF GENETICS

Remember

1 Define 'true-breeding organisms' and explain how Mendel ensured his parental generation were true-breeding plants.

2 How many genes for a characteristic are present in the cells of each organism? Where do each of these genes come from?

3 Name the process in the cell that segregates the chromosomes (and genes).

4 Define the term 'allele'.

5 Explain the difference between a dominant and a recessive allele.

6 Using an example, explain the difference between a genotype and a phenotype.

Apply

7 Suggest why Mendel had such an influence on genetics.

8 Explain how you automatically know the genotype of an individual with the recessive phenotype.

9 Match the following terms and symbols with their appropriate explanation.

pea pod colour	dominant allele
green pod	homozygous dominant
PP	homozygous recessive
P	heterozygous
pp	phenotype
Pp	gene

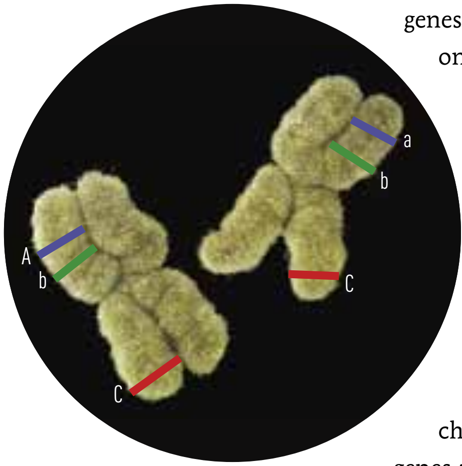
10 One of the characteristics Mendel investigated was flower position in pea plants. The two forms of this characteristic are flowers along the stem (axial) or only at the ends of the stem (terminal). Explain how you would determine which allele was dominant.

AUTOSOMAL INHERITANCE

Chromosomes exist in homologous pairs. They are homologous because they carry the same genes. Because many genes have more than one form, homologous chromosomes may not carry the same allele for those genes. Figure 1.26 shows a homologous pair of chromosomes that carry the same alleles for skin pigmentation and cheek shape, but different alleles for eye colour.

However, one pair of chromosomes is not always homologous. Sometimes the chromosomes carry completely different genes and are totally different lengths. This 'pair' of chromosomes are called **sex chromosomes**. Although they carry genes that code for normal body cells, they also determine the gender of the individual (see more about these chromosomes on page 33). All other chromosomes that have no influence on gender differentiation are called **autosomal** chromosomes.

Chromosomes can carry thousands of individual genes, but it is easiest to study them one at a time as Mendel did.



Eye colour
Dominant: brown
Recessive: blue

Skin pigmentation
Dominant: Freckles
Recessive: no freckles

Cheek shape
Dominant: dimples
Recessive: no dimples

Figure 1.26 A homologous pair of chromosomes with theoretical genes and alleles indicated.

Monohybrid crosses

A **monohybrid cross** is the genetic cross between two individuals that are heterozygous (hybrid) for one (mono) particular gene.

When Mendel crossed F_1 individuals with other F_1 individuals to produce the F_2 generation, this was a monohybrid cross.

In the example used on page 25, Mendel found when he crossed plants that were heterozygous for seed shape, the resulting offspring were in the ratio 3 round to 1 wrinkled. To work this out, you can use a Punnett square.

Coat colour in some dogs is controlled by one gene with two alleles. The black pigment allele is dominant over the recessive brown pigment allele.

Punnett squares

Punnett squares can be used to determine the possible genotypes of the offspring and to calculate the ratios in which the offspring's genotypes and phenotypes will occur. The parents' genotypes are used to work out the possible gametes that can be produced, and these are written around the outside of the Punnett square. Within the grid, all possible fertilisation combinations can be modelled.

Mendel repeated his experiments with so many plants (around 29 000 plants over seven years) that his actual data reflected the estimated mathematical ratios and percentages for the experiments. The huge numbers of plants that were cross-bred in every experiment, combined with Mendel's method of repeating all his experiments, made his data extremely reliable. This is one of the many reasons why his findings are the foundations of modern genetics and why Mendel is such a well-respected scientist.

Figure 1.27 Black fur is dominant over brown fur in labradors. Golden labradors are a result of a different gene.

SCIENCE SKILLS

Monohybrid crosses

Two black labradors known to be heterozygous for fur colour were crossed. Determine the likelihood of the different fur colours of their offspring, expressed as a percentage.

The layout of the cross shown in Figure 1.28 is considered to be the scientific convention. Complete the monohybrid cross using the template and Mendel's example in Figure 1.25 on page 25 as a guide.

Gene: Fur colour

Dominant allele: black (B)

Recessive allele: brown (b)

Questions

1 Explain how you know which allele is dominant for the trait.

2 How many genotypes are possible for the black-fur phenotype? How many genotypes are possible for brown fur?

3 Compare your results to Mendel's as shown in Figure 1.25. What does this tell you about the expected results for any monohybrid cross?

4 The Punnett square provides the ratios for all possible offspring (in other words, it indicates the expected results). Labradors usually have 5–10 puppies per litter. How close will the actual results be to the expected results after a single litter? Explain your answer in terms of reliability of data.

5 From your results, what is the percentage chance that one of the puppies will be brown?

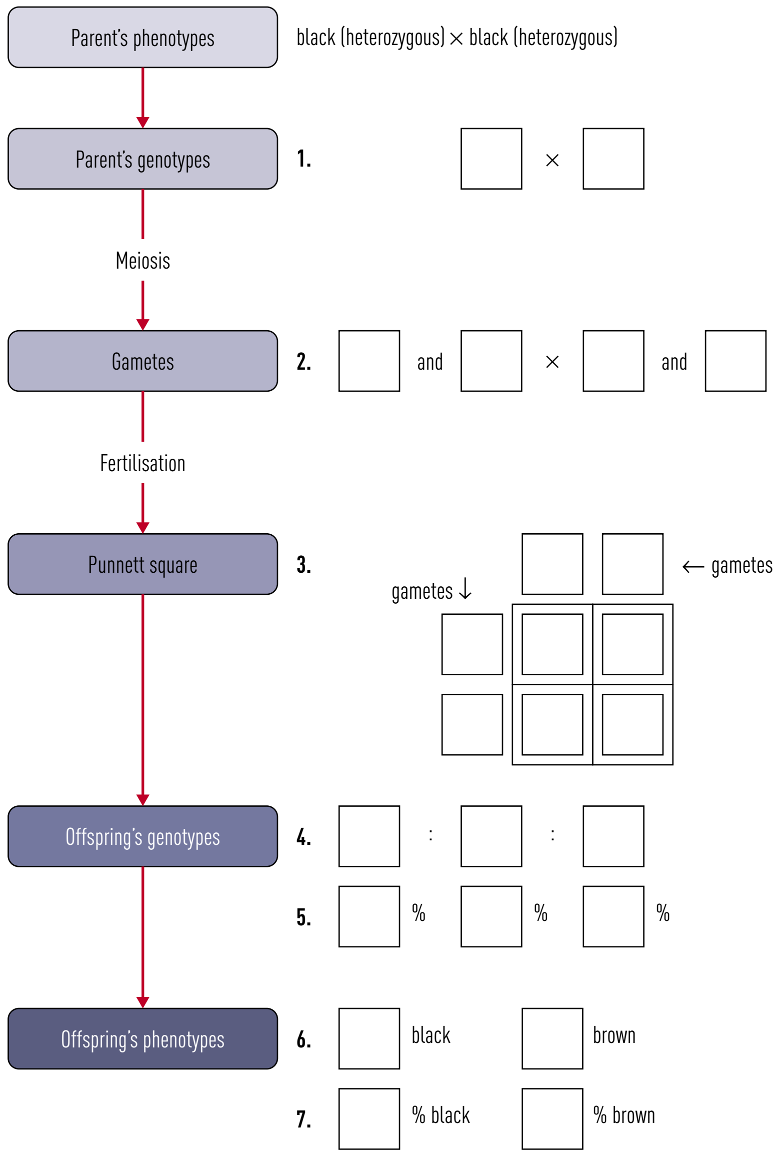


Figure 1.28 Complete the monohybrid cross for heterozygous labradors.

ACTIVITY 1.2.1: INVESTIGATING VARIATION

Most human characteristics are now well understood in terms of the genes and alleles involved. Some human characteristics are controlled by a single gene with two alleles. Table 1.3 shows some of these genes as well as their dominant and recessive alleles.

Table 1.3 Some common human characteristics and their dominant and recessive traits.

	Dominant trait		Recessive trait		Your trait	
Gene	**Description**	**Allele symbol**	**Description**	**Allele symbol**	**Phenotype**	**Possible genotype(s)**
Eye colour	Brown eyes	B	Blue eyes	b		
Tongue rolling	Ability to roll tongue	T	Cannot roll tongue	t		
Rhesus blood type	Rhesus positive (Rh^+) blood	D	Rhesus negative (Rh^-) blood	d		
Ear lobe shape	Free ear lobes	F	Attached ear lobes	f		
Hairline	Peaked hairline (widow's peak)	W	Straight hairline	w		
Red hair pigment	Not red hair	R	Red hair	r		
Hair on middle segment of finger	Hair present	G	Hair absent	g		
Skin pigmentation	Normal skin pigmentation	A	Pigmentation lacking (albinism)	a		

Copy and complete Table 1.3 by recording your own phenotype and possible genotypes for each of the traits listed. If you display the dominant trait, can you determine whether you are homozygous or heterozygous?

- Identify examples of traits for which your genotype (or that of another member of the class) is homozygous dominant, heterozygous and homozygous recessive.
- If you display a recessive trait, such as blue eyes or a straight hairline, there is only one possible genotype. Explain why this is so.
- In reality, there are often many more variations of particular traits in reality. Eye colour is a good example of this. Can you suggest why there are variations beyond simply 'blue' or 'brown' eye colour?

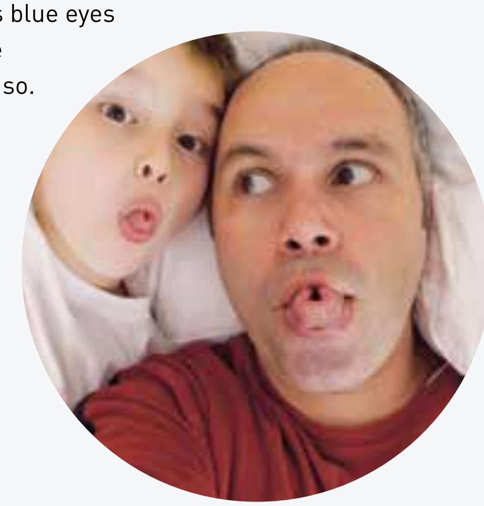


Figure 1.29 Tongue rolling is a dominant genetic trait that is inherited from at least one of your parents.

Test crosses

When looking at a single gene, it is easy to determine the genotype of an individual who expresses the recessive trait. There is only one possibility: they must be homozygous recessive. A dominant trait only requires the presence of one dominant allele for it to be expressed. This means an individual with a dominant phenotype could be either homozygous dominant or heterozygous for the characteristic.

To determine the genotype of an unknown individual, a DNA test could be carried out or a number of crosses could be performed. Mendel worked hard to ensure his parental generation were true-breeding plants. He would have carried out several test crosses to determine which dominant trait plants were homozygous and which were heterozygous.

A **test cross** is where an individual with the dominant phenotype but unknown genotype is crossed with a recessive individual. The recessive parent can only supply the recessive allele to the offspring, so the phenotypes of the offspring can be used to determine the genotype of the unknown parent. Figure 1.30 demonstrates the two possible outcomes of a test cross.

Homozygous dominant (a)

P purple flowers × white flowers
FF × ff
gametes: F and F × f and f

F_1

	F	F
f	Ff	Ff
f	Ff	Ff

genotypes: 100% Ff
phenotypes: 100% purple flowers

Heterozygous (b)

P purple flowers × white flowers
Ff × ff
gametes: F and f × f and f

F_1

	F	f
f	Ff	ff
f	Ff	ff

genotypes: 50% Ff, 50% ff
phenotypes: 50% purple, 50% white flowers

Figure 1.30 The results of a test cross can determine if the genotype of the unknown parent is (a) homozygous dominant or (b) heterozygous.

ACTIVITY 1.2.2: BREEDING LIKE RABBITS

Work alone or with a partner to solve the following problems. Present your working out clearly. Refer to Figure 1.28 (monohybrid cross) and Figure 1.30 (test cross) for correct setting out.

Rabbits on a small island are known to have the alleles for genes as shown in Table 1.4.

Table 1.4 Rabbit alleles.

Genes	Alleles
Ear form	E = upright, e = floppy
Fur colour	F = brown, f = grey
Fur length	L = short, l = long
Fur pattern	P = no spots, p = spots

Figure 1.31 Rabbits have many different phenotypes.

Questions

1 Define the terms 'genotype' and 'phenotype'.

2 Which alleles listed in Table 1.4 are dominant and which are recessive? How do you know?

3 Write possible genotypes for a rabbit that has:

  a upright ears

  b floppy ears

  c brown fur

  d long fur.

4 Write phenotypes for the following genotypes.

  a PP

  b Ll

  c ff

  d Ee

5 Determine the possible genotypes and phenotypes of offspring born to parents in the following crosses:

  a FF × FF

  b PP × Pp

  c Ee x Ee

  d ll x LL

6 For each of the crosses in question 5, state the percentage chance of each genotype and phenotype occurring in the offspring.

7 A long-fur rabbit was crossed with a rabbit that was heterozygous for fur length.

  a What are the genotypes of the parents?

  b What is the percentage chance that the first offspring will have long fur?

8 A rabbit with a spotted fur pattern was crossed with a rabbit with no spots. Five kittens (baby rabbits) were born and all had spots on their fur. Explain how this is possible.

Figure 1.32 Environmental factors have altered the phenotypes of this couple, but any children they may have will not inherit their blue hair.

Environmental influence on gene expression

While our genes determine what our physical characteristics will be, they do not act alone on the final phenotype. Environmental factors also influence phenotypes. Sunlight can bleach your hair, tan your skin, and cause freckles and moles to appear. The quality of nutrition during growth and development stages of life can influence height, muscle tone and proper cellular functioning. A car accident may result in a loss of a limb. All of these environmental factors can change an individual's phenotype. Identical twins, who have identical DNA, are never *exactly* the same. There are always some tiny differences between them. But changes to a phenotype cannot alter the genotype.

STUDENT DESIGN TASK

Genes versus the environment

It is often said that successful gardeners have a 'green thumb', but what difference does the right type of plants make? If you obtain healthy plants with genes suited to the environment, will such plants grow regardless of how they are treated?

Challenge

Your task is to work in small groups (2–4 students) to design an experiment to investigate the effect of the environment on a plant's growth.

Questioning and predicting

Select a plant, such as a geranium, where a new plant can be easily generated from a cutting of the parent plant. This process is known as propagation and is, essentially, asexual reproduction.

- How many parents are involved?
- How does the parent plant compare genetically with the offspring?
- Write a testable hypothesis about the appearance of the offspring compared to the parent plant.

Planning and conducting

- Write an appropriate aim for your experiment that is related to your hypothesis.
- What other factors need to be considered when selecting a plant for investigation within the science laboratory?
- Which factors within the environment are you going to investigate? Examples of factors include amount of water, quality of water, amount of light, type of light, soil quality, soil additives, levels of oxygen and carbon dioxide in the air. How will you measure your selected variables?
- How many plants will you test? What effect will this have on the reliability of your results?
- Write a list of all the equipment required.
- What method will you use? Consider details such as how long the investigation will run and how the results will be collected and presented. The design of the experiment should enable you to draw some conclusions about the significance of a plant's genes and environment.
- Which factor will be the independent variable and which factor will be the dependent variable in the experimental design? Which factor will you need to keep the same in all conditions and why?
- How will you present your results?

Processing, analysing and problem solving

- How valid and reliable is your data?
- In what ways could you improve your data?
- What have you learned about the effect of genes and the environment on your plant's growth? How did these affect its appearance compared to the parent plant?
- Can you extrapolate these conclusions to a wider variety of organisms?
- Compare your experiment and results with those of another group. Identify and explain at least one aspect of the other experiment that was better than yours, and describe how you could improve your experiment if you were to repeat it.

Communicating

Present your experiment in an appropriate format, which may include the use of spreadsheet and graph-drawing programs, audio-visual technology as well as written information.

QUESTIONS 1.2.2: AUTOSOMAL INHERITANCE

Remember

1 Rewrite each of these false statements to make it true.

- a Homologous chromosomes carry the same alleles.
- b A recessive allele can mask the dominant allele.
- c The recessive phenotype has two possible genotypes.

2 Describe the conditions of a monohybrid cross.

3 Recall when you would use a test cross.

Apply

4 You and your partner were simulating a cross between a long fur rabbit and a short-fur rabbit, when you noticed your partner was using S to represent short-fur and L to represent long fur. If short fur is dominant to long fur, explain where your partner went wrong with their notation.

5 Dimples (D) is dominant to no dimples. Write the genotypes for individuals who:

- a are homozygous for dimples
- b are heterozygous for dimples
- c have no dimples.

6 A girl wanted to find out if her grey cat is homozygous or heterozygous for fur colour. Assuming breeding was ethical and time efficient, what cross should she carry out? What result would she obtain if the cat were:

- a homozygous?
- b heterozygous?

7 The allele for blue eyes is recessive to the allele for brown eyes. What are the chances that two blue-eyed parents will have a brown-eyed child? What are the chances of two brown-eyed parents having a blue-eyed child?

8 Wavy hair in humans is dominant to straight hair. A wavy-haired man and a straight-haired woman have two children. The first child has wavy hair and the second child has straight hair. State the genotype of all four individuals and use suitable symbols to show your working.

9 Normal skin pigmentation is dominant over albinism (a lack of any pigmentation). A couple who are both heterozygous for this trait have three children who all have normal skin pigmentation. If they have a fourth child, is it guaranteed that they will have albinism? Explain your answer.

SEX-LINKED INHERITANCE

As previously mentioned, humans have 23 pairs of chromosomes – 22 pairs of autosomal chromosomes and one pair of sex chromosomes. The two sex chromosomes in mammals are called X and Y. The genotype for females is XX and the genotype for males is XY. The specific genes on the chromosomes contain the information required for sexual characteristics.

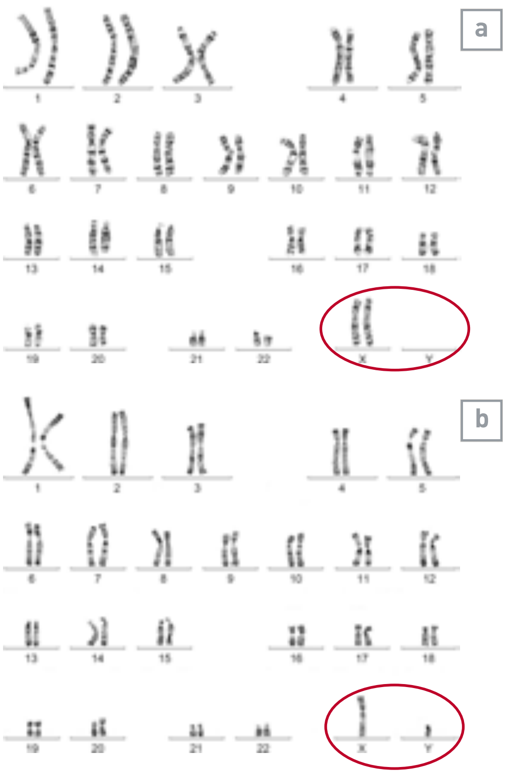


Figure 1.33 Karyotypes for (a) a female compared with (b) a male.

The X chromosome is significantly longer than the Y chromosome. The X chromosome is one of the longest human chromosomes, whereas the Y chromosome is one of the shortest. In addition to carrying the genes responsible for sexual characteristics, the X chromosome also carries many non-sexual genes, such as for blood clotting and red–green colour vision. Traits or phenotypes (and the alleles that code for them) that are carried on a sex chromosome are said to be sex-linked. Many more genes and the specific traits they control are linked to the X chromosome because it is so much larger than the Y chromosome (see Figure 1.34), therefore these genes are common called X-linked genes. Males are much more likely than females to show X-linked traits because they only have one X chromosome that cannot be masked by the Y chromosome.

In general, when investigating the pattern of inheritance for a particular trait, it is useful to consider each trait as one of the following:

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

Traits show different trends within populations, which may help identify whether they are autosomal or sex-linked, dominant or recessive. These trends are summarised in Table 1.5.

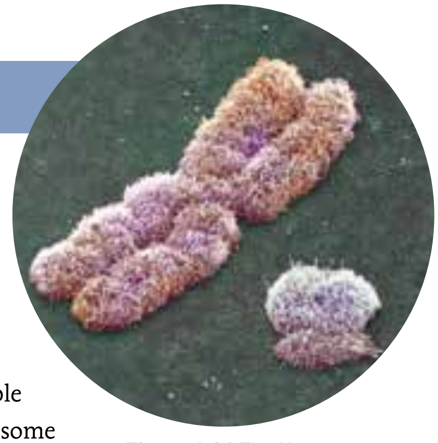


Figure 1.34 The X chromosome (left) is much larger than the Y chromosome (right) and carries more genetic information.

Figure 1.35 Most sex-linked genes are situated on the X chromosome. There are only a few Y-linked genes, such as hairy ears. So only males have hairy ears!

Figure 1.36 A male gets his X chromosome from his mother and his Y chromosome from his father. A female gets one of her X chromosomes from her mother and the other from her father.

Table 1.5 The trends of the four patterns of inheritance.

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

Sex-linked conditions

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

Red–green colour blindness

Red–green colour blindness is an X-linked recessive trait. A gene on the X chromosome controls the colour receptors in the retina of the eye. When the gene is defective, the receptors do not function properly and the person cannot distinguish red from green. Approximately 8% of males and less than 1% of females have red–green colour blindness. The difference in incidence is because the defective allele is recessive and can be masked by a dominant normal allele in females. It is very rare for a female to have two defective alleles, but not so rare for her to be a **carrier**. A carrier is someone who has an allele for a genetic disorder, but does not show the disorder in their phenotype – in other words, they are heterozygous for a recessive disorder.

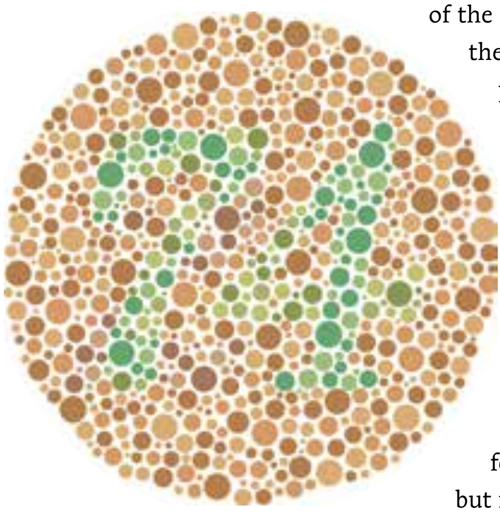


Figure 1.37 If you struggle to see a number in the dots, you may have red–green colour blindness.

Figure 1.38 A person with red–green colour blindness will have a very different view of the world.

Haemophilia

Haemophilia is an X-linked recessive disease that prevents blood from clotting. Even a small injury to a person with haemophilia can result in prolonged bleeding and excessive blood loss, or bruising (internal bleeding). It is possible to treat this disease today because the clotting factors can be produced from blood donations or made in the laboratory.

QUESTIONS 1.2.3: SEX-LINKED INHERITANCE

Remember

1 Which chromosome combinations produce a male and a female?

2 Define the term 'X-linked'.

3 Explain why X-linked recessive traits affect males more often than females.

Apply

4 Suggest a reason why X-linked genes are more common than Y-linked genes.

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

6 The girl from the family in the previous question married an unaffected man and produced a son who was colour blind. Identify the genotypes for this family.

7 The colour-blind son from the family in question 5 married an unaffected woman and had a son with normal colour vision and a colour-blind daughter. Identify their genotypes.

Research

8 Research another sex chromosome disorder. Identify how common the disorder is, the common characteristics of someone with the disorder, and whether there is any treatment. Present your finding to the class as a multimedia presentation.

PEDIGREES

Although each of your parents contributes to your genotype, the genotypes of other family members (such as grandparents, aunts and uncles) can all be important in explaining who you are. Inheritance of characteristics is often traced through families using family tree diagrams or **pedigrees**.

While a Punnett square shows the possible genotypes of the offspring and the percentage chance for each combination, a pedigree indicates what actually happened. Specific symbols are used when constructing pedigrees.

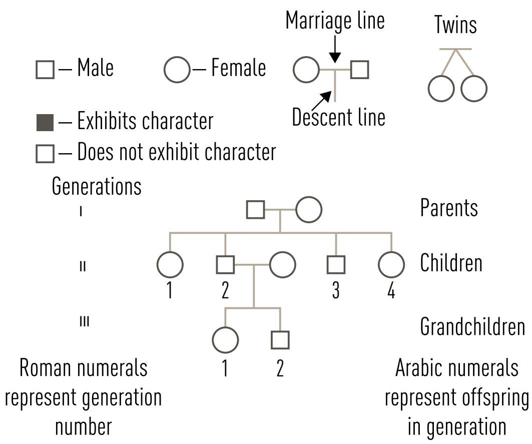


Figure 1.39 Some common symbols used in pedigrees, or family tree diagrams.

- Males are represented by squares.
- Females are represented by circles.
- If the sex is unknown, they are represented by triangles.
- A marriage or breeding is indicated by a horizontal line between a male and female.
- A vertical line between the parents indicates offspring; if there are multiple offspring, they are listed in order of birth and joined together by a horizontal line above them.
- The characteristic being investigated is shown by shading. Note that this is not always the recessive trait!
- Generations are represented by Roman numerals and individuals by Arabic numerals.

Pedigrees can be used to analyse the inheritance pattern of a particular characteristic. When analysing a pedigree to determine whether an allele is dominant or recessive, the following rules can be used:

- If neither parent has a characteristic and some of their offspring have it, then it must be recessive.
- If both parents have a characteristic and some of their children have it, then it must be dominant.
- If both parents have a characteristic and none of their children has it, then it must be dominant.

For the pedigree in Figure 1.430b, red hair is recessive because individual II2 and his partner do not have red hair but some of their children have it. The parents are both carrying the allele for red hair, but not expressing it. They both contribute their allele for red hair to some of their offspring.

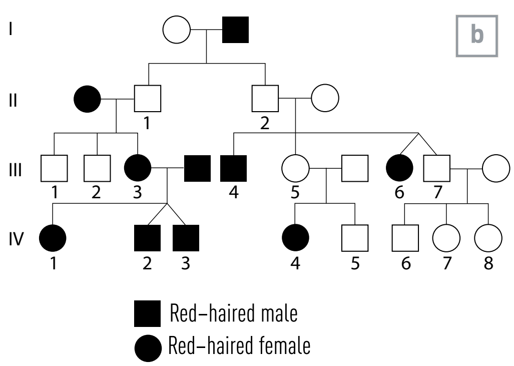


Figure 1.40 (a) Red hair is a recessive allele, so two non-red hair parents can have a child with red hair. (b) Pedigrees often show recessive alleles 'skipping' a generation.

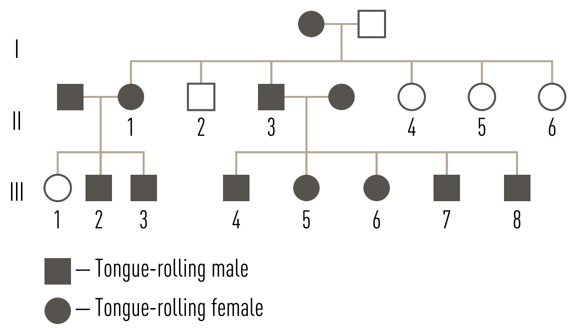


Figure 1.41 A pedigree for tongue rolling.

In the pedigree shown in Figure 1.41, tongue rolling is dominant. This is because individual II1 and her partner are able to roll their tongues, and some of their offspring can and some cannot. This means that both parents must be heterozygous for tongue rolling.

SCIENCE SKILLS

Analysing pedigrees

Pedigrees can be analysed to determine whether an individual will inherit a characteristic. Look at the family pedigree for the autosomal dominant condition of a peaked hairline shown in Figure 1.43. The father's genotype is either HH or Hh because he has a widow's peak (pointed hairline), but the mother's genotype is hh because she is unaffected (has a straight hairline).

1 Based on the pedigree, is the father's genotype HH or Hh?

2 What is the chance that the parents (generation I) will have a child with a straight hairline?

3 What is the chance that the parents (generation I) will have a child with a widow's peak?

4 Based on their children in generation III, what must the genotype be of individual II1?

5 None of the children of individual II2 have the trait of widow's peak. Does this match the expected results of such a cross? Explain how this is possible.

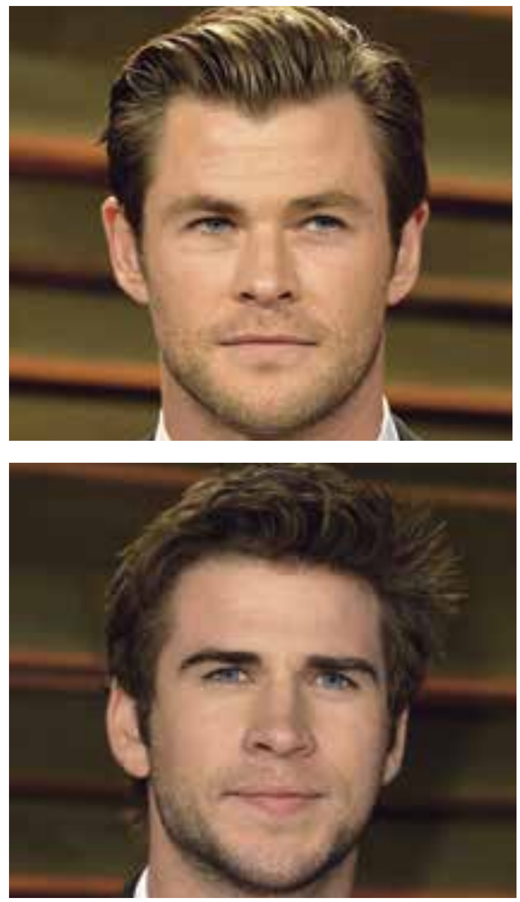


Figure 1.42 Although they are brothers, Chris Hemsworth has a widow's peak hairline but Liam Hemsworth has a straight hairline.

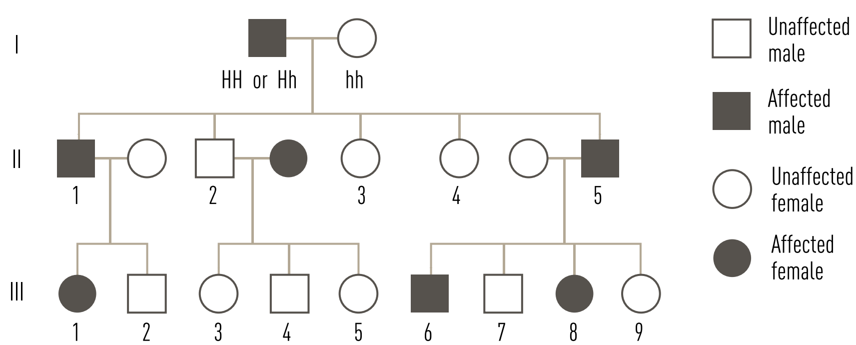


Figure 1.43 The pedigree of a family showing the inheritance of widow's peaks. Some of the children may have widow's peaks or straight hairlines.

QUESTIONS 1.2.4: PEDIGREES

Remember

1 What symbols are used to represent males and females in a pedigree?

2 A classmate believes the dominant trait is always shaded in a pedigree. Are they correct? Explain when shading should be used.

Apply

3 Some people have ear lobes that hang free and some people do not (Figure 1.46). Natalie has attached ear lobes but both Natalie's parents and her brother Daniel have free-hanging ear lobes (Figure 1.44).

a Identify whether the characteristic of free-hanging ear lobes is a dominant trait or a recessive trait. Explain your choice.

b Use suitable symbols to represent the alleles for the ear-lobe gene and then write the genotypes for Natalie and her parents.

c Identify the possible genotypes for Daniel. Explain why you cannot know his genotype for certain.

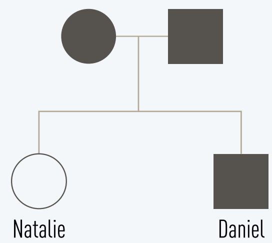


Figure 1.44 A pedigree of Natalie's family showing the inheritance of free-hanging ear lobes.

4 Examine the family pedigree in Figure 1.45.

a Identify whether the characteristic indicated by shading is dominant or recessive. Explain your answer.

b If B represents the allele for the dominant trait and b represents the allele for the recessive trait, write the genotypes for I1, I2 and person A.

c If II4 and her partner had another child, calculate the chance of the child having the characteristic indicated by shading. Show your working and Punnett square.

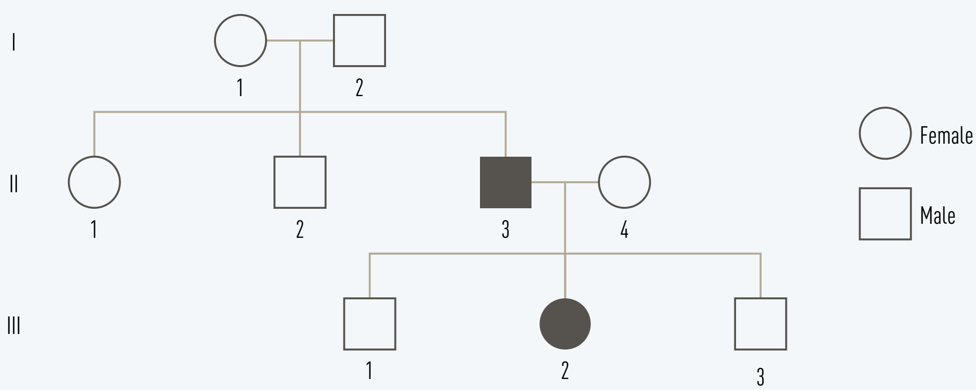


Figure 1.45 (a) Free-hanging ear lobes compared to (b) attached ear lobes.

Figure 1.46 Does this pedigree show a dominant or a recessive trait?

1.2 CHECKPOINT

GENETIC INHERITANCE

Remember

1 What are the purpose and the conditions of a test cross? [2 marks]

2 Provide the names of the two laws of genetics that were outlined by Mendel as conclusions from his work on breeding peas. [2 marks]

3 Explain the differences between the following pairs of terms: [3 marks]

- **a** autosome and sex chromosome
- **b** gene and allele
- **c** heterozygous and homozygous.

4 Explain in your own words what is meant by the formula: [1 mark]

Phenotype = genotype + environment

5 Explain the differences in purpose between Punnett squares and pedigrees. [2 marks]

Apply

6 A newborn baby shows distinct facial abnormalities. A karyotype (Figure 1.48) was prepared to determine whether there were any chromosomal abnormalities.

- **a** Identify the total number of chromosomes shown. [1 mark]
- **b** Determine if the child is male or female. How do you know? [2 marks]

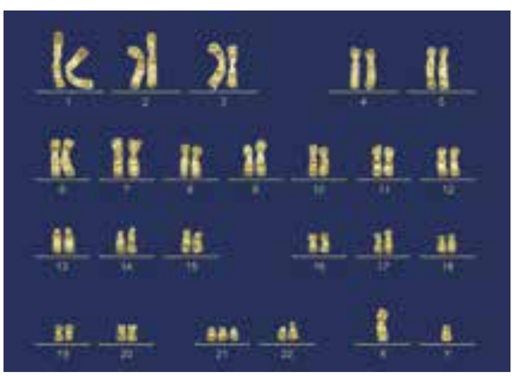


Figure 1.47 A karyotype of a newborn baby.

7 Draw a series of diagrams or a flow chart to demonstrate how the genotype XXY is possible. [2 marks]

8 Using the following information, draw a pedigree showing the inheritance of albinism. [4 marks]

- Generation I parents both have unaffected skin pigmentation.
- Generation I parents have three children: the first is a boy with unaffected skin pigmentation, the second is a girl with albinism, and the third is a boy with albinism.
- The girl with albinism in generation II has children with a man with unaffected skin: an unaffected daughter and a son with albinism.

9 List the information that can be determined from the pedigree in Figure 1.48. [4 marks]

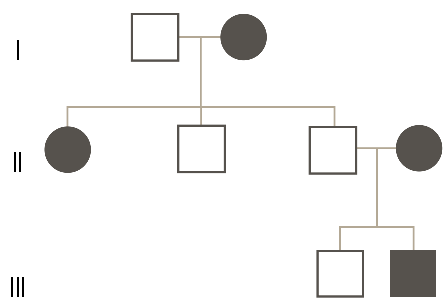


Figure 1.48 What does this pedigree tell you?

Analyse and evaluate

10 Determine who would be affected by a Y-linked gene. Explain why this is the case. [2 marks]

11 In your own words, describe the clues you would look for in a pedigree to determine if the characteristic being investigated was dominant or recessive. [2 marks]

Research

12 Find out about a genetic disease that is inherited as an autosomal recessive trait. Investigate:

- **a** the name and chromosome location of the gene responsible [2 marks]
- **b** the frequency of the disease in the population [1 mark]
- **c** how the disorder is diagnosed [2 marks]
- **d** symptoms [2 marks]
- **e** treatment. [2 marks]

TOTAL MARKS
[/36]

GENE TECHNOLOGY

1.3

There has been an explosion of knowledge and understanding of genetics during the last 50 years. Once the basic structure of DNA was understood, research into its function and the effects of mutations on the structure began. Now we have the ability to cut and paste sections of DNA to replace mutated genes or insert new genes from a different species.

GENETICS IN MEDICINE

A key step to using genetics in medicine was the completion of the Human Genome Project in the early 21st century. A **genome** is the full set of genes and alleles found in a species. The Human Genome Project determined the number of all human genes, their locations, and many of their key base sequences. The genomes of other species have also been determined and are stored in huge databases. Geneticists are continually adding to this database as new information and sequences are identified. Knowledge of the positions of genes and their specific sequences allows geneticists to identify mutations, and investigate the interaction between different genes and the proteins that they code for.

The analysis of genomes from humans and other species, and the base sequencing of the genes, has been made possible by the development of fast computers. Scientists and geneticists can also share their information all around the world in a matter of moments, saving time by not having to repeat work that has already been done.

Figure 1.49 Thomas Hunt Morgan in his laboratory with jars full of breeding flies.

Figure 1.50 The fruit fly, *Drosophila melanogaster*.

Figure 1.51 Two of the phenotypes of *Drosophila melanogaster* eye colour.

Advances in technology and scientific understanding

Scientists such as Walter Sutton, Theodor Boveri, Reginald Punnett, and Thomas Hunt Morgan in the 1920s made progress in understanding the location of genes on chromosomes. Where Mendel used the pea plant, Morgan used the fruit fly (*Drosophila melanogaster*), and his studies resulted in the discovery of sex linkage. Morgan and his team spent numerous hours anaesthetising the flies, and checking their eye colour and other characteristics. From his results, Morgan established the relative position of many genes on the chromosomes. This is called gene mapping and is used to determine the genome of a species.

The fruit fly was a very convenient organism to use to study genomes and inheritance because it only has four pairs of chromosomes: three autosomal pairs and one pair of sex chromosomes. Fruit flies also breed prolifically, with each pair producing dozens of offspring approximately every 2 weeks. This enabled Morgan to generate lots of data from repetitive trials and to ensure his results were reliable.

Knowledge of the genome and gene sequences of a species as well as understanding protein synthesis enabled geneticists to identify sequences that cause diseases or other characteristics of interest. The techniques and technology used for sequencing fruit-fly DNA were used to sequence genes and discover genomes of many other species, and also helped lead to the discovery of restriction enzymes and DNA ligases.

Restriction enzymes were first extracted from bacteria in the 1960s. Restriction enzymes are proteins that can cut the DNA molecule at specific base sequences. Their natural role is to protect bacteria from foreign DNA (which they cut up and destroy). They are called restriction enzymes because they restrict the growth of other organisms by destroying their DNA. The hunt for more restriction enzymes continues because each is specific for one sequence. The more restriction enzymes we can use, the more ways we can manipulate DNA.

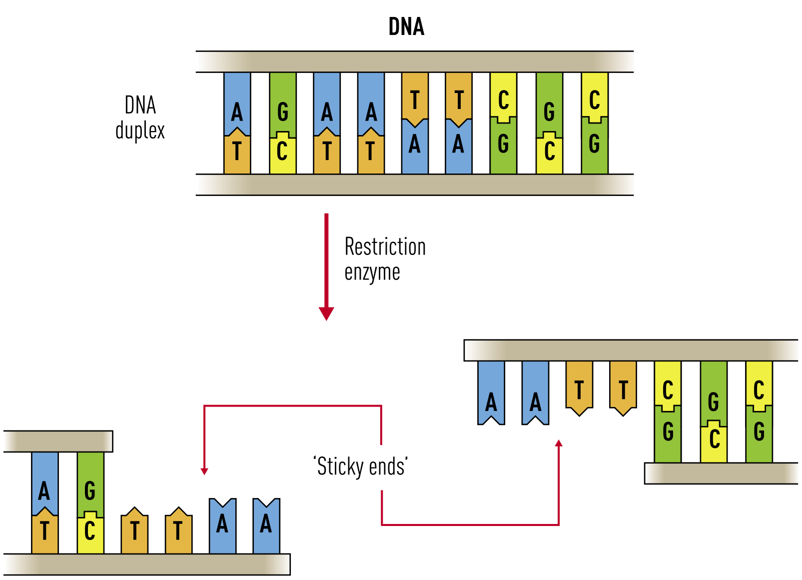


Figure 1.52 Different restriction enzymes 'cut' at different recognition sequences. The unpaired bases of 'sticky ends' make it easier for the DNA ligases to join segments.

Scientists and geneticists use restriction enzymes with another group of enzymes called **DNA ligases**, which were also discovered in the 1960s. DNA ligases are found in all types of living things, not just in bacteria. The ligases attach or 'link' pieces of DNA together. They tend to be less specific than restriction enzymes and so can be used on a number of different sequences. DNA ligases are vital for normal DNA replication and are one of the main enzyme groups responsible for repairing damage to DNA and mutations.

Geneticists use restriction enzymes as scissors and DNA ligases as glue. With these genetic tools, genes can be cut and pasted into different positions, chromosomes, organisms and even into different species. These different forms of DNA manipulation are collectively known as **genetic engineering**.

Genetic engineering and bioinformatics

Genetic engineering is the manipulation of the genome of an organism, usually through altering the base sequence of specific genes or by transferring genes from one organism to another. On a very basic level, genetic engineering may be simply altering phenotypes of organisms through artificial selection (bred by humans to possess specific characteristics).

Genetic sequencing of genes can be useful to identify the differences in base sequences between alleles, especially those that may cause genetic disorders. Sanger sequencing is a technique that was developed in 1977, but is still used today.

Sanger sequencing involves artificially replicating DNA with bases that have radioactive or fluorescent tags attached. The 'tagged' DNA is analysed by a computer that detects the different tags. The sequence can then be 'read', recorded, analysed, and stored in large databases and accessed by scientists all over the world.

Using fast computers is critical for the analysis of DNA sequences. It enables the comparison of DNA between individuals of the same or different species, and can help to determine changes in DNA over time and to establish evolutionary relationships. The use of computers in genetic analysis is termed 'bioinformatics'.

Once the sequence is determined for a chosen gene, it can be cut out of a chromosome using restriction enzymes and inserted into a different organism using DNA ligase. The second organism does not even need to be the same species as the donor organism. The organisms with new, inserted genes are called **transgenic** organisms. Transgenic organisms have artificially created genotypes.

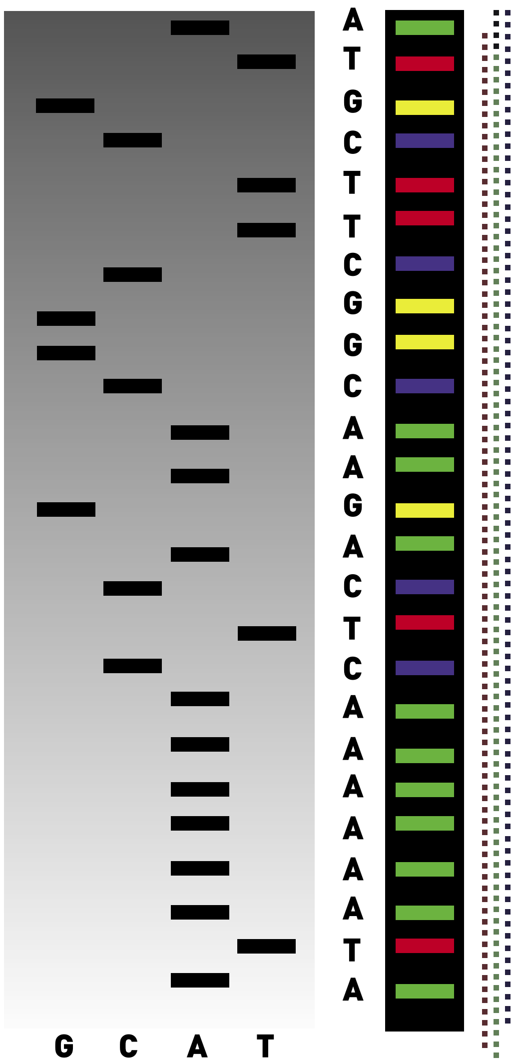


Figure 1.53 The Sanger sequencing technique determines the base sequence of DNA through the patterns produced using radioactive or fluorescent tags on the nucleotides. Running the sequence four times, each time only tagging one type of base, produces the radioactive readout on the left. The fluorescent tagging gives each base its own colour as shown on the right.

The scope of this work is enormous. Genes from other organisms can be cloned (copied) inside rapidly multiplying bacteria and then cut out of the bacterial chromosomes. The genes can then be purified and inserted into faulty cells to treat diseases. This process is called gene therapy.

Transgenic organisms can also be used to produce human hormones or tissues for transplants. For example, the human gene responsible for producing insulin can be inserted and expressed (activated) in bacteria. With the bacteria now containing recombinant DNA (DNA with the new gene), it produces human insulin that can be used to treat diabetes.

This form of biotechnology avoids the rejection issues faced by using similar products from animals such as pigs or sheep.

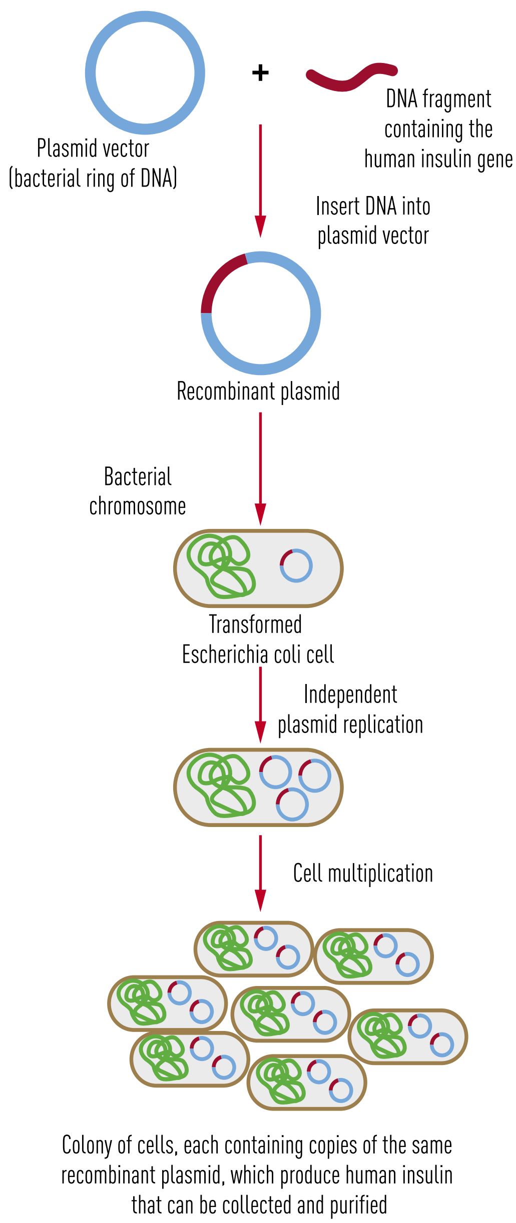


Figure 1.54 Transgenic bacteria are often used to clone specific genes and to make useful products like human insulin for treating diabetes.

Figure 1.55 These transgenic pigs produce a human protein that is important for blood clotting.

Gene technologies in medicine

Genetic technologies use the cutting power of restriction enzymes and the sticking power of ligases to remove genes from one organism and insert them into another. New transgenic organisms can be generated, such as pigs that produce human proteins, or bacteria that produce human hormones like insulin, that can be extracted and used to treat illnesses.

Genetic sequencing and fast computers are often used to diagnose and treat genetic diseases because the location of defective genes can be found quickly.

Gene therapy has been quite successful in the treatment of cystic fibrosis (CF). Patients with CF have a deficiency in a gene that controls the production of a protein that regulates the movement of ions across cell membranes. CF sufferers have an accumulation of thick mucus that can damage lung tissue, which reduces their life span significantly.

Medical scientists have been able to clone the healthy form of the cell membrane protein gene in bacteria. The purified gene is then attached to a carrier molecule called a vector. The vector is usually a harmless virus and it is administered as a drip inserted in the nose of a patient. The viruses enter many of the lung cells and insert themselves into the DNA in the nucleus, just like a normal virus. However, the DNA they inject is not harmful at all and contains the healthy gene. When the lung cells divide, the new cells contain the healthy gene.

In the cells where the gene is successfully inserted, the change is permanent. All new cells generated from these 'treated' cells will produce the protein required to regulate ion movement, and so reduce the build-up of mucus in the lungs.

A controversial type of gene therapy involves the insertion of a healthy gene into an embryo. Parents who are known carriers of a defective gene can undergo *in vitro* fertilisation (IVF) and the defective gene of the embryo can be replaced shortly after fertilisation – even at the zygote stage. As the embryo develops, the cells will have the unaffected gene. The controversy arises because some people believe that any alteration of an embryo is unethical.

Transgenic and gene therapy research is ongoing. While the immediate results look promising, there are still some concerns about possible long-term effects of genetic engineering on individuals and populations. However, with more research comes more data, which improves the reliability of the results and conclusions that can be drawn.

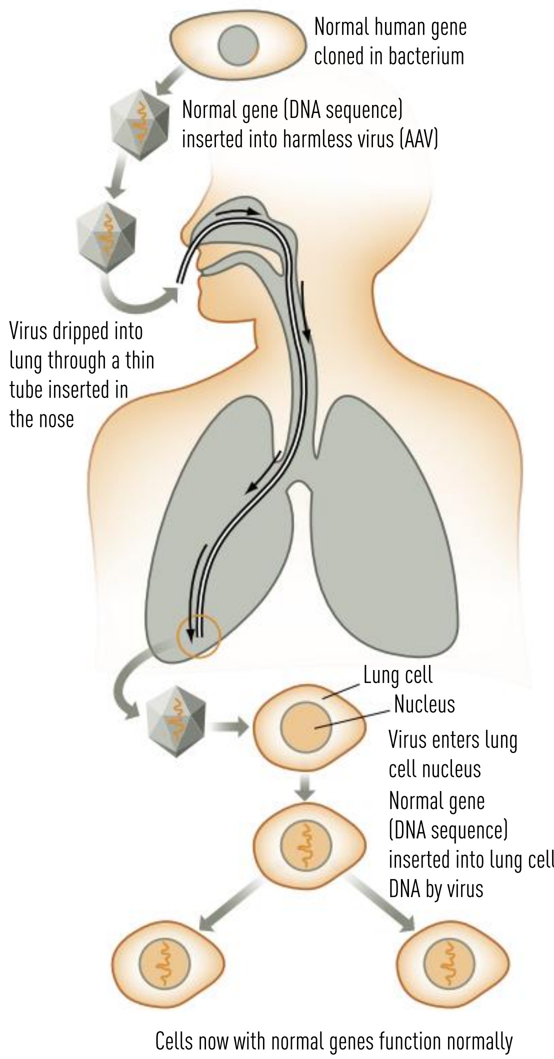


Figure 1.56 An example of gene therapy using a virus as a vector.

QUESTIONS 1.3.1: GENETICS IN MEDICINE

Remember

1 Define the term 'genome'.

2 Define the term 'recombinant DNA'.

3 What are the names of the enzymes used as 'scissors' and 'glue' in genetic engineering?

4 Provide two uses of DNA sequencing.

5 Distinguish between bioinformatics and genetic engineering.

Apply

6 Suggest a reason why geneticists often use bacteria to clone human genes.

7 Vectors are used in genetic engineering technologies.

- a Define the term 'vector'.
- b Give an example of vector used in genetic engineering.
- c Suggest why vectors are a necessary tool for genetic engineering.

Critical and creative thinking

8 Identify one discovery or innovation you consider to be a key step in the development in genetic technology and discuss why you think it was/is so important.

9 Assess whether or not the following scenarios would result in a transgenic organism. Justify your decision.

- a A mutation occurs during meiosis and the affected sperm cell goes on to fertilise an ovum.
- b Human Clotting Factor 8 genes are inserted into bacteria to produce a treatment for human haemophilia.
- c A car crash surviver receives a heart transplant.

Research

10 Investigate one technology that is used to sequence genes. Draw a flow chart to explain the main steps involved.

11 Research a disease that is currently being successfully treated with gene therapy (other than cystic fibrosis). Name the disease and describe its main symptoms. Draw a flow chart or diagram similar to Figure 1.56 to show how gene therapy for your chosen disease is administered.

OTHER APPLICATIONS OF GENE TECHNOLOGIES

Gene technology has wide applications. In addition to medicine, gene technology has uses in law, agriculture, ecology and conservation, world hunger problems and the economies of many countries. For example, the technique of DNA profiling has become established as a major tool in solving criminal cases and in determining paternity (identifying the father of a child).

Environmental applications

Some of the devastating effects of environmental oil spills and waste products from mines have been reduced by the development of bacteria containing genes that produce proteins to break down oil deposits and mining wastes. Other microbes are genetically modified to be able to extract heavy metals, such as copper and lead, from deposits. This is particularly useful when the amounts of metals in the earth become too low for large-scale mining.

Figure 1.57 Bacteria are sometimes used to digest uranium waste.

Agricultural applications

Agriculture has been significantly affected by the introduction of transgenic animals as well as genetically modified (GM) crops and foods, including plants that are resistant to certain chemicals and pests.

Crops that have been engineered to resist disease mean that poorer farmers can grow them without the extra expense of spraying herbicides and pesticides. Because lower amounts of sprays are necessary when growing these crops, production costs and environmental pollution are reduced. It is also possible to produce plants that are resistant to herbicides, meaning that when herbicides are sprayed on crops and weeds, only the weeds will be killed.

Plants have even been developed with genes that control the production of vitamins and minerals. Golden rice has had genes inserted from daffodils that help produce vitamin A, making Golden rice much richer in vitamin A than non-transgenic rice. Without adequate amounts of vitamin A, people's eyesight can be severely impaired, even leading to blindness. Other GM rice strains are being developed to increase iron content. There are also 'pharm' plants and animals that produce pharmaceutical proteins required by humans.

Increasing the nutrient value of cheap crops, such as rice and wheat, may prevent starvation and reduce malnutrition in areas where people may not have enough money to produce a wide variety of food for the population.

Examples of plants that have been genetically engineered include those shown in Figures 1.58–1.60.

Figure 1.58 Transgenic pest-resistant varieties of cotton, corn and potatoes do not need to be sprayed with pesticides.

Figure 1.59 Genetically engineered herbicide-resistant soy plants will survive the application of glyphosate, whereas the weeds are killed.

Figure 1.60 Golden rice has the potential to dramatically reduce the incidence of vision impairment due to vitamin A deficiency.

DEEPER UNDERSTANDING

DNA profiling

Your DNA is like a fingerprint. While the base sequences of large sections of genes must be identical for proper functioning, the specific sequence of bases in each chromosome is unique to you. Certain regions of chromosomal DNA are known to be highly individual. Because of this, identifying criminals (using samples found at crime scenes) has been made easier and more accurate. DNA profiling is also very useful in paternity cases, in which there is more than one possible father.

In criminal cases, DNA samples are obtained from all suspected individuals and the victim. In paternity cases, DNA samples are usually obtained from the mother, the child and the possible fathers.

All the samples are treated in the same way. Each DNA sample is broken into fragments using the same restriction enzymes. The fragments are then separated on an electrophoresis gel. The fragments are visualised using either a fluorescent dye or radioactive tags. The fragments appear as bands in different positions. The bands of DNA from different individuals can then be compared (see Figure 1.61).

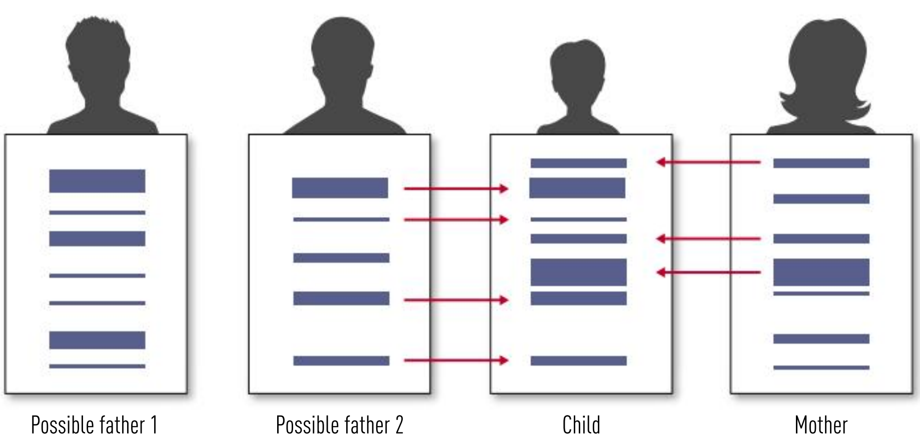


Figure 1.61 DNA profiling can reveal a child's biological father.

ACTIVITY 1.3.1: DNA MATCHING

The DNA profiles in Figures 1.62–1.64 show how 'matches' can be made. The more bands that two individuals have in common, the more likely they are to be related. In a criminal case, you would expect the bands from a crime-scene specimen to completely match the suspect before a guilty verdict is pronounced.

1 The forensic DNA fingerprint analysis in Figure 1.62 shows the DNA profiles of a blood sample taken from a crime scene and blood samples obtained from four suspects.

   a Explain which suspect has been incriminated by the DNA analysis.

   b Investigate the process of gel electrophoresis and describe how it produces DNA profiles.

   c Other than forensic DNA fingerprinting, suggest an application of this DNA-profiling technology.

Figure 1.63 An electrophoresis plate comparing DNA profiles of four suspects with a crime scene sample.

2 Figure 1.62 shows a small section of the gel electrophoresis results from a family's DNA fingerprint analysis. Which of the children is least likely to be the offspring of both parents? Explain your choice.

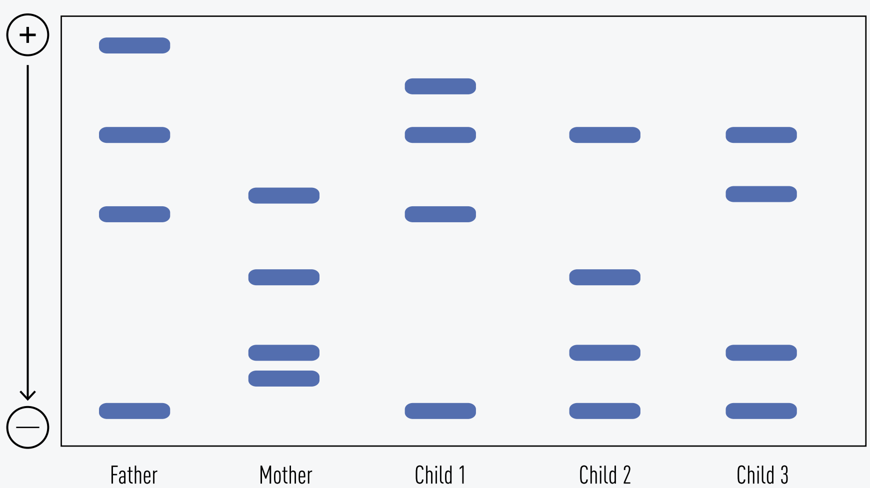


Figure 1.63 An electrophoresis plate comparing DNA profiles of five members of a family.

3 Figure 1.64 shows DNA fingerprints from four sources: a sample removed from a crime scene, a sample from the victim, and samples from suspects A and B. Do these DNA fingerprints give conclusive proof that either of the suspects was involved in the crime? Support your argument with evidence. Suggest why a sample from the victim was included.

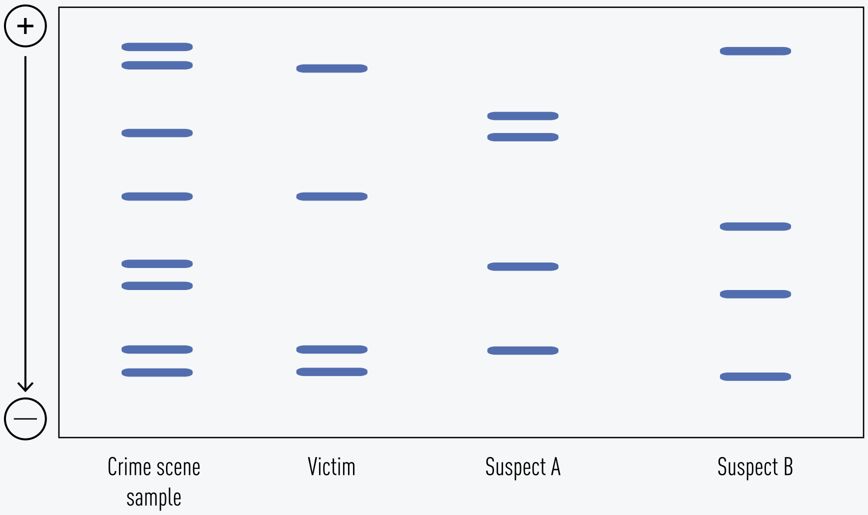


Figure 1.64 An electrophoresis plate comparing DNA profiles of the victim and two suspects with a crime-scene sample.

QUESTIONS 1.3.2: OTHER APPLICATIONS OF GENE TECHNOLOGIES

Remember

1 Define 'DNA fingerprinting' and give two examples of when it may be used.

2 Provide an example of a genetically modified organism and explain why it was created.

3 Briefly describe a method that is used to insert 'new' genes into cells.

Apply

4 Suggest at least two reasons for genetically modifying crop plants.

5 Relate advances in technology to developments in genetic applications.

Research

6 If you have not completed Activity 1.3.1, you may need to carry out some additional research.

  a Identify the two properties of DNA fragments that enables gel electrophoresis to work.

  b Draw a labelled diagram of the equipment required to run a gel electrophoresis plate.

THE ETHICS DEBATE

Ever since humans began to domesticate plants and animals approximately 10 000 years ago, we have been influencing nature. The artificial selection of plants and animals for breeding became common about 200 years ago. Some of the results include cattle with good muscle mass for beef or high milk production for dairy products, high-yielding rice and wheat, and disease-resistant crops.

The discovery of DNA and the development of various gene technologies have enabled us to manipulate organisms even further. But along with all the benefits there are ethical issues. It is no longer a question of 'can we?' but rather 'should we?' How much is human interference affecting human welfare and the welfare of other species? Do the advantages outweigh the disadvantages?

LITERACY BUILDER

Debating scientific issues

The media regularly presents scientific issues. The articles tend to be opinion pieces and use language to persuade the reader to reach the same conclusions as the author. But there is always more than one side to any topic. Scientific journal articles tend to be unbiased and rely on the facts and data to carry the message. However, some scientific issues, especially those involving genetic engineering, often inflame personal opinion. The ability to comment on and formulate an opinion about a scientific issue requires some understanding of the process involved and an ability to critically analyse the evidence presented in relation to the issue.

The art of debating

A debate is essentially a structured argument with strict rules of conduct and quite sophisticated arguing techniques. Debating requires a topic and two teams of three members each, who make up an affirmative side and a negative side. The affirmative side begins, with alternating speakers from each team.

The team that argues to support the topic is the affirmative team and the team that argues against the topic is the negative team. Often one of the most challenging aspects of being in a debate is being a member of the team that is arguing against your own beliefs.

The debaters present their arguments to support their team's position, and rebuts, or points out the flaws in, the other team's arguments.

A debate is usually judged on matter, method and manner. Matter is what you say, method is how you organise what you say and manner is how you present what you say.

Relevant scientific issues

Working in small groups, brainstorm some of the relevant scientific issues that have dominated the media over the past year. From your brainstorm, formulate some potential debate topics. Each topic should begin with the word 'That'. For example, 'That the government should collect and store a genetic fingerprint of all individuals at birth'.

Arguing your point

Form groups of six and then two groups of three. Randomly select a topic and a side (affirmative or negative). As a team of three, research as much evidence as you can about your issue and prepare to debate the topic accordingly.

Other members of the class will act as your audience and will be responsible for assessing your team in terms of matter, method and manner.

Genetic screening and testing

Genetic testing is carried out on people who are known to be at risk of a particular genetic disease or condition. This is usually evident from an individual's family history or pedigree. **Genetic screening** refers to testing for a variety of conditions regardless of a previous family history of genetic disease.

Genetic screening and testing services available in Australia include:

- maternal serum screening (MSS) – offered to all pregnant women for the detection of Down syndrome and spina bifida
- newborn screening – the screening of all newborn babies for genetic diseases, including phenylketonuria (PKU), hypothyroidism and cystic fibrosis
- adult screening to diagnose an existing disease, determine a predisposition to disease, or identify carriers with a reproductive genetic risk.

Genetic screening helps with early diagnosis of genetic diseases and subsequent intervention. This will potentially minimise the frequency of such diseases in subsequent generations; however, it sometimes involves some very difficult decisions. For example, should parents who are carriers of genetic mutations have children? What are the risks of the tests? Who should be screened, and for what? What is the impact of false positives? What options are available if the result is positive?

Genetic counsellors can help clarify the situation, but they cannot make the decision for the people involved.

Privacy is another big issue. Insurance companies in the future may make a DNA analysis part of an application for insurance. Such information could lead to discrimination against affected individuals or denial of insurance.

The collection, storage and potential uses of genetic information raise many ethical questions, including access to and the possible misuse of such information.

Gene therapy

Gene therapy involves the insertion of a healthy gene into the chromosomes of an individual with a defective gene. Gene therapy that involves the body cells (somatic cells) can be therapeutic only. This means that the treatment of the mutation cannot be passed on to the next generation. At present, gene therapy targeting germ-line cells (cells destined to become gametes) is not legal in Australia.

Apart from the success with cystic fibrosis and the great potential of gene therapy, limited progress has been made since the first clinical trials of gene therapy in 1990. Human trials with gene therapy suffered setbacks with the deaths of several people as a consequence of the technique. The ethics of treating patients with a technique that involves significant risks to life have to be considered carefully.

Figure 1.65 A blood sample is collected from a newborn infant to screen for phenylketonuria.

Stem cells

Stem cells are undifferentiated cells that can differentiate (change in structure and function) into many different types of specialised cell types, such as muscle, nerve, liver and blood cells. There are two types of stem cells. Embryonic stem cells are able to give rise to most cell types, whereas adult stem cells can only give rise to certain cell types. The use of adult stem cells is relatively common and does not raise the ethical concerns associated with embryonic stem cell use.

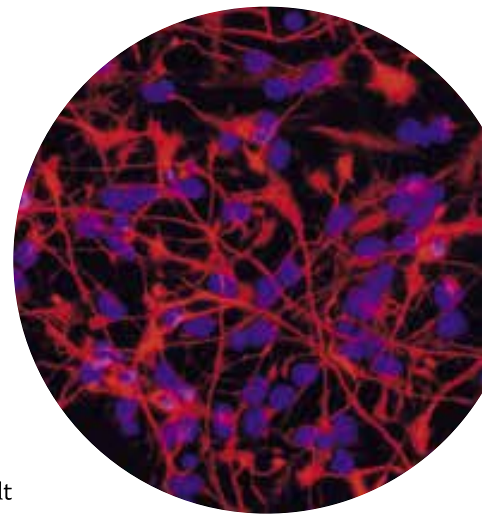


Figure 1.66 Neural stem cells, a type of adult stem cells, may one day be used to treat nerve diseases.

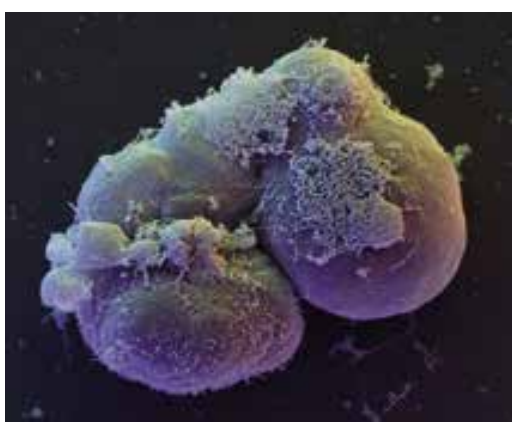


Figure 1.67 Embryonic stem cells can differentiate into any specialised body cell.

Embryonic ethical concerns

There are many ethical issues associated with the use of embryonic stem cells. Fertilising ova in a laboratory can artificially produce embryos. At present, such procedures are illegal in Australia. The only embryos used for research are those classed as 'excess embryos', having been originally produced for use in IVF. The use of these excess embryos is considered unethical by some people because the collection of stem cells destroys the embryo. In their opinion, the embryos are potential life and their use in research represents the deprivation of life to these embryos. However, embryonic stem cells have the potential to treat a variety of diseases, including cancer, multiple sclerosis (MS), Parkinson's disease, motor neurone disease and spinal cord injuries.

Some potential parents may also want to select certain embryos over others. For example, they may want a male child or a female child. They may want a child with particular eye colour or hair colour. They may choose a healthy embryo over one with, say, cystic fibrosis.

Should parents be able to pick and choose the characteristics of their child? What if the embryo that has been produced does not have the desired characteristics? What happens to undesirable embryos? Should embryonic screening be mandatory to help eradicate genetic disorders?

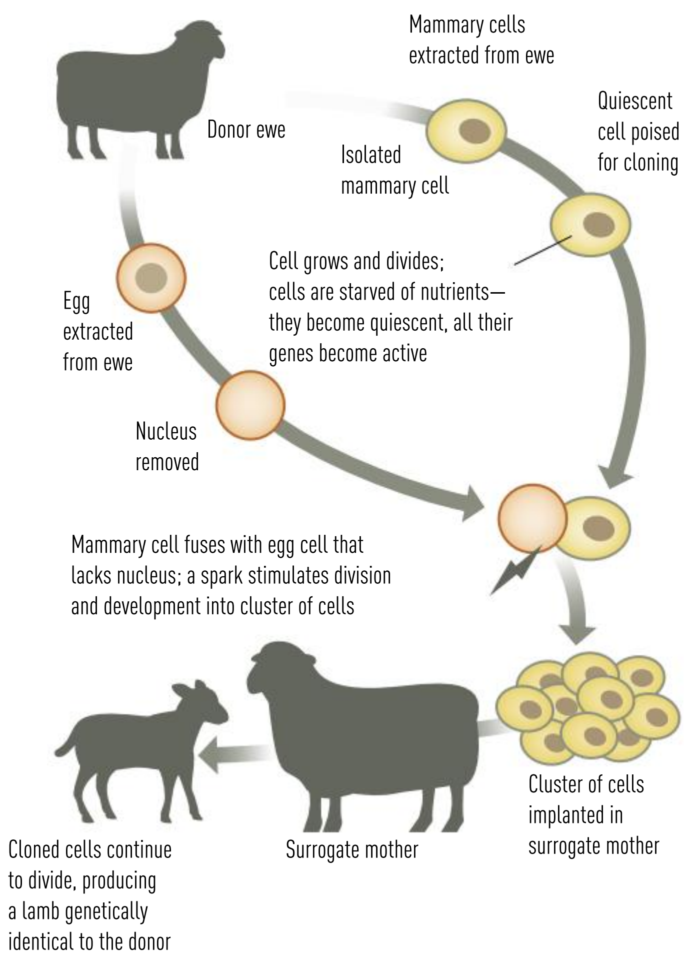


Figure 1.68 Cloning through nuclear transfer.

Cloning

A clone is an exact copy of something else. Individual genes are often cloned using bacteria (see Figure 1.68). It is also possible to clone an entire organism by the technique of nuclear transfer. This production of a new organism is called reproductive cloning.

Therapeutic cloning is a type of reproductive cloning that uses the embryo as a source of embryonic stem cells. Because the embryo is effectively 'killed' for this to occur, some people are ethically opposed to this technology, which raises the question 'when does life actually begin?'

Some simple animals are able to clone themselves, such as some worms and seastars. Many plants are easily cloned from cuttings. Large mammals including sheep and cows have also been cloned by nuclear transfer. However the process is not perfect, as the clone organisms tend to have a much shorter life span than normal.

Figure 1.69 Dolly the sheep was the first mammal to be cloned using nuclear transfer.

The prospect of cloning organs and tissues for transplants would have enormous medical potential; there would be no risk of rejection because the transplanted tissue would be genetically identical to that of the patient. But what if a whole human were cloned? What ethical concerns would need to be considered?

Genetically modified organisms

One of the most controversial developments in modern food production is the apparent rise in genetically modified organisms, or GMOs. As mentioned earlier, GM plants have been modified to enhance desired traits, such as increased resistance to herbicides or improved nutritional content.

GM crops pose a threat to biodiversity because they replace a number of natural varieties of plants with one variety: the genetically engineered plant. The number of GM plant varieties has significantly increased in the last decade or so.

The organic food movement is completely against the principle of GM foods, and public debate into the benefits and dangers of such foods is likely to continue well into the future. Some people believe that GM foods pose health risks, although there is no clear evidence for or against this.

A criticism of GM foods is the potential for accidental gene transfer to other species. GM plants may also contaminate non-GM plants of the same species through natural cross-pollination. Another concern is that increased pesticide and herbicide resistance may develop in insects and other pests. The GM plants that have the pesticide and herbicide resistance may then become vulnerable to the resistant pests.

Figure 1.70 This corn has been genetically modified so that it produces a toxin that kills harmful insects.

Figure 1.71 The first commercial GM food in supermarkets was the Flavr Savr tomato, in 1995.

QUESTIONS 1.3.3: THE ETHICAL DEBATE

Remember

1 Identify the potential importance of stem cells in medicine.

2 Define the term 'cloning'.

3 List the main ethical concerns associated with the use of embryonic stem cells.

Apply

4 Suggest why some genetic diseases are screened for in the community, while others are only tested for in individuals with a family history.

Ethical understanding

5 Suggest some ethical issues that may be associated with DNA profiling.

6 As a consumer, do you think that GM food should be labelled? Justify your decision.

Research

7 Research the history of Dolly the sheep and other cloned mammals. Construct a timeline indicating when, where and what mammals were cloned, and their life span.

1.3 CHECKPOINT

GENE TECHNOLOGY

Remember

1 Define
  a GMO [1 mark]
  b transgenic organisms [1 mark]
  c DNA profile [1 mark]
  d bioinformatics. [1 mark]

2 Explain in your own words the processes of:
  a gene therapy [3 marks]
  b therapeutic cloning. [3 marks]

3 Recall two reasons why GM plants may be a threat to the environment. [2 marks]

4 Explain why mapping and sequencing the human genome has huge medical benefits. [2 marks]

Apply

5 Distinguish between gene mapping and genetic sequencing. [2 marks]

6 Explain why DNA profiling is reliable in identifying individuals. [2 marks]

7 The process of DNA profiling is often used to analyse evidence in a crime.
  a Explain why this technique is a more useful tool than just sampling blood types. [2 marks]
  b Suggest why an exact, 100% perfect DNA match between suspect and the crime scene evidence is sometimes not possible. [2 marks]

Analyse and evaluate

8 Give at least one example where technological developments have led to advances in biological or medical understanding. [2 marks]

9 Describe the factors that would influence your decision to purchase or avoid GM food products. [2 marks]

10 Analyse whether or not large-scale genetic screening programs have the ability to reduce the prevalence of genetic disease. Justify your decision. [3 marks]

Ethical understanding

11 Select one of the issues raised in this section. Write a letter to the editor of a newspaper stating your viewpoint on the issue. Include evidence to support your stance and consider the language you would use to help persuade your readers. [3 marks]

12 Produce a scientific brochure outlining the advantages and disadvantages of purchasing GM food products. Remember to use unbiased scientific language and facts and data to support both sides of the issue. [3 marks]

Research

13 The debate around embryonic stem cells is heated. Research the main reasons for and against using embryonic stem cells. How have governments intervened in this area? Based on your findings, do you think that using embryonic stem cells could provide benefits to humans? Justify your reasoning. [5 marks]

TOTAL MARKS
[/40]

1 CHAPTER REVIEW

1 Fill in the gaps using the words in the Word Bank below:

Inheritable characteristics are coded for in the _____________ structure of the molecule DNA. Lengths of _____________ that code for a particular characteristic are called _____________, which are organised into strands called _____________.

DNA is passed from parents to offspring in _____________, which are produced and developed in the _____________ organs. Due to _____________, each gamete only contains half the chromosomes of the parent, so only the characteristics coded for in the gamete will be passed on.

As technology improves, so too does the ability to discover new facts about the structure and _____________ of DNA. Gene mapping and _____________, and the discovery of _____________ enzymes and DNA ligases have enabled mutations to be identified, located and replaced in gene _____________. However, the benefits of gene technologies should be weighed against any disadvantages and _____________ considerations taken into account.

WORD BANK

chromosomes	function	reproductive
DNA	gametes	restriction
double helix	genes	sequencing
ethical	meiosis	therapy

Identify that genetic information is coded in lengths of DNA called genes, which are joined together as chromosomes

2 Identify where DNA is usually located in a cell. [1 mark]

3 Define the terms 'haploid' and 'diploid'. [2 marks]

4 The structure of genes, chromosomes and DNA is sometimes explained using an analogy of letters and words. Describe how you would apply this analogy to nitrogen bases, genes, chromosomes and genome. [2 marks]

Outline the Watson–Crick model of DNA, and how it applies to replication and mutation

5 Describe the basic structure of the DNA double helix. [2 marks]

6 Describe complementary base pairing and explain how it is important for replication. [3 marks]

7 Recall the two main types of gene mutation and identify which type usually has the greater effect on the phenotype of the individual. [3 marks]

Relate the structure and function of human reproductive organs

8 Identify the key structures of the human male reproductive system and outline their role in sperm production. [3 marks]

9 Identify the key structures of the human female reproductive system and outline their role in ova production. [3 marks]

10 Explain why gametes are haploid. [1 mark]

Identify that heritable characteristics are controlled by the transmission of genes and chromosomes

11 Explain the difference between genes and alleles. [1 mark]

12 Explain the difference between a dominant allele and a recessive allele. [1 mark]

13 Describe how you would determine the genotype of an individual with the dominant phenotype. [3 marks]

14 Explain why only germ-line mutations are heritable. [2 marks]

1 CHAPTER REVIEW

15 A blue-eyed woman, whose parents both have blue eyes, has two children with a brown-eyed man. Both the children have brown eyes.

- **a** Suggest which allele is dominant and justify your choice. [2 marks]
- **b** The couple have a third child, who has blue eyes. Suggest the genotypes for both parents. [2 marks]
- **c** Identify which parent is homozygous and which is heterozygous for the eye-colour gene. [1 mark]

Describe how developments in genetic technology have advanced medical understanding

16 You were growing peas in your backyard and noticed that some of the peas had yellow pods, while others had green pods. Following in the footsteps of Gregor Mendel, you decide to determine which phenotype is dominant.

- **a** Identify the genotypes of the individuals you would cross to determine which phenotype was dominant. [1 mark]
- **b** Explain how you would determine that the parents were pure-breeding individuals. [3 marks]
- **c** All the offspring of your cross had green pods. Deduce which allele is dominant. [3 marks]
- **d** If two F1 plants were crossed, what proportions of green and yellow pods would you expect in the next generation? You may like to complete a Punnett square to determine this ratio. [3 marks]

17 Explain how the completion of the Human Genome Project has enabled faster identification and location of genetic disorders. [3 marks]

18 Embryonic stem cells have the ability to differentiate into any body cell. Using your knowledge of DNA, explain how this is possible. Explain why gametes cannot be used for stem cell treatments. [2 marks]

Discuss some ethical advantages and disadvantages of biotechnology

19 Identify at least two benefits and two limitations of genetic screening. [4 marks]

20 Give two examples of when GM crop plants would be a significant advantage over organic strains. [2 marks]

Assess the role of computers in DNA sequencing and analysis (additional content)

21 Explain how the development of fast computers has enabled DNA to be sequenced efficiently. [2 marks]

Research the applications of bioinformatics (additional content)

22 Explain how the bioinformatics databases are a powerful tool for geneticists. [2 marks]

23 Research an example of when the Sanger sequencing technique has been used in Australia and describe how the use of information technology is a vital component. [3 marks]

TOTAL MARKS
[/60]

RESEARCH

Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report as a multimedia presentation.

Breast cancer

To what extent does a family history affect an individual's chances of developing breast cancer? How is breast cancer detected and treated?

A shrinking Y chromosome

The Y chromosome has been losing genes over the course of time, and it is now only a fraction of the size of the X chromosome. How has this happened? Will it disappear altogether? What is the future of the Y chromosome? What effect will this have for humans?

Cloning

What other types of animals have been cloned since Dolly the sheep in 1996? What are some of the arguments for and against cloning?

Stem cell survival technique

Australian scientists have found a way to keep muscle stem cells alive so they can regenerate damaged tissue around them. Why is this technique a breakthrough? What does the technique involve? What are the immediate uses of this technique?

REFLECT

Me

1 What was the most surprising thing you found out about how DNA gives its instructions?

2 What were the most difficult aspects of this topic?

3 How has your understanding of genes changed?

4 What new science skills have you obtained from this chapter?

My world

5 Why is it important to know about how genes are inherited?

6 Why is it important to understand how genetics can shape our lives?

My future

7 How do you think genetic screening might be used in the future?

KEY WORDS

allele
amino acid
autosomal
base
carrier
chromosome
codon
deoxyribonucleic acid (DNA)
diploid
DNA ligase
dominant
double helix
fertilisation
gamete
gene
genetic engineering
genetic screening
genome
genotype
haploid
heritable
heterozygous
homologous pair
homozygous
karyotype
meiosis
monohybrid cross
mutation
nucleic acid
ovary
ovum
pedigree
phenotype
recessive
replication
restriction enzyme
sex chromosome
somatic
sperm
sugar–phosphate backbone
test cross
testis
transgenic
Watson–Crick model

1

MAKING CONNECTIONS

Cystic fibrosis

Cystic fibrosis (CF) is a genetic disease that predominantly affects children. CF is inherited as an autosomal recessive trait. In most instances, an affected child is born to two unaffected carrier parents who may have no family history of the trait. Diagnosis is made shortly after birth from routine screening. A positive test result can often be devastating and confusing for the baby's parents. In such instances, the roles of the genetic counsellor and the associated team of health professionals are crucial in helping family members to understand the diagnosis and what the future holds for those affected by CF.

The mutation

In 1989, scientists identified the gene associated with cystic fibrosis: the *CFTR* gene on chromosome 7. Various types of mutations have arisen in this gene, resulting in CF, but the most common type of mutation results in the delta F508 allele. This specific mutation is a deletion of three base pairs at position 508 in the *CFTR* gene. The deletion prevents the codon for phenylalanine obtaining its normal position in the protein coded for by the gene. Having two copies of this mutation, inherited from both parents, is the leading cause of CF.

Figure 1.72 Cystic fibrosis affects the production of mucus in the lungs, and people with CF may need help breathing.

Effects of the mutation

The product of the *CFTR* gene is a protein that forms a chloride ion channel, which is important in creating sweat, digestive juices and mucus. People with CF have mucus and digestive secretions that are thicker than normal. Although most people without CF have two working copies (alleles) of the *CFTR* gene, only one working copy is needed to prevent CF. When neither allele can produce a functional CFTR protein, CF develops.

Prevalence

In Caucasian populations in Australia, America and Europe, 1 in 25 people are carriers for the CF allele. In other words, they are heterozygous for the *CFTR* gene and have the ability to transmit this mutation to subsequent generations. This proportion of carriers results in approximately 1 in 2500 children born being affected by CF. The frequency of carriers is much less in some other populations. For example, in Japanese populations, the proportion of those affected with CF is estimated to be as low as one in 300 000 births.

a

b

Figure 1.73 The mucus build up in the lungs can be easily seen with an X-ray. (a) The lungs of a healthy woman compared to (b) the lungs of a woman with cystic fibrosis.

Treatment

There are many aspects to the treatment of people with CF. Traditional treatment involves the input, advice and expertise of various healthcare professionals, with regular check-ups and tests to monitor the condition and to keep a check on a child's growth, development and wellbeing.

The future

CF is a lifelong condition. With improved treatment, life expectancy has increased from less than 10 years in the 1960s to an average of 30–40 years. With current treatment, most people with CF can live reasonably normal and productive lives.

The discovery of the *CFTR* gene and its faulty alleles, as well as further understanding of its function, are now opening up new possibilities in terms of treatment. One such possibility is gene therapy. The field of genetics has proposed gene therapy as a plausible method for curing genetic disease. Through gene therapy, a healthy version of the defective *CFTR* gene could be inserted into the affected cells in the body, particularly those of the lungs. Such treatment does not just treat the disease symptoms, it cures the illness. To date, clinical trials involving gene therapy have produced disappointing results, with the effects short-lived and the benefits quickly reversed. However, gene therapy as a method of treatment does hold much promise for the future as research into the most effective methods of gene therapy continues. Carrier genetic testing (the testing of at-risk individuals for the presence of the gene before they have children) is currently available in Australia.

Figure 1.74 Physiotherapy helps clear the thick mucus secretions in people with CF.

Questions

1. Why is CF considered an autosomal recessive disease?
2. How would a mutation arise in this gene?
3. Why does the deletion of the codon prevent phenylalanine from obtaining its normal position?
4. How does the genotype of a person with CF affect their phenotype?
5. How does being heterozygous for CF affect the phenotype?
6. Do you think CF will become more common in populations as time goes on? Why or why not?
7. How has modern technology benefited people with CF?
8. How do you think gene therapy could cure CF?
9. Why do you think clinical trials are conducted in new areas of research?

2

EVOLUTION

Change is inevitable. In every aspect of our lives and our world, change occurs whether we like it or not. The non-living world is constantly in a state of flux and may be influenced by the living world, particularly the actions of humans. Change is also occurring within the living world, with organisms adapting to changes in their environment over short- and long-term time scales. If a species does not have variations and adaptations that allow it to survive environmental changes, it becomes extinct (dies out).

EXPLAINING BIODIVERSITY 2.1

We know that different plants and animals live in different parts of the world, but why are they different? Why aren't they more different? Early naturalists sought to explain the biodiversity of the world they knew and to explain the presence and diversity of fossils of creatures that no longer existed.

Students:

» describe scientific evidence of the evolution of present-day organisms

EVOLUTION OF A SPECIES 2.2

Although Darwin may have been amongst the first to hypothesise the effect of natural selection on evolution, it is current research and evidence that has confirmed the theory that species change and adapt to better suit and survive in their environment. Any mutation that is an advantage to an organism increases the likelihood of that individual surviving and reproducing to pass on 'good' genes to the next generation.

Students:

» explain how natural selection can change populations
» outline how genetics and environmental factors influence the survival of individuals and species

EVIDENCE FOR EVOLUTION 2.3

Evolution is a scientific theory, which means it is supported by valid and reliable evidence from a range of different sources. The fossil record, plate tectonics, genetic mutations and changes in environmental conditions all point towards evolution. Carefully designed experiments and fair tests have generated huge amounts of data, all of which help confirm the theory of evolution.

Students:

» relate the fossil record to evidence of the age of the Earth and evolution

2.1 EXPLAINING BIODIVERSITY

We know there are many different types of plants and animals across the planet, and we are only beginning to appreciate the diversity of bacteria, fungi and protists. The diversity of living things is not consistent across the planet; different places have different organisms. It was once thought that all organisms were created in their current form, and that organisms do not change over time. Early naturalists started to look for other explanations of why organisms look like they do and whether they change over time.

EARLY EVOLUTIONARY IDEAS

Evolutionary ideas were all first proposed without any knowledge of DNA and genetic inheritance. As scientific knowledge has increased, some ideas have been rejected, while some have been supported by new findings in genetics, developmental biology and palaeontology. There is now considerable unbiased, reliable and valid scientific evidence that supports **evolution**, which is why it is now considered a **scientific theory**.

Figure 2.1 Lamarck believed that giraffes stretched the length of their necks to reach food and that their offspring, and later generations, inherited the resulting long necks.

Lamarckian theory

One of the first documented explanations for changes in **species** over time was by Jean-Baptiste de Lamarck, a French naturalist, who believed in evolutionary change – that organisms change over time due to changing environmental conditions. He is best known for his theory of inheritance of acquired characteristics, which was first presented in 1801. In this theory, Lamarck proposed that an organism can develop characteristics during its lifetime in order to adapt to its environment, and that those changes are passed on to its offspring. In other words, the change is made by what the organism wants or needs. Lamarck also stated that body parts not being used, such as the human appendix and little toes, are gradually disappearing and eventually people will be born without these parts. So, the more a limb or aspect of the body was used, the bigger or stronger it became. The less a limb was used, the smaller and weaker it became until it disappeared entirely.

Although most of Lamarck's ideas were supported by what he saw around him, they could not be tested or replicated and were attacked by the French scientific establishment as being unreliable.

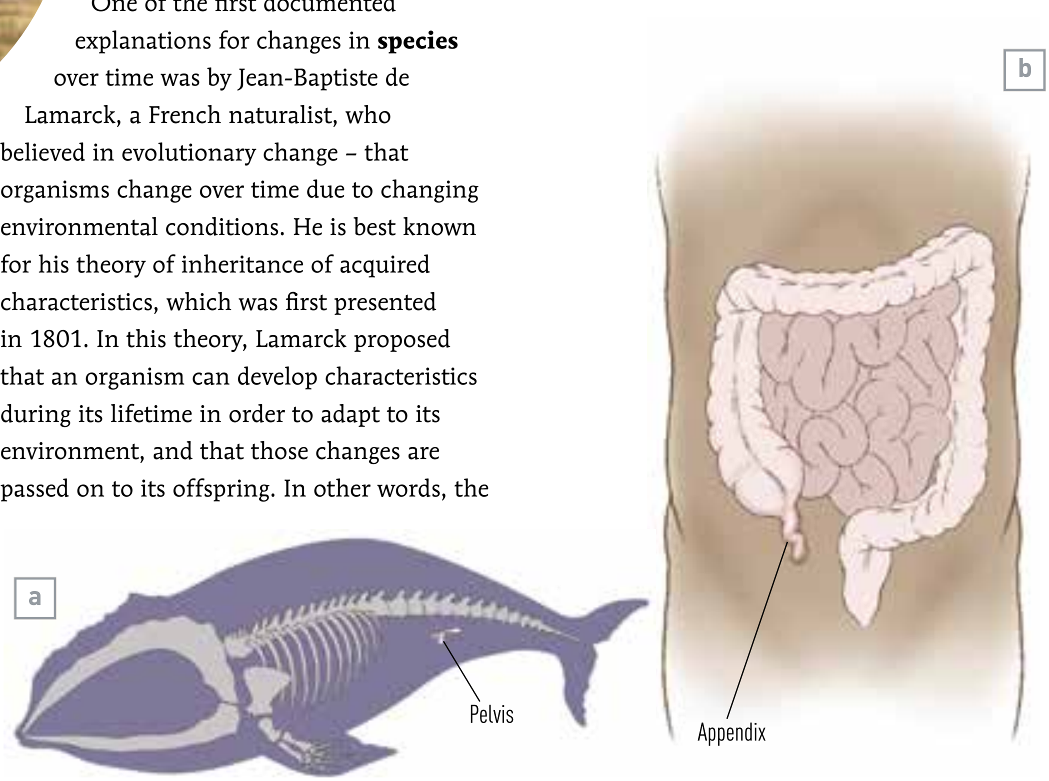


Figure 2.2 Lamarck's theory identified 'shrinking' vestigial structures as those that were no longer useful, such as (a) the whale pelvis and (b) the human appendix.

Darwin sets sail

For Charles Darwin, an English naturalist and geologist, explaining biodiversity was of great importance. Darwin was well educated and had been exposed to the sciences through his father and grandfather, who were both physicians. Darwin's grandfather had sought to explain life in evolutionary terms in a book he published in 1794: 'Would it be too bold to imagine that all warm-blooded animals have arisen from one living filament?' This question was too bold for its time and lacked substantial evidence.

Darwin had also read the works of Lamarck. With this background of scientific thought and process, the young naturalist set sail on a 5-year world cruise as the unpaid naturalist aboard HMS *Beagle*. The year was 1831 and Darwin was just 22 years of age.

Figure 2.3 The HMS *Beagle*.

A diversity of life

Over the 5 years of the HMS *Beagle*'s voyage, Darwin investigated the geology of the places he visited and collected all manner of wildlife and **fossils** – the remains of living organisms. Darwin carefully recorded the details of each specimen before sending the collection back to England by ship. During this period of intense record keeping and observation of natural systems, Darwin questioned traditional views and developed his hypothesis for the origin of species. Darwin made his most significant observations during the final stages of the voyage, when the HMS *Beagle* headed westward into the Pacific to the Galapagos Islands.

Figure 2.4 Darwin collected a huge range of samples, and sent the specimens back to England.

Galapagos Islands

The Galapagos Islands are a chain of volcanic islands about 1000 km west from mainland Ecuador. The eastern-most islands are the oldest, with substantial plant growth and weathering, whereas the western-most islands are the newest and are still volcanically active. Darwin and his helpers collected specimens from the Galapagos, seeking to obtain at least one of each species. Among the specimens collected were 13 finches, all of which resembled one another in terms of the general form of their bodies and plumage. Yet each specimen had slight differences in beak size and shape and represented a new species. Most had also been found on different islands. In his journal, Darwin noted that these creatures held a striking similarity to those found on the mainland. He wondered, if new and different beings had been created for each island, why did they look so much like those from the mainland?

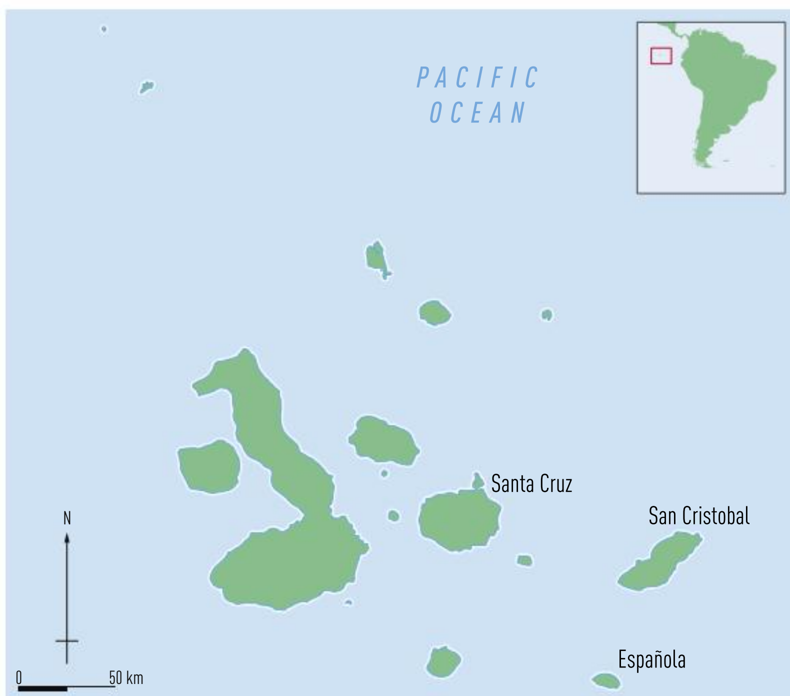


Figure 2.5 The Galapagos Islands.

Figure 2.6 Three different species of 'Darwin's' finch, found on three different islands: (a) medium ground finch on San Cristobal Island, (b) large cactus ground finch on Española Island and (c) cactus ground finch on Santa Cruz Island.

ACTIVITY 2.1.1: ANALYSING BEAKS

Figure 2.7 shows the various finch species that are now recognised from the Galapagos Islands. In pairs or small groups, analyse the size and shape of the beak to account for the relationship between beak shape, habitat and food types. Report back to the class and try to establish trends of similarities or differences.

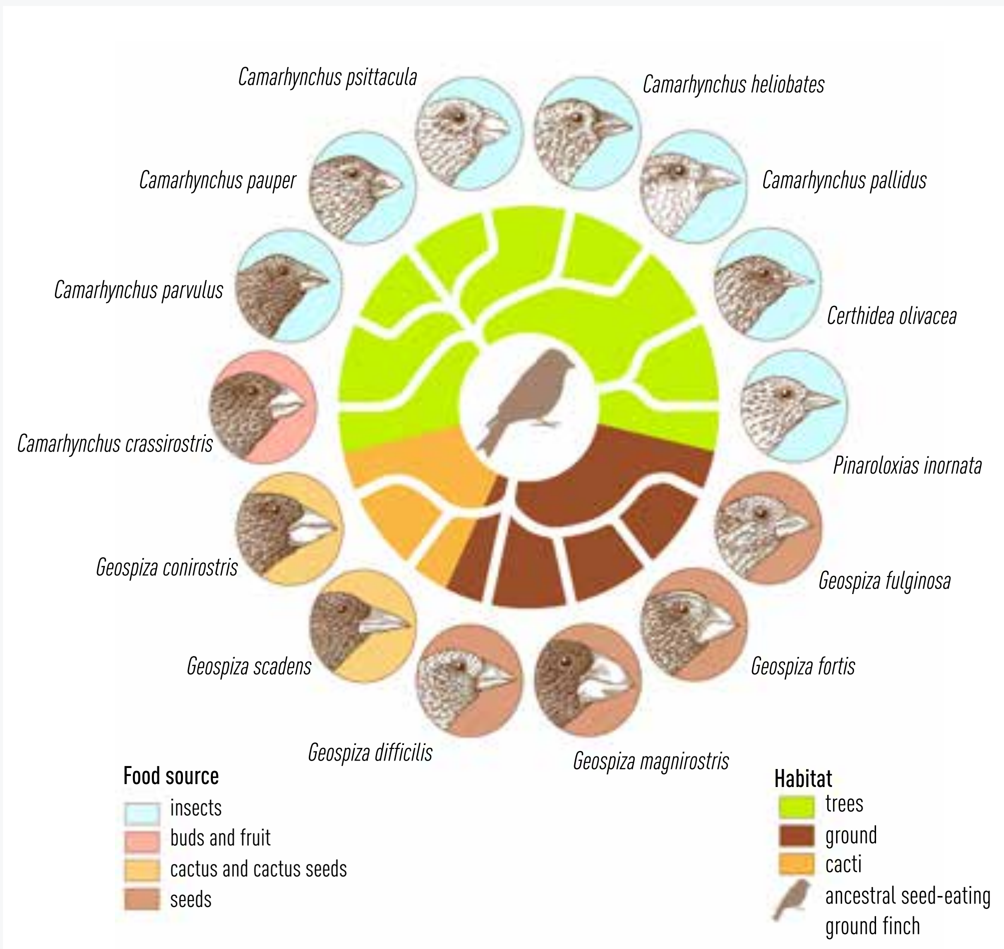


Figure 2.7 The Galapagos finches show beak diversity because of the types of foods they eat and variations in their habitat.

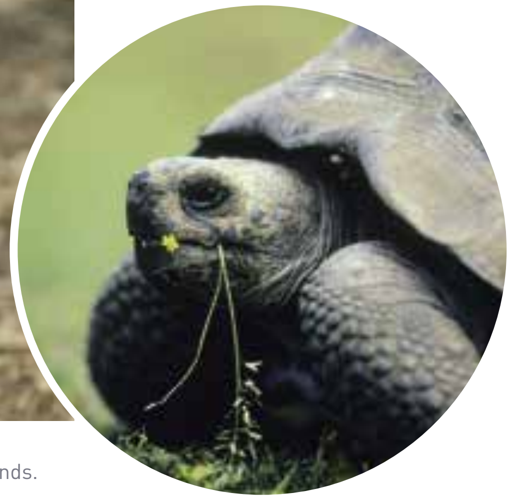


Figure 2.8 Different species of tortoise have distinctly shaped shells as a result of the different habitats on the different islands.

The dry, volcanic Galapagos Islands looked desolate and the only plants present struck Darwin as 'wretched-looking weeds'. As he walked across Chatham (San Cristobal) Island's rugged lava surface, Darwin came across two huge tortoises ambling along a well-beaten path.

A few days before Darwin left the Galapagos Islands, the Islands' Vice-Governor remarked that he could tell which island a tortoise came from by the shape of its shell. This provided Darwin with the inspiration he needed. Indeed, this is the main way in which the various types of tortoise on the Galapagos Islands differ: the shape of the tortoise's shell depends on its environment, which varies significantly depending on the island. Tortoises that live on dry islands, such as Española Island, have shells that are raised at the front so the tortoises can reach up for vegetation. In contrast, tortoises that live on large islands with dense vegetation have domed shells to help them push through the shrubbery.

QUESTIONS 2.1.1: EARLY EVOLUTIONARY IDEAS

Remember

1 In your own words, describe how Lamarck thought species changed over time.

2 List the feature of the tortoises that identified which of the Galapagos Islands they were from.

3 Finches are found in many places around the world, including South America and the Galapagos Islands. Identify features of the Galapagos finches that led Darwin to believe they should be classified as several new species.

Apply

4 Propose a piece of evidence that refutes Lamarck's theory of inheritance of acquired characteristics.

5 Fennec foxes have particularly large ears (Figure 2.9). Suggest how Lamarck would account for this characteristic.

6 Are the east islands or west islands of the Galapagos younger? Explain how the age of the islands could influence the variety of finches found there.

Figure 2.9 How would Lamarck explain why the Fennec fox has such large ears?

DEVELOPING THE THEORY OF EVOLUTION

Figure 2.10 In Darwin's time, pigeon breeding was a popular pursuit and many new forms of different traits were being bred.

On 2 October 1836, the HMS *Beagle* reached the shores of England. A year later, Darwin was arranging his Galapagos collections and finishing work on his journal, which became known as *The Voyage of the Beagle*. Again, it struck Darwin that if each species had been created independently, why should some details have been repeated in the different tortoises and birds, whereas other features were distinctly different?

The idea of species haunted Darwin and he thought that if he was ever to make sense of it, he needed to collect as many facts about variations in plants and animals as possible. This search led him to investigate the breeding of domestic species such as pigeons.

Artificial and natural selection

Selective breeding, or **artificial selection**, has been a human pursuit for well over 10 000 years, when many human populations moved from the hunter–gatherer lifestyle to more permanent settled communities. Selective breeding is essentially humans choosing breeding partners for plants and animals in an effort to 'select' certain traits for their offspring. Over many generations, the 'wild' traits are often lost and the species is considered 'domesticated'. Darwin, and many other pigeon breeders, selected all manner of different traits to create new breeding lines of pigeons.

Figure 2.11 Alfred Russell Wallace (1823–1913) arrived at the same theory as Darwin about the same time. Wallace's work was conducted in Asia, whereas most of Darwin's observations were made in the Americas and Africa. Darwin had the advantage of a wealthy family that could assist him in being published. Perhaps this is why Darwin received most of the credit.

Darwin then wondered how 'selection' occurred in nature. The answer Darwin was seeking came from the work of Thomas Malthus, whose paper *An Essay on the Principle of Population* gave Darwin the insight he needed. Malthus argued in his paper that the human race would completely overrun the Earth if it were not held in check by war, famine and disease. Darwin extrapolated from this that, under changing circumstances, favourable variations would tend to be preserved and unfavourable ones would be destroyed.

At last Darwin had a hypothesis to test, although it would take another 20 years of painstaking hard work before he was convinced that his hypothesis had enough support to be developed into a theory. Alfred Russell Wallace, a naturalist who had worked in the East Indies, sent Darwin a copy of his manuscript in which he had independently arrived at the same concept of **natural selection**. In 1858, Darwin and Wallace jointly published a paper, and in 1859 Darwin published his book *On the Origin of Species by Means of Natural Selection*.

One mechanism Darwin proposed that enabled natural selection to occur was sexual selection. All organisms that reproduce sexually have some measure of choice over which individual they reproduce with, although some much more than others. This is most easily seen in animal species where one gender picks or selects the other based on particular characteristics. For example, female peafowl (peahens) will mate with the male peafowl (peacock) with the most and brightest eyespot feathers. This is probably because the quality of feathers is an indication of health.

Evolution by natural selection occurs as a result of competition between individuals in a population with different traits. This competition may be for food, shelter or mates. Selection for traits that provide an advantage with regard to mating is called **sexual selection**. **Sexual dimorphism** is the term that describes the male and female of the same species being different in appearance (di means two; morph means shape).

Figure 2.12 Female peahens will 'select' a mate based on the quality of the peacock's feathers.

Figure 2.13 The devil angler (*Linophryne indica*) fish is an example of extreme sexual dimorphism. The female is approximately 51 mm long, whereas the male attaches himself as a parasite to the female and is only 15 mm long!

ACTIVITY 2.1.2: SEXUAL SELECTION IN HUMANS

In small groups, discuss the factors that determine mate choice in humans. For example, are there certain features of a person's physical, mental, intellectual or emotional make-up that tend to make them more attractive to the opposite sex? Do these factors change from one generation to another? Do these factors change from one culture to another? How might these choices affect the human species? Are there similarities with other animals?

Share your groups' thoughts with the class, and then discuss whether you believe this to be artificial or natural selection.

On the origin of species

Darwin's book *On the Origin of Species by Means of Natural Selection* was largely one long argument for the theory of evolution by natural selection. Darwin made the following observations.

- Individuals in a species vary.
- Much of the variation is heritable (traits are passed from parents to offspring).
- Reproductive capacity is greater than needed (many species produce more offspring than are required to maintain population size).
- Resources are limited.

Figure 2.14 The number of individuals in a population or species tends to remain constant if the ecosystem in which they live is also stable. In other words, the birth rate matches the death rate and, as a consequence, equilibrium, or balance, is achieved.

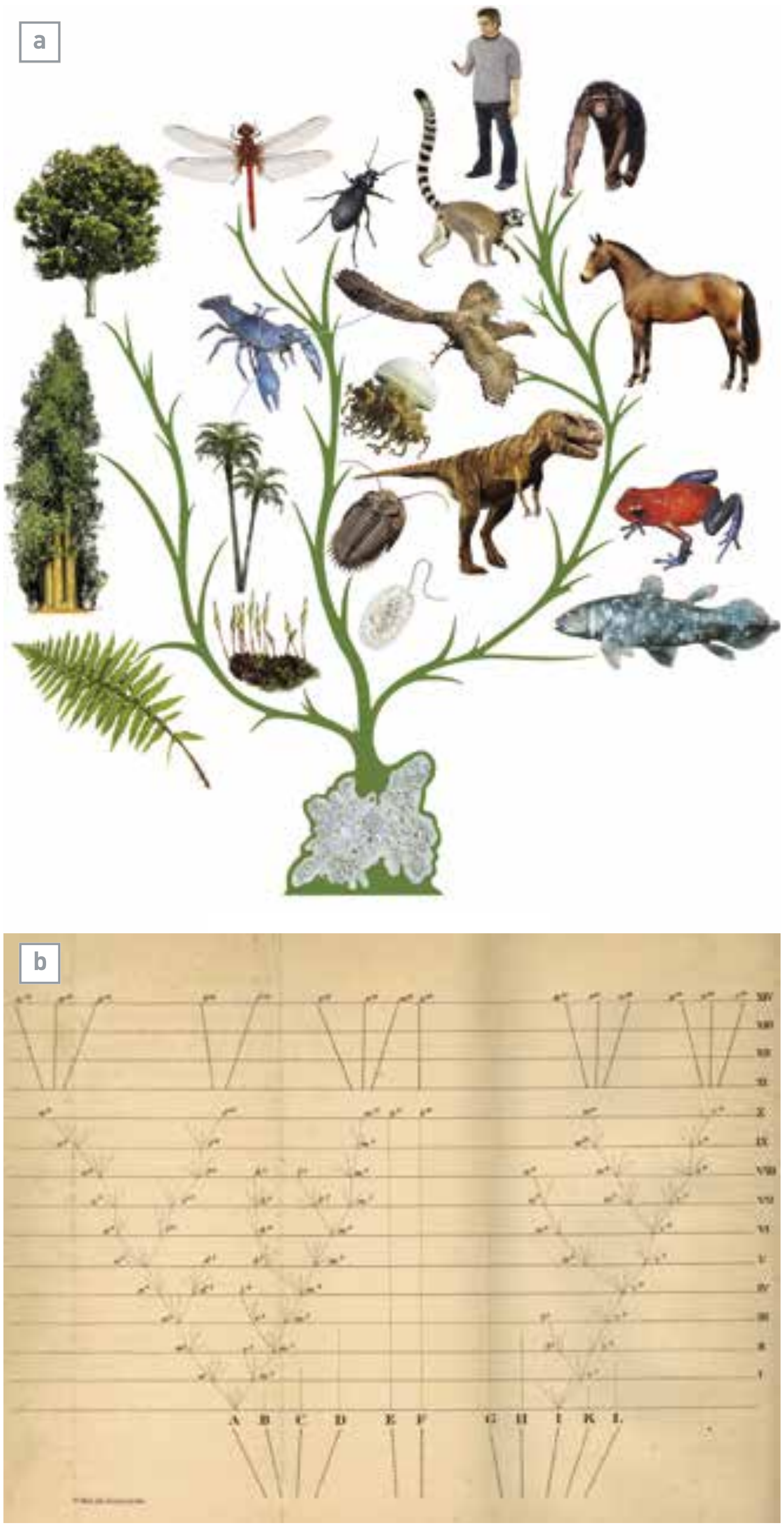


Figure 2.15 (a) An interpretation of Darwin's tree of life and (b) his diagram in notes for his book *On the Origin of Species by Means of Natural Selection*.

Based on these observations, Darwin inferred:

- there is a struggle for existence
- individuals best suited to the environment (the 'fittest' individuals) survive and reproduce
- over time, this results in populations adapting to the environment and can lead to new species.

Darwin recognised the role of geographic isolation in the formation of new species and said that the small differences within a species could lead to more distinct differences between species over time. Although these observations may seem relatively obvious to us, they were nevertheless a major conceptual challenge for many people, including many scientists, of Darwin's time.

The two basic ideas that flowed from Darwin's book are the concept of the 'tree of life' and the theory of evolution by means of natural selection.

In his tree-of-life metaphor, Darwin depicted living organisms as being organised like the limbs of a great tree, with more general groups branching into more specific ones. He noted that classification systems already reflected this branching in their hierarchical arrangement of species. Darwin suggested it was the conditions of the environment in which a species lived that determined which traits and characteristics would make them 'fit', and the differences in environmental conditions across the world explained the differences between species.

In his theory of evolution by means of natural selection, Darwin concluded that:

- species change over time
- some species become extinct
- some species keep diverging, splitting eventually into multiple descendent species – '**common descent**'.

DEEPER UNDERSTANDING

Wallace's Line

Alfred Russell Wallace was a naturalist working at the same time as Darwin. Wallace collected specimens in tropical regions, particularly the Malay Archipelago, which is now Malaysia and Indonesia. During his eight years in the Archipelago, Wallace collected thousands of insects, shells and bird skins, as well as mammal and reptile specimens, many of which were new species to science at the time. One of his notable discoveries was Wallace's golden birdwing butterfly.

During his time in the Archipelago, Wallace proposed the theory of natural selection as the mechanism of evolution. After corresponding with Darwin, both he and Darwin published papers in a journal of the Linnaean Society of London.

Wallace is best known for his discovery of what is called Wallace's Line. Wallace found that the fauna (animal species) of Asia and Australia, which are strikingly different, divide along a line that runs through Bali and Borneo, continues north through Lombok and Sulawesi, and then east of the Philippines. It has since been discovered that this line is approximately the collision zone between the Asian and Australian continental plates.

Figure 2.16 Wallace's golden birdwing butterfly.

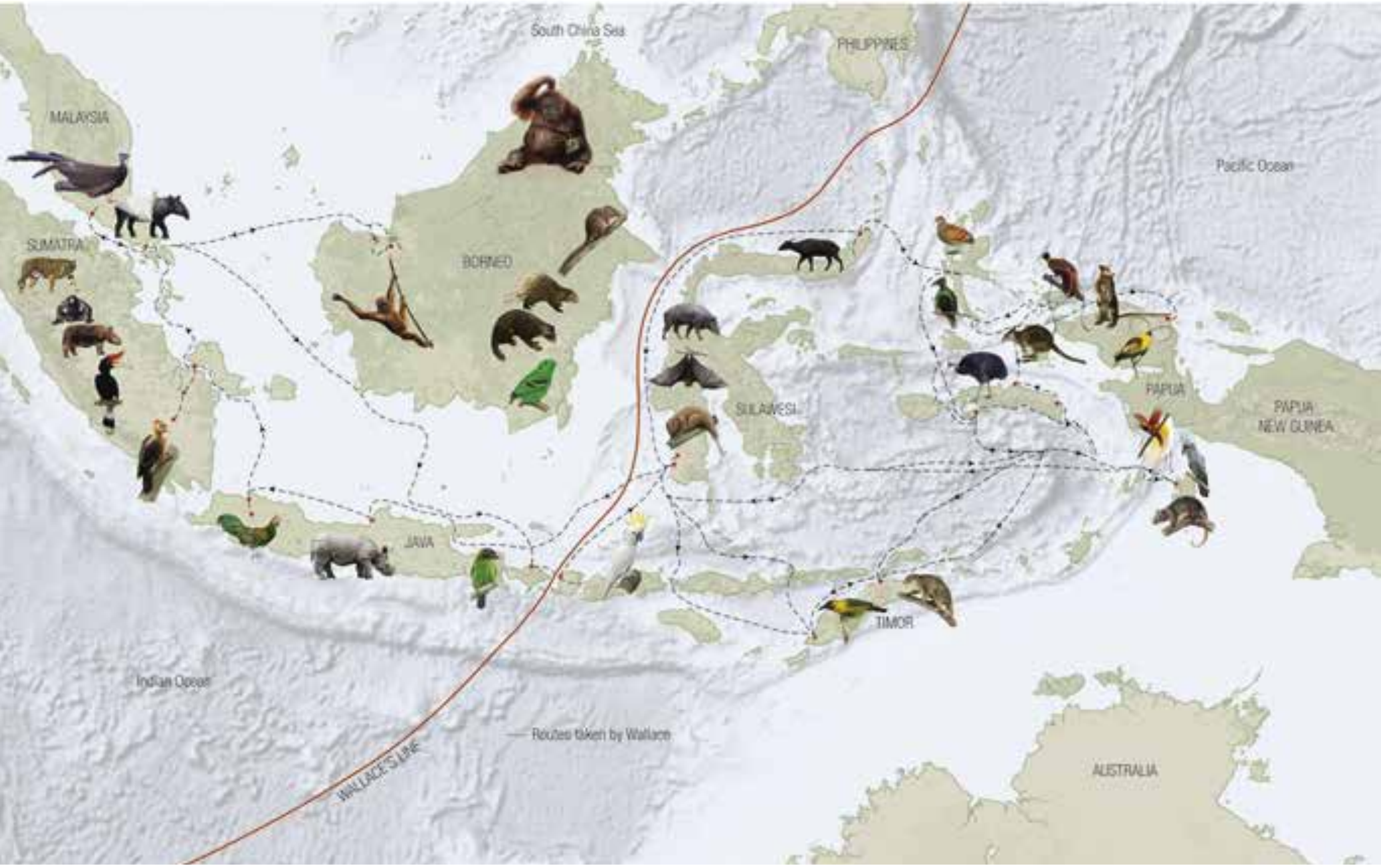


Figure 2.17 Wallace's Line – the fauna are strikingly different on either side of the red line.

Figure 2.18 A jigsaw fit of Africa and South America.

Biogeography

At the beginning of the 17th century, the English philosopher Francis Bacon noted that the east coast of South America and the west coast of Africa looked as though they could fit together like pieces of a jigsaw. Since this time, geologists have developed our knowledge of the structure of the Earth and the movement of continents. The theory of **plate tectonics** is well supported by observations across the planet. At one time all the continents were connected in a single landmass called Pangaea. This supercontinent then broke in two to form Gondwana in the south and Laurasia north of the Equator.

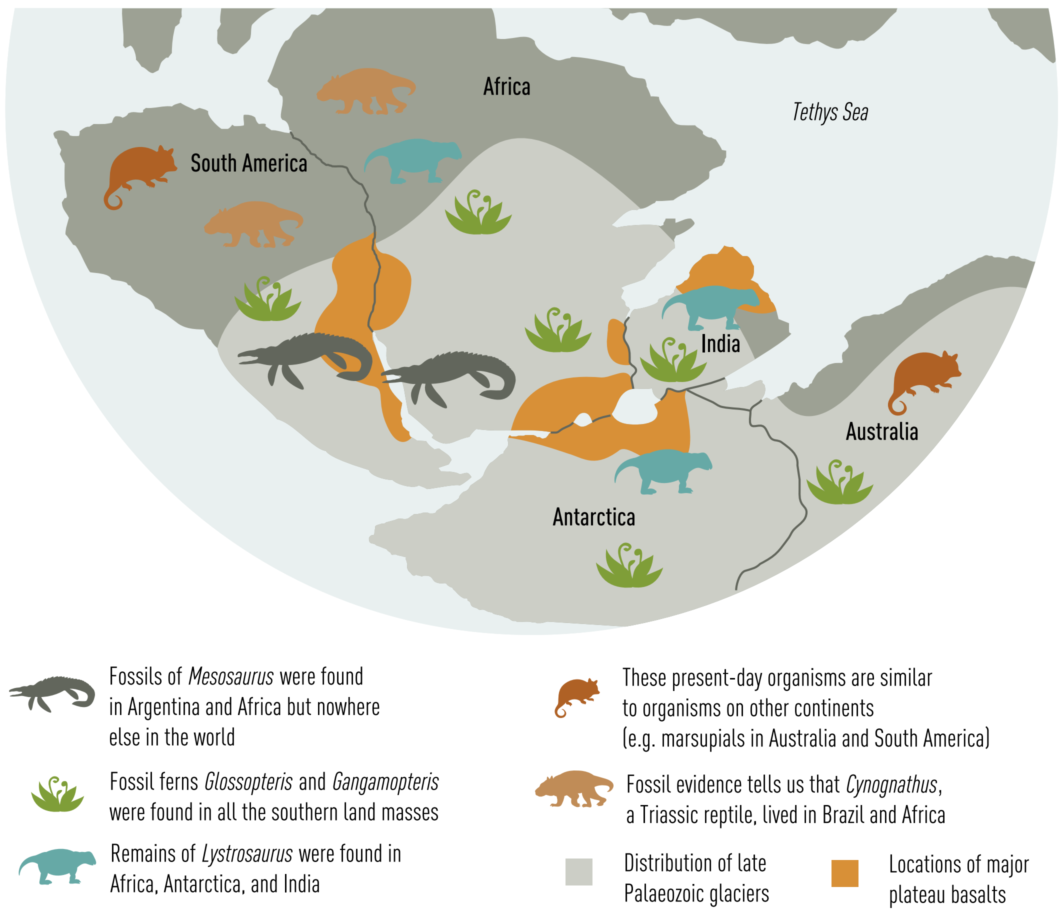


Figure 2.19 Evidence for the existence of supercontinent Gondwana.

The theory of plate tectonics has had a major impact on evolutionary theory because living organisms were carried on the landmasses when they moved and separated.

Biogeography, the distribution of the fossils of extinct plants and animals as well as modern-day species, supports the theory of plate tectonics. Some continents share very similar organisms even though they are separated by large stretches of ocean because they were once joined together. The distribution for animals that are able to fly or swim is less predictable, but for the rest, continental movement is the only convincing explanation.

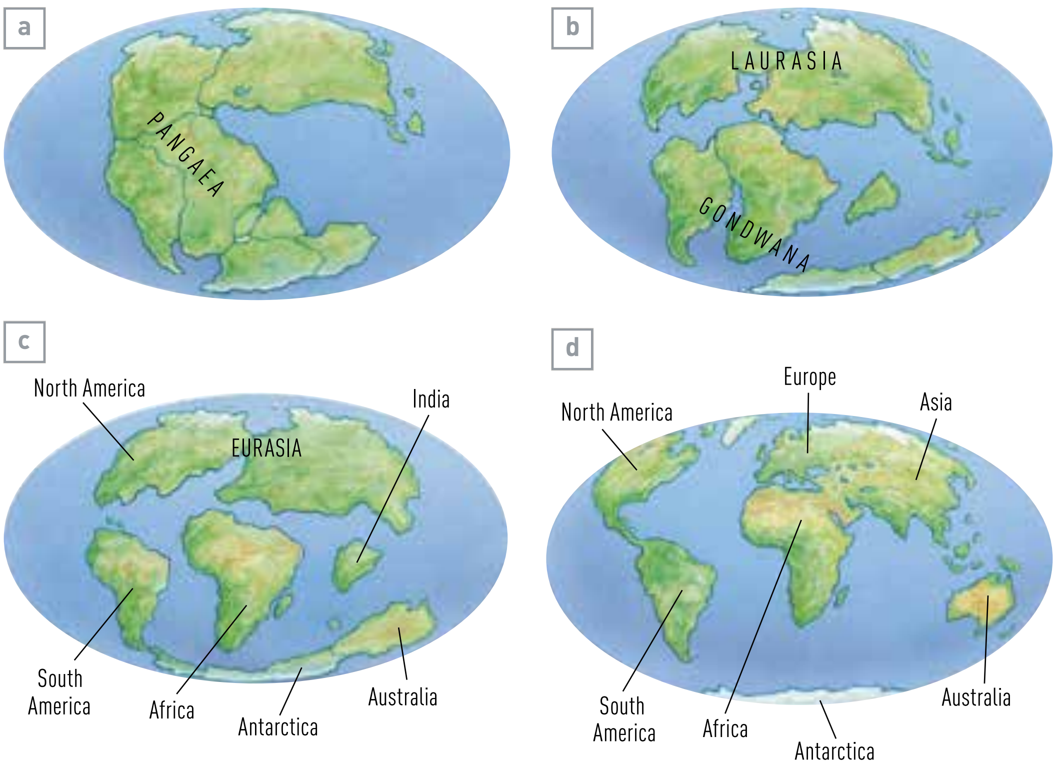


Figure 2.20 How the continents have drifted: the continents (a) 220 million years ago; (b) 135 million years ago; (c) 65 million years ago; and (d) today.

Plate tectonics provide a well-supported explanation for the geographical isolation of species that eventually results in **speciation** – the evolution of a new species. The biogeography of groups of similar species, such as the ratites (flightless birds), and the existence of marsupials on several continents, can be explained by movement of continents. 'Coincidence' is simply not a scientific explanation. Wallace's line identifies this variation and similarity in species according to geography, although he did not have the knowledge and understanding of plate tectonics to explain why this variation existed.

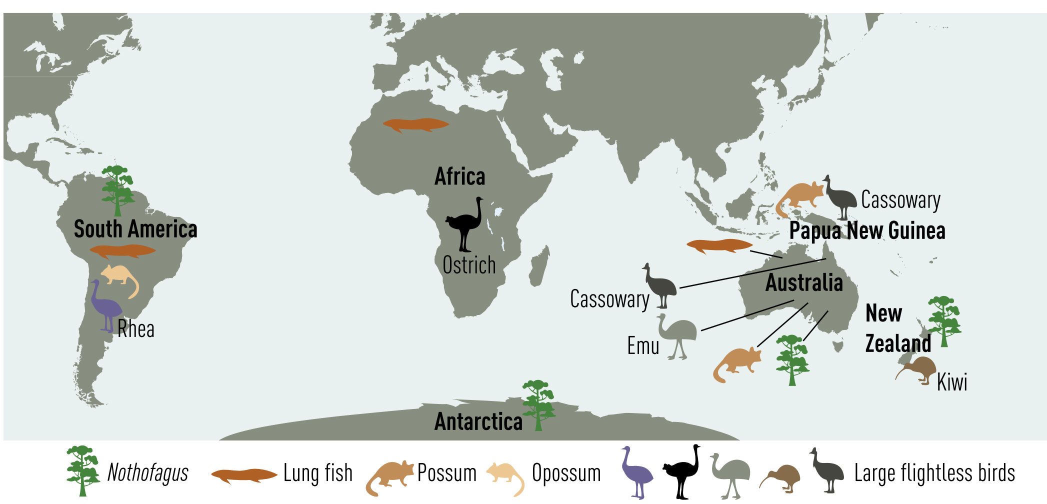


Figure 2.21 Similar species of animals and plants are found in continents that originally made up Gondwana.

QUESTIONS 2.1.2: DEVELOPING THE THEORY OF EVOLUTION

Remember

1 Explain, in your own words, the concepts of the 'tree of life' and the 'struggle for existence'.

2 Name the continents that made up the ancient supercontinent of Gondwana.

3 Identify the significance of Wallace's Line.

Apply

4 Propose a reason why Darwin waited so long between arriving at his hypothesis and publishing his theory of evolution by natural selection.

5 Explain the links between the relevant observations Darwin made with his inferences that were published in *On the Origin of Species by Means of Natural Selection*.

6 The frogs of Australia show their closest evolutionary relationships to frogs in Africa and South America (Figure 2.22). Suggest a logical explanation of how is this possible.

Figure 2.22 (a) An Australian orange-thighed tree frog and (b) an orange-eyed brown tree frog from Madagascar.

Analyse

7 The Virginia opossum is a common marsupial found in North America. There are 5-million-year-old fossils of opossums from South America and 1-million-year-old fossils from North America. Identify whether this supports or disproves the theory of plate tectonics. Justify your reasoning.

EXPLAINING BIODIVERSITY

2.1 CHECKPOINT

Remember and understand

1 Identify the observations made by Darwin about the origin of species. [2 marks]

2 Explain the difference between a hypothesis and a theory in science. [2 marks]

3 Propose how Wallace's Line may have formed. [2 marks]

4 Define 'artificial selection' and explain why it is different from 'natural selection'. [2 marks]

5 Identify reasons why organisms found on islands, like the Galapagos, would be similar to those on the mainland, but not identical. [2 marks]

Apply

6 Develop your own hypothesis about something you have observed in the animals or plants around you. How might you test this hypothesis? [3 marks]

7 Use an example, other than those used in the text, to illustrate Darwin's inference of the struggle for existence. [2 marks]

8 Relate the structure of Darwin's tree of life to modern classification systems. [2 marks]

Analyse and evaluate

9 Compare natural selection and sexual selection. [2 marks]

10 Sexual selection may lead to exaggerated traits such as the peacock's tail. Explain why traits that may be a disadvantage in the natural environment may be favoured in sexual selection. [3 marks]

11 Both Darwin and Wallace developed the theory of evolution by natural selection while studying life in the tropics on islands such as the Galapagos. Suggest why studying islands was so helpful. [2 marks]

Critical and creative thinking

12 Create a timeline of important scientific events leading up to the publication of Darwin's book about the origin of species. [5 marks]

13 The field of palaeontology was relatively young in Darwin's time. He predicted that 'missing links' between groups would be found in the fossil record. Research one example of a transitional fossil such as *Archaeopteryx, Australopithecus* or *Tiktaalik* and propose how the fossil record may 'fill in the blanks'. [3 marks]

14 The theories of Lamarck and Darwin are often compared and contrasted in the form of cartoon strips. Prepare a three-part cartoon strip for each theory that clearly identifies the similarities and differences between these theories. [5 marks]

Making connections

15 Speculate how Darwin's theory may have been different had he known about genetics, the age of the Earth, plate tectonics and other related ideas. [3 marks]

TOTAL MARKS
[/40]

2.2 EVOLUTION OF A SPECIES

Dogs have been bred for centuries by most human cultures. Dogs were originally bred for qualities such as hunting, herding, companionship and protection, but since the 1850s they have also been bred for their looks. When organisms reproduce sexually and the resulting offspring are able to survive and continue reproducing, then the original parents are considered to be of the same species. This idea of 'species' is relatively recent and is a crucial aspect of evolutionary theory.

NATURAL SELECTION

To date, the theory that best explains the diversity of life forms and the evidence of change over time is Darwin's theory of evolution by natural selection. Darwin argued that it was entirely possible for one species to evolve gradually into a separate species, with its own unique traits, over many generations.

As Charles Darwin and Alfred Russell Wallace pointed out, an individual doesn't evolve; rather, populations do. A **population** is a group of interacting individuals of a species living in a particular area. A species is defined as organisms that can reproduce to produce offspring that are both viable (able to survive) and fertile (able to reproduce).

Figure 2.23 It is sometimes possible for organisms of different but similar species to reproduce; however, their offspring are often unable to live a normal, healthy life and usually cannot reproduce. These hybrid animals are the result of crosses between a zebra and (a) a horse (zorse) and (b) a donkey (zonkey).

Natural selection is the principle mechanism for evolution. Darwin proposed four requirements for natural selection:

1. Variation exists between individuals in a population.
2. Many differences between individuals in a population are inherited.
3. Not all individuals in a population survive to produce offspring.
4. Those individuals in a population that are 'fitter' (better adapted to the environment) contribute more to the next generation than those that are less fit. This is known as **survival of the fittest** (Figure 2.24).

Figure 2.24 'Survival of the fittest' doesn't refer to those animals that can run the fastest; it refers to any feature or characteristic of a species that will help to survive and 'fit' into its environment.

ACTIVITY 2.2.1: GENERATIONAL CHANGE

This is a whole-class activity but requires students to be in groups of four or five.

What you need: different tools (e.g. spoons, forks, chopsticks or straws), different types of lollies (e.g. soft, hard-boiled or wrapped), plastic bowls

WARNING

> Remind your teacher if you have food allergies or diabetes – you may not be able to eat the lollies.

1 Each group of students has a different type of eating utensil, such as spoons, forks, straws and chopsticks. Every member in the group has the same type of utensil.
2 Each group has the same mix of lollies.
3 Using only the tool provided, try and move as many of the lollies as possible from one bowl to another in 1 minute.
   - Which of the eating utensils was the most successful at gathering lollies?
   - Which of the eating utensils was the least successful at gathering lollies?
   - Was there a relationship between the type of lolly and the type of effective tool?
   - Over time, what might happen to the numbers of each lolly type?
   - If a new tool that enabled certain lollies to be gathered much more easily was introduced, what effect could this have on the numbers of each lolly type?
   - How could this simulation be used to analyse the changing features of populations over several generations?

ACTIVITY 2.2.2: SELECTION CHALLENGE

What you need: gymnasium or space outside set up for different physical challenges such as jumping height, reaction time or flexibility. There could even be some basic problem-solving challenges such as 3D puzzles or other logic games. Students could be responsible for planning and setting up the stations. You may be able to borrow equipment from the PE department. Make sure you choose a range of activities to suit everyone's abilities.

1 All members of the class are to complete each station in a 'round robin' style, recording their results for each station in a previously agreed format.
2 Where members are unable to complete the activity, either for time or health reasons, this should be noted as 'unable to complete'.
3 Once complete, merge the data into a single class set for analysis.
   - Who was the best at each activity? Were these people the same for every activity?
   - If these tasks represent the activities an organism needs to do to survive, how many people in the class will survive? What if one activity was much more important to survival?
   - Evaluate this activity as a model for evolution by natural selection.

Variations in populations

Natural selection depends on the variation of traits within a population, but where does this variation come from? All members of a species share a set of common traits that help to define them as a species. For example, *Homo sapiens* (humans) are identified for the purpose of classification as:

- an animal (kingdom Animalia)
- with a notochord (phylum Chordata)
- with a segmented spinal cord (subphylum Vertebrata)
- that suckles its young (class Mammalia)
- that gestates its young with the aid of a placenta (subclass Eutheria)
- that is equipped with five-digit limbs, a collarbone and a single pair of mammary glands on the chest (order Primates)
- that has eyes at the front of the head, stereoscopic vision and a proportionately large brain (suborder Anthropoidea).

Figure 2.25 Kingdom Animalia, phylum Chordata …

Figure 2.26 … subphylum Vertebrata …

Figure 2.27 … class Mammalia …

Figure 2.28 … subclass Eutheria …

Figure 2.29 … order Primates …

Figure 2.30 … suborder Anthropoidea …

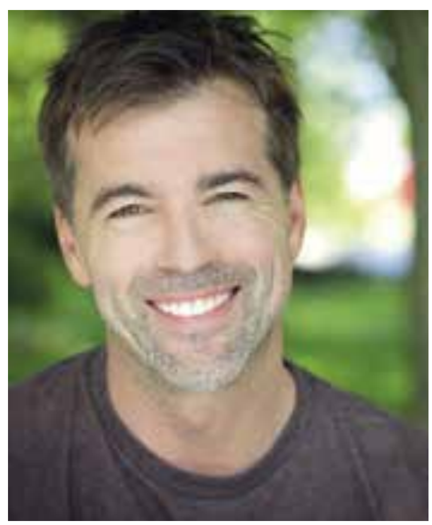


Figure 2.31 *Homo sapiens*.

Figure 2.32 These Siberian huskies have genes for eye colour, but different versions, or alleles, of these genes.

Our species belongs to the family Hominidae and the genus *Homo* (larger-brained hominids that appeared approximately 2 million years ago) and is characterised by a higher and more vertical forehead, a round skull, small face and teeth, a prominent chin and a longer, more slender skeleton. Despite these unifying traits, no two people (except for identical twins) look the same. Most traits differ from one individual to another, especially in sexually reproducing species.

Much of the variation between individuals is due to genetic differences that can be inherited – something that Darwin and his contemporaries observed but did not understand. Individuals of the same population generally have the same number and types of genes, but different alleles (variations of the genes, as discussed in chapter 1). All the genes in the entire population can be thought of as a **gene pool** – a collection of genetic information. The gene pool includes all the alleles for all the genes in the population: all the variations possible without new mutations.

Mutations

You have about 20 500 genes, each of which may have several alleles. It has been estimated that there may be more than 70 trillion different allele combinations! Consequently, it is extremely unlikely that another person with your exact genetic make-up has ever lived or ever will (unless you have an identical twin). Only alleles that already exist in parent DNA can be inherited, unless a mutation creates new alleles in the DNA of gametes.

As you read in chapter 1, mutations can occur at the gene level or at the chromosome level. Some mutations may be lethal, having a drastic effect that results in death. Others may be neutral, neither helping nor harming an individual. Natural selection does not increase or decrease the frequency of neutral mutations in a population because they do not influence an individual's chances of surviving or reproducing. One example of this is syndactyly – webbing between the fingers or toes. It is common because a developing foetus has webbing that undergoes apoptosis, or 'programmed cell death', to remove it before the baby is born (see Figure 2.34).

A mutation may also give an individual a survival advantage. Even if the advantage is small, it increases the chance of that individual surviving to reproduce and pass on those 'favourable' alleles. Chance events or natural selection may preserve the mutated gene and ensure its representation in the next generation.

Beneficial and neutral mutations have been accumulating in different lineages for billions of years. Through all that time mutations have been the raw material for evolutionary change – the basis for the staggering range of biological diversity, past and present, as environmental conditions change and favour them.

Allele frequencies

In the real world, populations are always evolving. How common an allele is within a population is considered to be its frequency. The allele frequency changes when environmental conditions change to make that allele favourable or detrimental.

Figure 2.33 Gametes contain all the genes, and therefore alleles, of new life. Mutations in gamete cells are the only way for new alleles to be introduced into the next generation.

Figure 2.34 Syndactyly is neither an advantage nor a disadvantage to modern humans and so the mutation persists at a relatively constant frequency in the population.

DEEPER UNDERSTANDING

Camouflaged moths

In the 1950s, scientists in England documented changes in the colour of the moth species *Biston betularia*. These moths range in colour from light grey to nearly black. During the day the moths rest motionless on tree trunks. In unpolluted areas, tree trunks are covered with light grey lichens, against which the light grey moths are well camouflaged. In areas with severe air pollution, lichens cannot survive, so the tree trunks are lichen-free and dark, exposing lighter moths to predation from birds.

It seemed to researchers that, as areas became more polluted, dark moths increased in frequency – natural selection seemed to be changing allele frequencies in the population. This was selection in favour of the 'dark' allele.

Figure 2.35 The number of dark-coloured moths of the species *Biston betularia* increased as a result of air pollution killing the lichen on trees.

In 1952, strict pollution controls went into effect so that the lichens returned and the tree trunks became free of soot, for the most part. As may have been predicted, selection started to operate in the reverse direction. In areas where levels of pollution declined, the frequency of dark moths also declined.

Other examples of directional selection include the evolution of pesticide-resistant insects and antibiotic-resistant bacteria. In these cases, our use of pesticides or antibiotics has selected for variants that are resistant to the chemicals.

EXPERIMENT 2.2.1: MODELLING THE EFFECTS OF NATURAL SELECTION

Aim

To model the effects of natural selection on the allele frequency of a population.

Hypothesis

Read the introduction and method carefully, and then write an appropriate hypothesis in an 'If ... then ...' format.

Materials

- Set of cards or counters to represent the beetles (30 red, 30 yellow and 30 orange)
- Six-sided die

Introduction

The following assumptions can be made about the beetle population.

- There are 30 beetles in the original population: 10 red, 10 yellow and 10 orange.

- Each year the beetles mate once at random and each pair produces one offspring.
- The colour of the offspring is determined by these rules:
  red × red = red
  yellow × yellow = yellow
  red × yellow = orange
  orange × yellow = 50% orange, 50% yellow (Roll the die: odd = orange, even = yellow)
  orange × red = 50% orange, 50% red (Roll the die: odd = orange, even = red)
  orange × orange = 25% red (1), 50% orange (2 or 3), 25% yellow (4); other numbers roll again.
- After the beetles have reproduced, a predator kills one-third of the total population each year. The population, therefore, returns to 30 at the beginning of each breeding season.
- There is no migration, immigration or death other than that caused by the predator.

Method

1 Take 10 red, 10 yellow and 10 orange beetle cards to represent the original population of 30 beetles.

2 Use the remaining cards when you need 'extra' beetles.

3 To model random mating, shuffle the 30 cards well and deal them into 15 different pairs (assume that there is a male and female in each pair).

4 Using the rules in the introduction, determine the colour of the offspring for each of your 15 pairs.

5 Take a beetle card that represents each of your offspring from the spare pile and add them to the population pile.

6 Your population should now have a total of 45 beetles. Fifteen beetles will be removed from the population each year due to predation, simulated by the following method:
   - Roll the die and remove a beetle corresponding to the colour indicated by the die: 1 = yellow, 3 or 5 = orange, 2, 4 or 6 = red.
   - Repeat this for 15 times in total. If the population does not have any individuals represented by the colour shown on the die, roll again.

7 After the beetles have mated and predated for one year, collect all the remaining beetles and record in the results table the number of surviving individuals for each colour. The total population should be back to 30.

8 In a table such as the one below, record the colour of beetles for each year over ten simulated years of the beetles' mating and predation.

Results

Colour of beetle	Year									
	1	2	3	4	5	6	7	8	9	10
Red										
Orange										
Yellow										
Total	30	30	30	30	30	30	30	30	30	30

Discussion

1 Describe the changes seen in the beetle population during the 10-year 'survey'.

2 Identify why these changes occurred.

3 Suggest a reason why a predator might prey on a particular coloured beetle more often than beetles of other colours.

4 Does the chance of survival for an individual beetle change from year to year? Explain your answer.
5 Does the chance of survival for the population as a whole change from year to year? Explain your answer.
6 If the predation intensity changed to 4 red, 2 orange and 0 yellow, suggest the changes in allele frequency in the population you could expect in your results over time.
7 If the predation intensity changed to 1 red, 1 orange and 1 yellow, suggest the changes in allele frequency in the population you could expect in your results over time. Would this type of predation show natural selection? Why or why not?
8 Evaluate this experiment as a model for natural selection. How valid is it? How reliable? Suggest ways to improve the validity and/or reliability of your results.

Conclusion

Re-read the aim and your hypothesis. Write a statement that addresses the aim, and states whether your hypothesis was supported or refuted, using your results as experimental evidence.

QUESTIONS 2.2.1: NATURAL SELECTION

Remember

1 Outline the factors that may cause variation among individuals of a population.
2 Explain why natural selection cannot increase or decrease the frequency of neutral mutations in a population.
3 Both Darwin and Wallace stated that individuals do not evolve, populations do. Outline how this is different from what Lamarck believed.

Apply

4 Suggest why mutations of somatic (body) cells of an organ will have no effect on evolution.
5 A horse and a donkey can be crossed to produce a mule. Is the mule a new species? Are horses and donkeys the same species? Explain how this fits with our concept of species.
6 Albino animals (Figure 2.36) are usually healthy and normal in every respect except pigmentation; however, they are rarely found in the wild. Explain why wild albino animals are rare.
7 In your own words, describe the mechanism by which natural selection can influence the frequency of alleles in a population.

Figure 2.36 Albinism is a pigmentation mutation that occurs in most animal species.

Analyse and evaluate

8 Contrast the concept of 'fitness' as used in mass media with what Darwin meant when he referred to a 'fit' organism and 'survival of the fittest'.

SPECIATION

When a variation is favoured by the environmental conditions, it is referred to as an adaptation. Variations within a species provide 'options' for the species in the face of changing environmental conditions. Although individual organisms may be wiped out, some members of the population will continue the species gene pool.

Along the way, some entire species will become extinct and new species will emerge. Under normal conditions, genes in a given population are exchanged via breeding, which is known as **gene flow**. Even if some variation occurs, it is limited by gene flow. Gene flow is interrupted if the population becomes divided into two groups so that the groups experience some sort of **isolating mechanism**.

Temporal isolation occurs when individuals of different populations reproduce at different times. For example, cicadas mature underground (Figure 2.37). One species emerges and reproduces every 17 years. A different species, which is almost the same in terms of appearance, emerges every 13 years to reproduce. At this rate, the two species would release gametes at the same time only once every 221 years!

Figure 2.37 Cicadas experience temporal isolation as different species breed at different times.

Behavioural isolation prevents gene flow between related species living in the same territory through differences in behaviour. Many animals have elaborate species-specific courtship rituals that must occur before individuals can mate. For example, female birds use colour, song and displays to identify potential mates (Figure 2.38), whereas female fireflies identify the pattern of blinking lights produced by the males.

Mechanical isolation occurs when there is a physical incompatibility between the body parts of potential mates or pollinators. For example, the flowers of some plants vary in size and shape, or they may have spiny barriers, thus excluding certain pollinators (Figure 2.39).

If there is no exchange of genes between the two isolated groups, then they may begin to look and behave differently from each other. Given enough time for evolution to occur, the two populations may become so different that they are incapable of interbreeding should they ever come together again: a new species has been created (speciation). Speciation can occur in a variety of ways.

Figure 2.38 Lyrebirds have specific courting rituals that are essential for mating. This is a form of behavioural isolation.

Figure 2.39 Teasel flowers are physically incompatible with many other species. This is a mechanical isolation.

Allopatric speciation

Allopatric speciation occurs when one species divides into two or more through some form of **geographic isolation** like the development of a mountain range, widening of a river or even continental drift. Each population begins to experience very different environmental selective pressures. In their separate habitats, the groups go their own evolutionary ways, accumulating different gene mutations and being subjected to different selective pressures, which favour different adaptations.

The finch species on the Galapagos Islands (refer back to Figure 2.7 on page 62) would have most likely evolved from a population of an ancestral finch species that was blown off mainland South America by a storm. The distance between the islands and the mainland is too far for the little birds to fly and so gene flow between the mainland and the island species stopped. The conditions on the Galapagos Islands were, and still are, different from those on the mainland. Thus, the finches evolved from the ancestral mainland species by allopatric speciation.

Extreme events can also result in geographical isolation (Figure 2.41). In the summer of 1995, Hurricane Luis and Hurricane Marilyn ripped through the northern Lesser Antilles in the Caribbean. Fifteen green iguanas survived on a raft of uprooted trees for nearly a month, floating over 300 km before reaching the northern-most island of Anguilla. These few individuals were the first recorded of their species, *Iguana iguana*, to reach the island. The iguanas have since established themselves as an independent breeding colony on the island and, in time, natural selection may operate on this isolated group until they become a new species through allopatric speciation.

Allopatric speciation is thought to have occurred among rock wallabies in Australia (Figure 2.40). Rock wallabies live in rocky outcrops, which are often separated by long distances, resulting in their geographic isolation from each other. There are approximately 20 different genetically and chromosomally different forms of rock wallabies in Australia, of which 16 are classified as different species.

Figure 2.40 Rock wallabies in Australia are separated by long distances. This geographical isolation is believed to be responsible for allopatric speciation.

Figure 2.41 After hurricanes destroyed their island home, a small number of green iguanas were geographically isolated, leading to a new species through allopatric speciation.

Sympatric speciation

In **sympatric speciation**, new species arise within an existing species that share the same geographical location. This form of speciation is much more common in plants than in animals. It may occur as a result of the failure of chromosome separation during meiosis or it may be the result of a cross between two (plant) species. The resulting new species cannot breed with the parent species, but, in the case of plants, may be able to reproduce asexually.

Sympatric speciation is most common in animals when some individuals take advantage of a different **niche** (small area within the habitat with highly specific and limited conditions) within the same environment. A new niche may arise because of an environmental change, such as a new food source. Sympatric speciation is less common than allopatric speciation because gene flow is not disrupted within the original population.

Figure 2.42 Sympatric speciation may explain the diversity of Cichlid fish in some African lakes. Here, the competition for resources is so great that the isolation of populations without a physical barrier may have occurred.

The Galapagos finches have also shown sympatric speciation. It is likely that the ancestral finches were of a single species, but due to the fierce competition for food on the newly established volcanic islands, the finches became highly specialised foragers. Large, thick beaks are better at cracking the hard seeds of the *Tribulus* plant, whereas long slender beaks are better at reaching the nectar in cactus flowers, and small beaks are better at dealing with little seeds. The natural variation within the population of beak shape and size meant that different individuals were better equipped to eat certain foods. Slowly, over time, the different feeding groups became different species, occupying different niches within the same habitat.

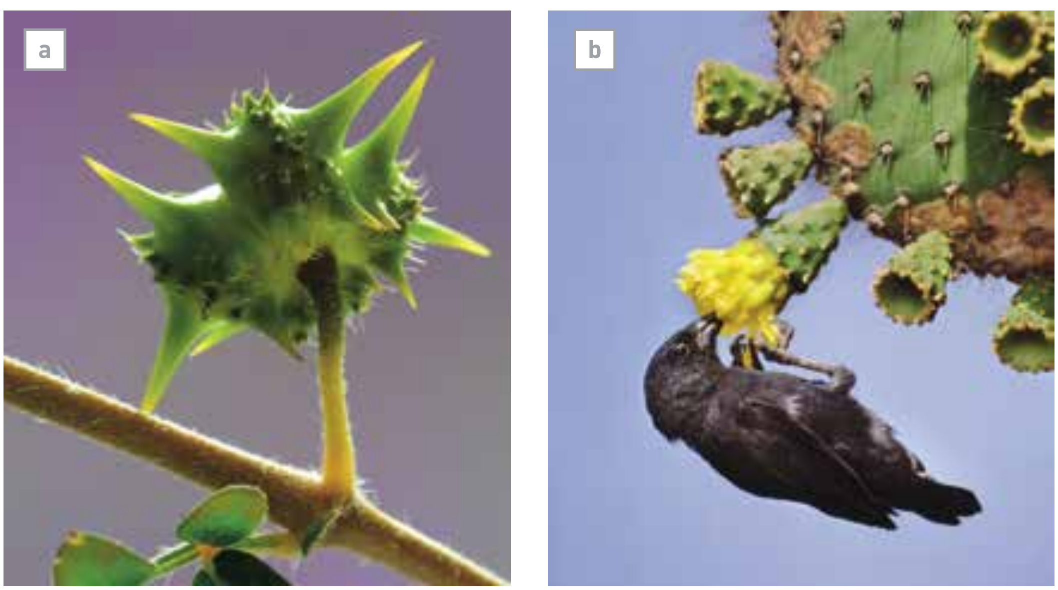


Figure 2.43 Sympatric speciation explains the diversity of beak shapes between the finches of the Galapagos Islands. (a) Large beaks enable some birds to crack the hard and spiky *Tribulus* seeds; (b) long slender beaks allow other species to drink the nectar of cactus flowers.

STUDENT DESIGN TASK

Modelling speciation

Challenge

Design an experiment that models allopatric speciation. This experiment is to be hypothetical only, but ethical considerations should still be outlined.

Questioning and predicting

Formulate a testable hypothesis.

Planning

- What species would you use to demonstrate allopatric speciation? You will need to consider life span, length of breeding cycles and the average number of offspring that survive to breeding age.
- What aspects of the environmental conditions do you think would drive natural selection if they changed?
- How would you separate your populations to prevent gene flow?
- Would you perform this experiment in a laboratory or in the field?
- Identify your dependent and independent variables, and all other variables that should be controlled.
- Write out a logical procedure, identifying any specific equipment you may require.
- Assess the risks and ethical issues that may be associated with your method.

Processing and analysing

- How would you collect and collate your data?
- What data would support your hypothesis? What data would disprove it?
- How would you determine if your data is valid and reliable?

Communicating

Present your model to the class, accompanied by a formal written report to support your methodology.

QUESTIONS 2.2.2: SPECIATION

Remember

1 List four different ways in which populations of a species may become isolated.

2 Compare and contrast the two main processes of speciation.

Apply

3 Explain, in your own words, what an isolating mechanism is.

4 Describe, using a real-life example, how physical isolation could create a new species.

5 Explain how gene flow influences the process of speciation.

6 Compare the mechanisms of sympatric speciation in plants and animals.

7 Why is speciation most likely to be a result of geographical isolation?

EVOLUTION OF A SPECIES

2.2

CHECKPOINT

Remember and understand

1 Outline the four essential requirements for evolution by natural selection. [4 marks]

2 Name the two main processes of speciation. [2 marks]

3 Define the term 'gene pool' in your own words. [1 marks]

4 Isolation usually refers to physically being away from others. Is this the case for all forms of isolation that apply to speciation? Explain your answer. [2 marks]

Apply

5 Explain why it is incorrect to say an organism has evolved but correct to say that a population of organisms has evolved. [2 marks]

6 *Callistemon* (bottlebrushes) are unusual because their stems (branches) do not terminate in flowers. Instead, the stem keeps growing out past the old flower. Consequently, a mature plant may contain the ripe seed of numerous years in its branches. Deduce how this adaptive feature enables *Callistemon* to exploit the current Australian environment. [2 marks]

Analyse and evaluate

7 Reword Darwin's observations of and inferences about variation in terms of genetic mutations and alleles. [2 marks]

8 Compare the terms 'allopatric speciation' and 'gene flow'. [3 marks]

9 The tortoises of the Galapagos Islands have either a domed shell and a short neck on islands with significant rainfall, or a shell with the front flared up and a long neck on islands that are more arid. The tortoises both feed on prickly pear cactus and other vegetation. On islands with no tortoises, the prickly pear plant is low and spreading, but on islands with long-necked tortoises, the prickly pear plant is tall and has harder spines protecting it.

   a Propose why the tortoises might have two very different phenotypes. [2 marks]

   b Discuss whether the tortoises that originally reached the islands are likely to resemble any of the tortoises that live there today. [2 marks]

   c Using the terms 'variation' and 'survival of the fittest', explain why the prickly pear plant on islands with long-necked tortoises is so different from those plants growing elsewhere. [2 marks]

   d Identify the type of speciation occurring on these islands. [1 marks]

Figure 2.44 This tortoise has a flared shell so it can reach up high and tear off cactus pads.

Critical and creative thinking

10 Describe two different scenarios in which a population of a species becomes (naturally) reproductively isolated from other populations. [5 marks]

11 Explain the ways in which the terms 'diversity' and 'evolution' are linked. Consider whether one can exist without the other. [5 marks]

TOTAL MARKS
[/35]

2.3 EVIDENCE FOR EVOLUTION

A scientific theory is an explanation of some aspect of the natural world, based on facts that have been confirmed repeatedly through observation and experiment. Evidence is needed to support a theory and, initially, this evidence may be unconfirmed or limited. There is no set number of pieces of evidence that 'prove' a theory, but evidence that disagrees with a theory can cause scientists to reject or modify that theory. Scientists seek out evidence from a range of sources, which must be critically examined. So, what evidence do we have to support the theory of evolution by natural selection?

Figure 2.45 Nicholas Steno studied fossils in the late 1600s.

RELIABLE EVIDENCE

Support for any theory requires valid and reliable evidence from a range of sources. Evolution is no different. Research continues to discover more detail about the mechanisms and the relationships between selective pressure and the nature of adaptation, but the data gathered from this kind of research consistently supports the overall theory.

Early evidence

Early evidence for the theory of evolution came from the study of fossils. Fossils are the remains or traces of organisms from a past geological age embedded in rocks or other substances by natural processes. In the late 1600s, Danish anatomist and geologist Nicholas Steno realised that fossils were not just interesting things to collect and catalogue, but the remains of past life. He observed the landscape around him and came up with the law of superposition – that older layers of rock are deeper and younger layers lie on top of them. He argued that these layers form slowly and that each set of fossils is a snapshot of life at that time. Evidence of large-scale **extinctions** reinforced that life forms change with changing environmental pressures, even if that simply means that many die and only few survive.

In the 1790s, British naturalist William Smith studied mines and proposed that rock layers with the same type of fossils must have been laid down at the same time. This allowed scientists to estimate the age of a rock layer relative to others. Geologists realised that the Earth must be millions of years old, but an accurate estimate was not made until the 1900s, after the discovery of radioactive decay and the development of radiometric dating. The fact that the Earth is more than 4 billion years old provided more evidence for evolution, as it allowed time for significant changes to occur.

Another step forward in support of evolutionary theory came from the extensive records that were created, and continually added to, as curious observers travelled the globe and documented the different species they saw. Anatomists studied the wealth of new organisms and noticed underlying similarities in many groups, sometimes finding similarities to fossils.

Figure 2.46 William Smith proposed that rock layers with the same type of fossils were laid down at the same time.

Human influence on evolution

Humans play a role in evolution, both intentionally and unintentionally. New species of domestic animals and plants are created by artificial selection. These species make it possible to feed and clothe the rapidly growing human population. However, our use of pesticides and antibiotics has had unintended consequences.

The pesticide DDT (dichlorodiphenyl-trichloroethane) was introduced in the 1940s to kill insects that spread human disease, such as mosquitoes, which transmit malaria. This was a great success, reducing malaria cases in Sri Lanka from 3 million per year before the program to just 18 in 1963. Five or six years after the start of spraying for both mosquito control and agricultural use, insects resistant to DDT began to increase in numbers as resistant insects survived and bred. DDT is now virtually useless for mosquito control in Sri Lanka and many other countries.

The evolution of antibiotic-resistant bacteria has been even faster due to the short generation times of bacteria. Penicillin was first introduced in the 1940s, and resistant bacteria appeared in that same decade. Widespread use of penicillin in the 1950s and 1960s, to treat diseases caused by bacterial infections and to promote growth in livestock, accelerated the evolution of resistant bacteria. Hospitals are home to many strains of multidrug-resistant bacteria, commonly called 'superbugs'. Use of antibiotics is now strictly regulated in an attempt to control the problem and preserve the effectiveness of existing antibiotics.

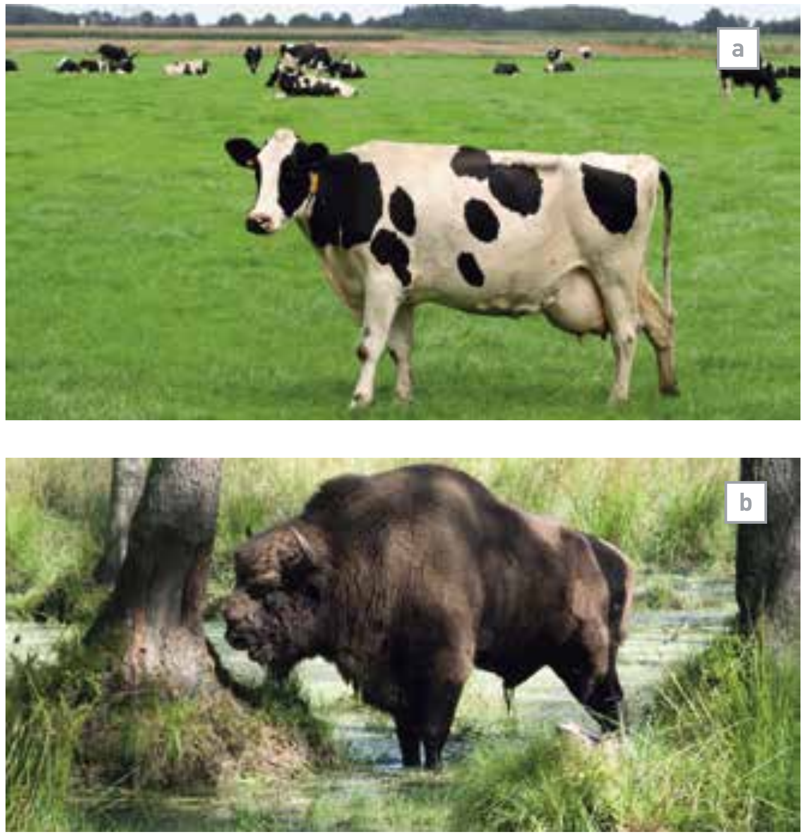


Figure 2.47 (a) Modern domestic cattle were bred from (b) a bison-like species called aurochs, which is now extinct.

Many people get 'flu' vaccinations each year to reduce the likelihood of catching the influenza disease. However, the need to have a new vaccination each year is another indication of evolution. The high rate of mutation in the influenza virus results in the evolution of dozens of new strains each year.

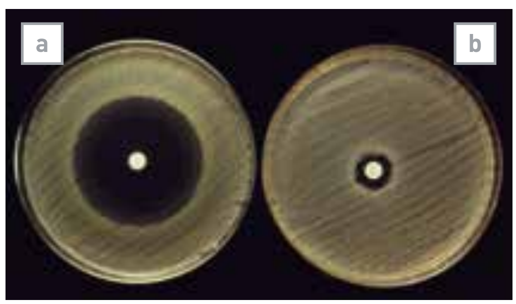


Figure 2.48 Resistance to penicillin of two strains of *Staphylococcus* bacteria. (a) The normal strain cannot grow near the penicillin pellet. (b) The resistant strain is relatively unaffected.

QUESTIONS 2.3.1: RELIABLE EVIDENCE

Remember

1. Identify what is required for a group of ideas to be considered a scientific theory.
2. Why is the theory of evolution so widely accepted?
3. Explain how the age of the Earth provides support for the theory of evolution.
4. List both helpful and harmful examples of humans influencing evolution.

Apply

5. Suggest how observations of living organisms might contribute to the evidence for evolution.

ANALYSING FOSSILS

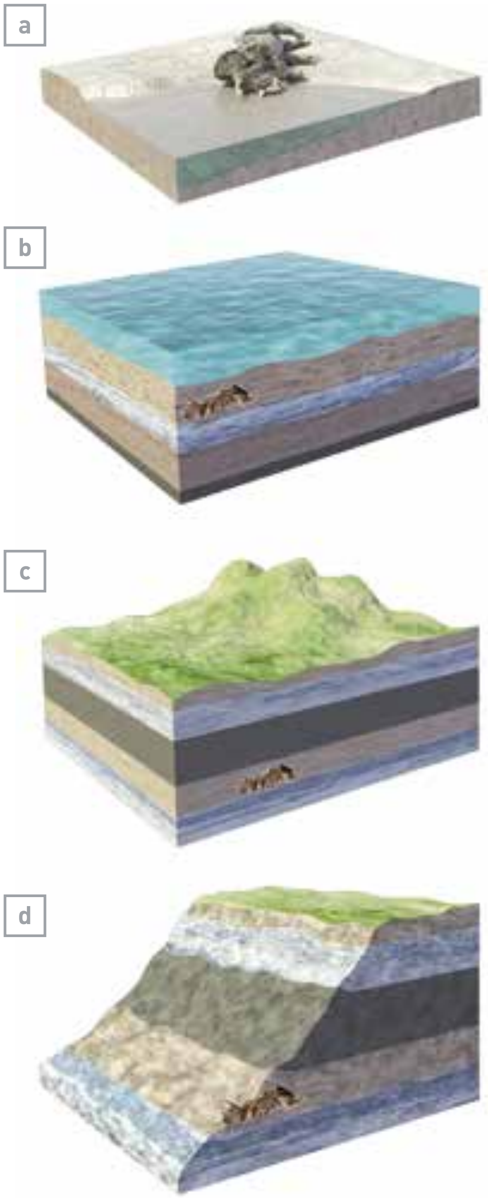


Figure 2.49 Formation of a fossil. (a and b) If an organism dies near water, it has a greater chance of being covered by sediment. The sediment protects the body from predators and weathering. (c) Over millions of years, more sediment is deposited. The soft parts of the organism often rot away, while hard parts are replaced by minerals. The sediment layers eventually form rock. (d) Years of geological movement, weathering and erosion may eventually expose the fossil.

Fossils include the remains of dead organisms, parts of a dead organism or even the evidence that an organism existed. Fossils are extremely important for understanding the evolutionary history of life on the Earth because they provide direct evidence of evolution and detailed information on the ancestry of organisms. **Palaeontologists** study fossil records and determine their relationships with different geological time periods.

Fossilisation requires the organism, or its traces, to be buried quickly so that weathering and total decomposition do not occur. Skeletal structures, as well as other hard parts of the organisms that resist weathering and are slower to decompose, are the most commonly occurring form of fossilised remains. **Trace fossils** are moulds, casts or imprints of the activity of previous organisms. An example of a trace fossil is a dinosaur footprint preserved in rock.

Figure 2.50 Fossilised megafauna (giant animal) footprints.

ACTIVITY 2.3.1: EXAMINING BONES

Examine a selection of real bones or cast bones carefully. Use your understanding of the skeletal and muscular systems to identify features of the bones that could indicate characteristics such as muscle attachment, animal size, the entry and exit of blood vessels and nerves or the function of that bone. How might the bones of modern animals be used to help interpret fossils?

DEEPER UNDERSTANDING

Lightning Ridge fossil site

Lightning Ridge fossils are among the most precious and beautiful fossils in the world. Approximately 110 million years ago, Australia was part of Gondwana and the area around Lightning Ridge (northern New South Wales) was a river delta. Animal and plant fossils found at the site include microbes, pine cones, snails, dinosaurs, plesiosaurs, pterosaurs, lungfish and monotremes. Some of these fossils retain internal details, whereas others are an opalised cast of the original material. The most beautiful fossils are preserved in the black opal for which Lightning Ridge is famous.

As well as being beautiful, the fossils of Lightning Ridge have given scientists a valuable snapshot of Australia's flora and fauna at the end of the Cretaceous period, and include some of the oldest mammal fossils found in Australia.

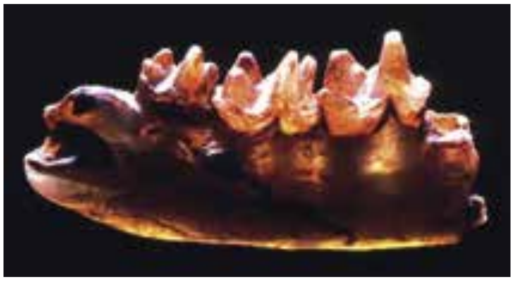


Figure 2.51 Opalised jawbone of *Steropodon*, a toothed platypus-like monotreme.

ACTIVITY 2.3.2: EXAMINING FOSSILS

From a selection of fossils, examine each fossil individually and make careful observations of the structures you can see.

1. What do you definitely know about the organism preserved in the fossil?
2. What can be inferred from the structures you have observed in the fossil? Consider lifestyle, diet, reproductive behaviours etc.
3. What further evidence would you require to support your inferences?

Dating fossils

It is possible to find out how a particular group of organisms evolved by arranging its fossil record in a chronological sequence. **Relative dating** can provide approximate dates for most fossils because fossils are found mainly in sedimentary rock. As you learned in year 8, layers of silt or mud on top of each other form sedimentary rock. The resulting rock contains a series of horizontal layers, or **strata**. Each layer contains fossils that are typical for a specific time period during which they were made. The lowest strata contain the oldest rock and the earliest fossils, whereas the highest strata contain the youngest rock and more recent fossils.

Geological time is divided into eras and periods on the basis of different sets of fossils. Major changes (extinction events) mark the larger divisions.

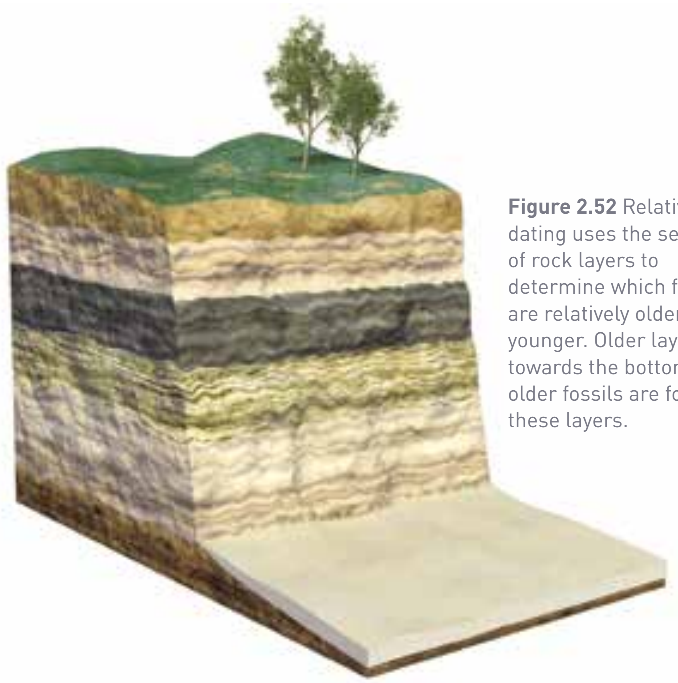


Figure 2.52 Relative dating uses the sequence of rock layers to determine which fossils are relatively older or younger. Older layers are towards the bottom, so older fossils are found in these layers.

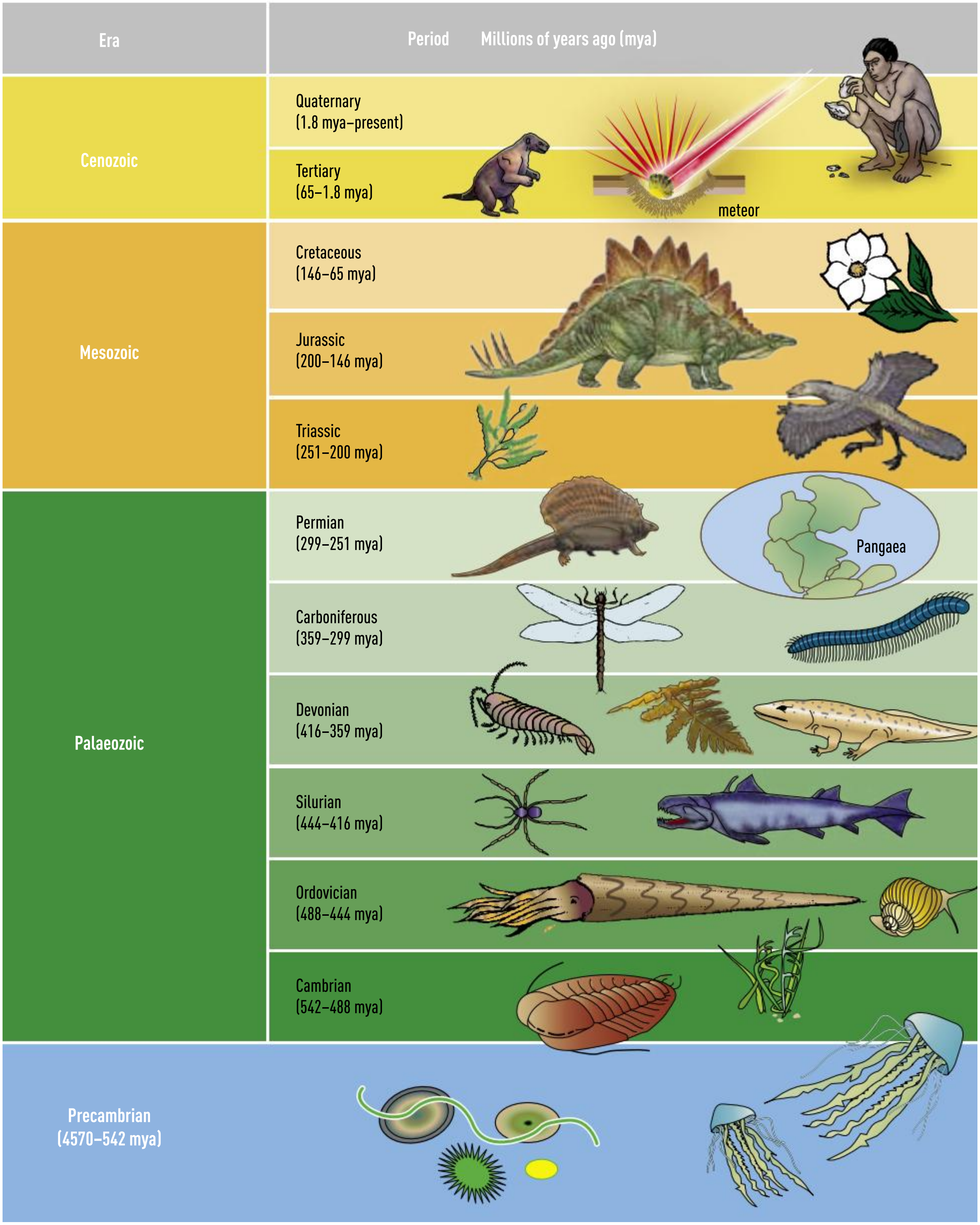


Figure 2.53 Each period within the geological time scale is characterised by fossils of particular plants and animals.

Advances in our understanding of matter have led to technologies that can provide more accurate timeframes for fossils. **Absolute dating** (also known as radiometric dating) relies on the level of radioactivity detected in rocks containing radioisotopes. The best rocks for radiometric dating are volcanic rocks that contain uranium isotopes, but these rocks do not contain fossils. To obtain a more accurate idea of the age of a fossil, scientists examine volcanic rock layers above or below the fossil. These provide a range of dates for that rock stratum. Scientists can calculate an absolute date range for a set of fossils by combining data from several sites. In rare cases, a layer of volcanic ash in sedimentary rocks will provide an absolute date.

Transitional fossils

It is thought that life originated in the sea, crawled onto land and then took to the skies. But what evidence links these stages? **Transitional fossils** show the intermediate states between the 'before' and 'after' stages. They are sometimes referred to as 'missing links', but knowledge of geology and evolution allows palaeontologists to predict the location of transitional fossils and find them.

When Darwin first published his theory of evolution, he stressed that the lack of transitional fossils was the most formidable obstacle to his theory because, at that time, very little was known about the fossil record. Since then, numerous examples have been found, starting with the discovery of *Archaeopteryx* in the Solnhofen area of Germany just 2 years after Darwin's work was published.

Archaeopteryx is considered by some scientists to be the earliest and most primitive bird known, displaying a number of features common to both birds and reptiles. Other scientists think that *Archaeopteryx* should be considered a feathered dinosaur. All agree that it is an important transitional species.

Figure 2.54 *Archaeopteryx* fossils are called transitional fossils as they help explain the previously unknown link between dinosaurs (reptiles) and modern birds.

Living fossils

According to fossil records, some modern species of plants and animals are almost identical to species that lived in ancient geological ages. **Living fossils** are existing species of ancient lineages that have remained unchanged in structure and form for a very long time.

Examples of living fossils include the coelacanth fish (Figure 2.55), horseshoe crabs, the Ginkgo trees and Metasequoia conifers of China, and the Wollemi pine, which was discovered in New South Wales in 1994.

Figure 2.55 Unique in the animal kingdom, the coelacanth fish is a 400 million-year-old species! The coelacanth pre-dates dinosaurs by millions of years and was thought to have become extinct with them. In 1938, coelacanths were discovered living in caves off the continental shelf. This environment has changed little over the past 400 million years and, as a result, neither has the coelacanth.

ACTIVITY 2.3.3: BUILDING ANIMALS

The challenge of this activity is to reconstruct an animal's skeleton from a pile of bones to simulate the processes undertaken by palaeontologists.

What you need: whole roast chicken, water, dishwashing liquid, saucepan, colander, stove, toothbrush, newspaper, diagram of a chicken skeleton, camera (optional)

1. Remove as much flesh from the bones of the roast chicken as possible.
2. Boil the bones in a saucepan of water for 20–30 minutes.
3. Strain the water from the bones using the colander.
4. Gently remove the rubbery pieces of cartilage from the bones.
5. Scrub the bones with a toothbrush and a small amount of dishwashing liquid.
6. Rinse the bones and leave them to dry overnight on newspaper.
7. Use a diagram of a chicken skeleton to help you reconstruct the chicken. Your finished skeleton will be laid out on a piece of newspaper rather than as a three-dimensional model. Hint: It may be helpful to group bones into long bones, flat bones etc.
8. Include images showing your method and finished skeleton.

Analyse how this process may be similar to the work of a palaeontologist.

- What sorts of bones may palaeontologists be dealing with?
- Would they be reconstructing entire skeletons?
- Would they attempt to reconstruct the layers of flesh that cover the skeleton?
- What indicators on the bones may they be looking for?
- Write a brief statement about the work of palaeontologists to reconstruct skeletons.

Figure 2.56 How does a palaeontologist reconstruct an entire animal from its bones?

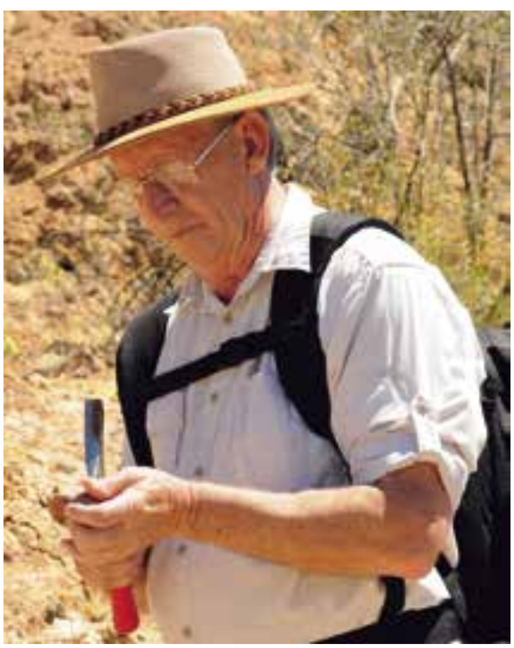


Figure 2.57 Palaeontologists study fossils to learn about extinct species.

QUESTIONS 2.3.2: ANALYSING FOSSILS

Remember

1 List the parts of organisms most likely to be found in fossils. Explain why this is the case.

2 Describe a transitional fossil.

3 Provide an example of a plant and an animal that are considered living fossils.

Apply

4 Outline the method of relative dating. In your answer, explain why relative dating is often used before absolute dating and why both methods are required to narrow down a fossil's age.

5 Explain how knowledge of both geology and evolution helps palaeontologists to discover transitional fossils.

Analyse

6 Living fossils have remained relatively unchanged, often for millions of years, while around them other species have adapted or become extinct. Explain how this has been possible.

7 Palaeontologists must try to reconstruct extinct life based on a few fossils that only show part of the organism. Suggest what clues they would look for and what parts of the organism would be most useful.

Create

8 Palaeontologists can match the shape of dinosaur feet with their tracks if they have relatively complete fossils, as shown in Figure 2.58. These trace fossils give insight into the behaviour of dinosaurs, such as whether they travelled in large herds or not. Write a brief scene you imagine from the time of the dinosaurs and illustrate your story with an appropriate trace fossil. See if your classmates can decipher the fossilised footprints without the story.

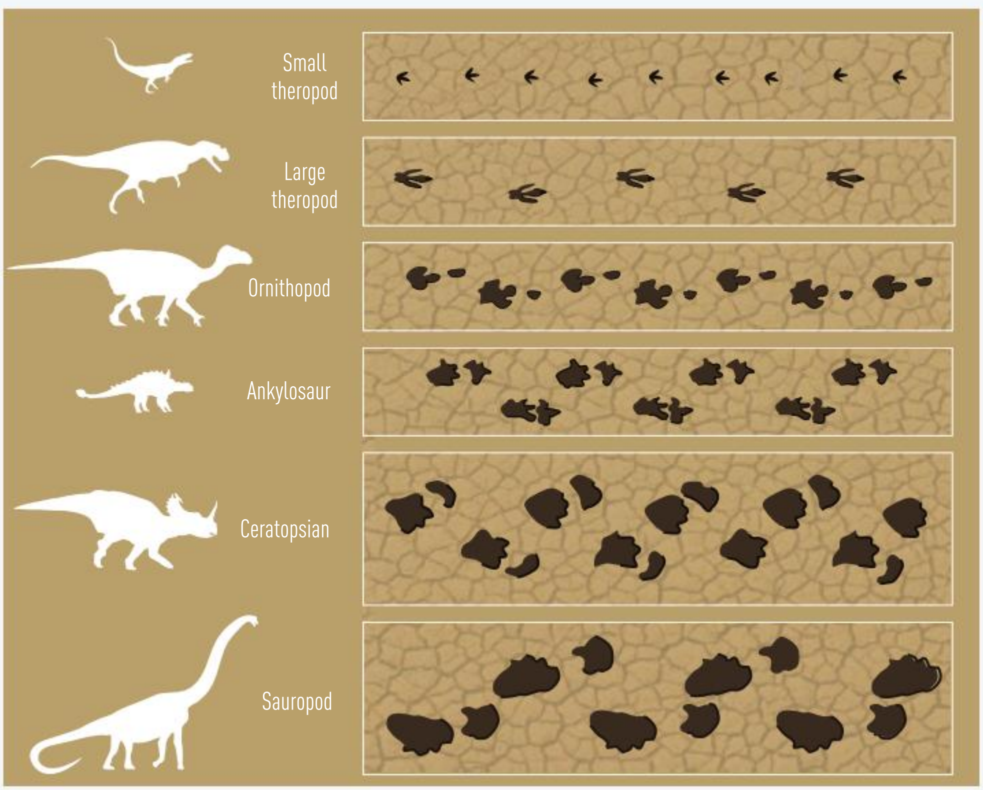


Figure 2.58 Some examples of footprint trace fossils.

Figure 2.59 The appendix in humans appears to be getting smaller through the generations and has not been useful to human digestion for a long time.

Figure 2.60 The 'spurs' on some snakes are an example of vestigial rear legs.

ANALYSING THE LIVING

Your family shares similar traits. There are more similarities shared between members of the immediate family than with extended family. The same applies to all living organisms. Such observations of the living are considered important evidence for evolution.

Evolutionary theory is supported by the analysis of similarities between organisms – both living and dead. These similarities can be in body parts, cell structure, biochemistry, embryo development or even **vestigial structures** (structures that once performed a function in an ancestor but are now functionless). The evidence studied to date suggests that the greater the level of similarity, the more closely related two organisms are.

Comparative anatomy

Comparative anatomy is a method of studying evolutionary relationships between different species, and involves comparing the similarities and differences in anatomy (physical body structures). Structures that are found across different species and have a similar pattern but different function are known as **homologous structures**. The basic pattern comes from common ancestry, whereas differences come from adaptations to specific environmental conditions in a form of evolution called adaptive radiation or **divergent evolution**.

The most commonly discussed homologous structure is the **pentadactyl limb** – the pattern of limb bones in all groups of tetrapods (four-legged vertebrates) that ends in five digits (Figure 2.61). This structure can be traced back to the fins of certain fossil fishes from which the first amphibians are thought to have evolved. In all tetrapods, the fundamental structures of the pentadactyl limbs are the same, indicating that they originated from a common ancestor. During the course of evolution, these structures have been modified to serve different functions as a result of adaptations to different environments and modes of life.

Structures in organisms that perform the same function but are structurally different are described as **analogous structures**. An example of this is the wing of a butterfly and the wing of a bird (Figure 2.62). They have a similar shape because they are both used to fly, but the fundamental structure is very different. This absence of similarity in structure suggests there is no common ancestor in the recent past. However, the similarity in function suggests that both species have evolved under similar environmental pressures and arrived at similar adaptations.

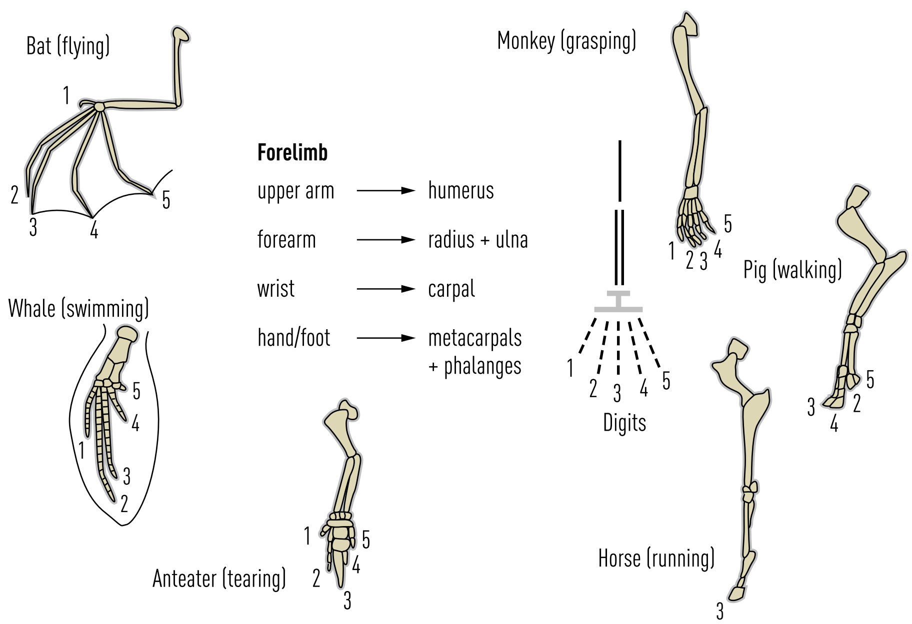


Figure 2.61 The forelimbs of different mammals show the same basic structure, with five digits that are adapted to different uses.

Figure 2.62 The wings of (a) a bird and (b) a butterfly are analogous structures: they perform the same function but have significantly different structures. This is an example of convergent evolution.

When organisms become more similar with time due to similar environmental pressures, this is referred to as **convergent evolution**. Early naturalists exploring Australia noticed convergent evolution of Australian marsupial mammals and placental mammals on other continents.

Analysing embryos

Scientists have noticed that, although adult vertebrates have clear differences, many embryos demonstrate huge similarities during the early stages of development. For example, a chicken and a human are very different when fully formed, but chicken embryos are very similar to human embryos. Even reptile embryos are similar to human embryos. Embryos may also show many interesting features that are not seen in the fully developed animal. As the embryo develops, it goes through a variety of stages. Many of these stages show homologous structures with different species.

If the various life forms developed independently, it would be logical that their embryonic development would be distinct and reflect what the organism would look like when it was fully developed. Why should a bird's three-digit wing develop from a five-digit limb? This makes no sense if organisms developed independently. The embryological similarities are explained by inferring that these organisms all had a common ancestry. Birds develop their three-digit limbs as embryos from five-digit limbs because they evolved from ancestors with five-digit limbs.

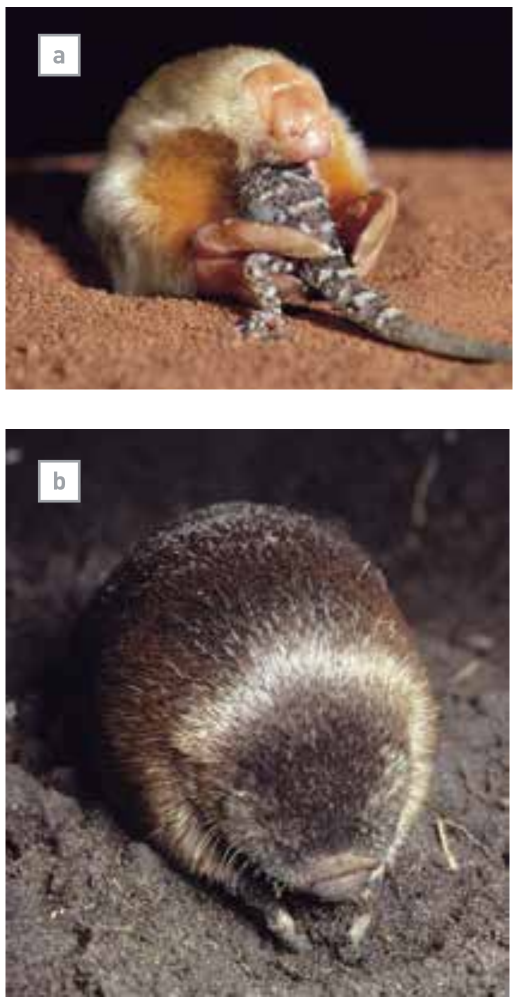


Figure 2.63 (a) The Australian marsupial mole and (b) the African placental golden mole live in very similar environments and are extremely similar in appearance, clearly showing convergent evolution.

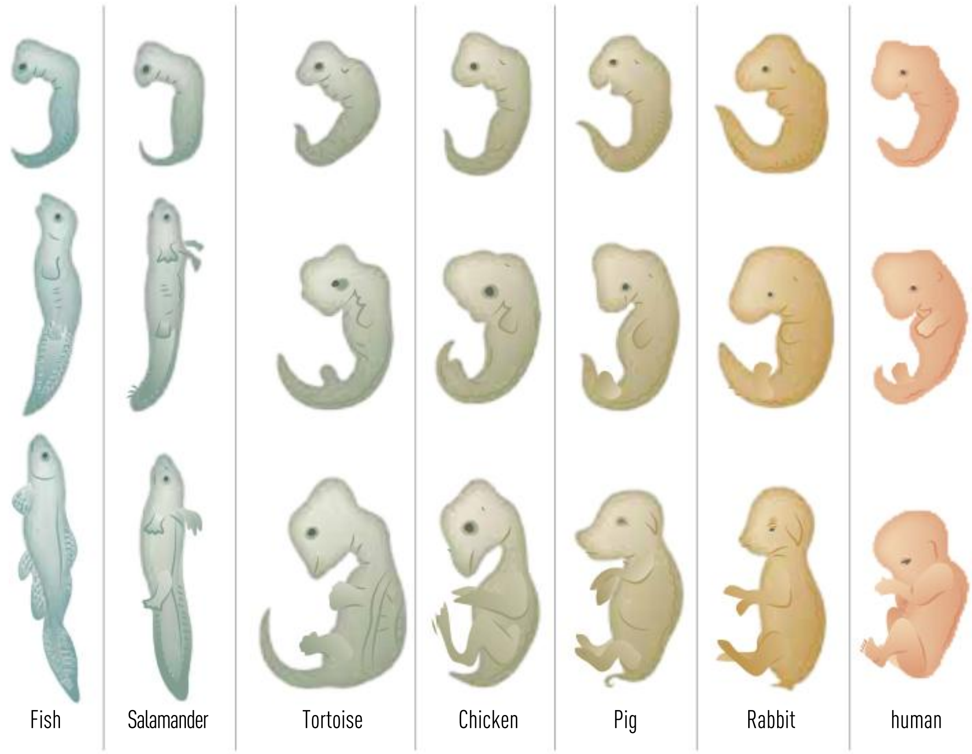


Figure 2.64 Stages in the embryonic development of a range of vertebrates.

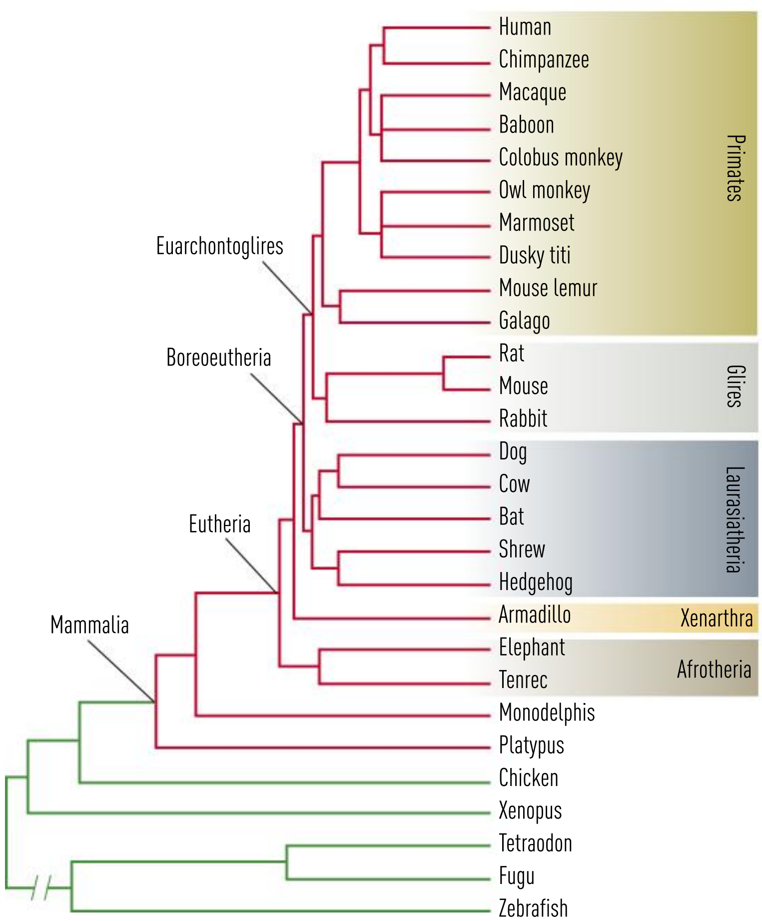


Figure 2.65 Research comparing genomes has helped define relationships among vertebrate species. The lengths of the branches on this phylogenetic tree, which are based on DNA sequence comparisons, show how closely each animal is related.

The more similar the early stages of embryonic development, the more closely related the species are or the more recently divergent evolution has caused the species to separate.

Comparing molecules

Advances in the understanding of the biochemical processes of life have provided a wealth of evidence in support of evolution. Biochemical homologies (similarities) provide some of the strongest evidence for evolution because of the detailed level of information they give. Most biochemical evidence for evolution comes from comparative examination of genes or proteins.

Comparing DNA

The best evidence in support of evolutionary theory comes from a study of the base sequences of genes (see chapter 1, page 7). Comparing DNA sequences examines the relationship between different species, where the more similarities indicate a closer relationship. Darwin's original hypothesis of common descent (all life evolved from a single life form) is reinforced by this evidence.

If the hypothesis of common descent is true, then species that share a common ancestor will have inherited that ancestor's DNA sequence. In addition, they will have inherited mutations unique to that ancestor. These specifics can be used to produce timelines that indicate roughly when speciation would have taken place and therefore can be used to create a 'family tree' similar to Darwin's tree of life.

The most detailed DNA sequence reconstructions have been performed using the genomes of mitochondria, which are shared by all eukaryotic organisms and are shorter and easier to sequence than nucleic DNA.

Early DNA sequencing work on the genome of humans and great apes has shown that humans share an ancestor with gorillas and chimpanzees (Figure 2.67). The chimpanzee is our closest living relative, with a 98% similar genome. DNA sequencing of the β-haemoglobin gene has also confirmed this common ancestry.

Figure 2.66 Very distant relatives!

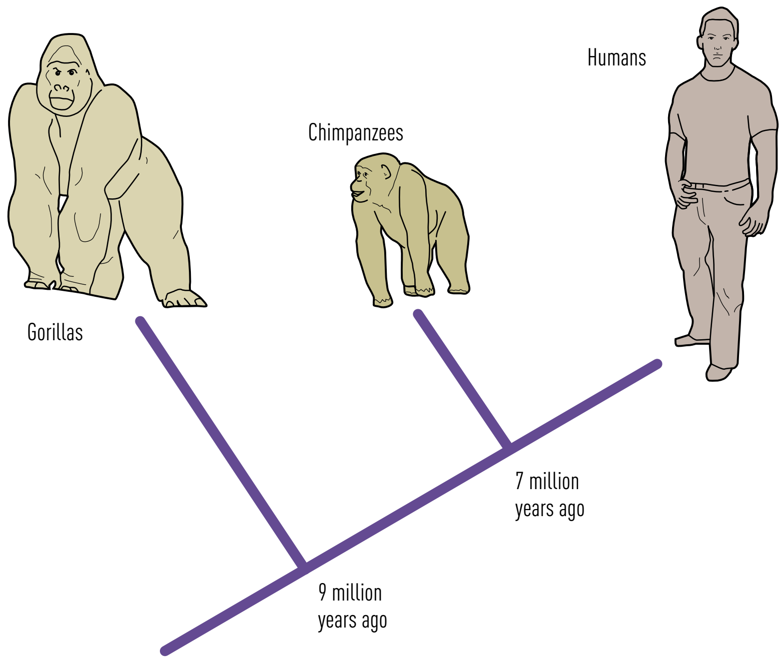


Figure 2.67 Gene sequencing has shown that humans, gorillas and chimpanzees all evolved from a common ancestor.

DEEPER UNDERSTANDING

Galapagos Islands finch DNA study

Peter and Rosemary Grant, with the help of numerous research fellows, ran a 35-year-long study on the finch species of Daphne Major, a very small island in the Galapagos Islands. With DNA samples, accurate body feature measurements and detailed observations of just about every finch on the island, the award-winning Grants documented significant evolutionary changes in the different species in as little time as 2 years, when the selection pressures were right. Some of their major conclusions included that evolution is constantly happening, evolution is in direct response to changes in environmental conditions, and evolution is not necessarily something that takes millions of years.

Figure 2.68 Peter and Rosemary Grant spent up to 6 months of every year for 40 years on Daphne Major collecting data and evidence that supports the ongoing evolution of the Galapagos finches.

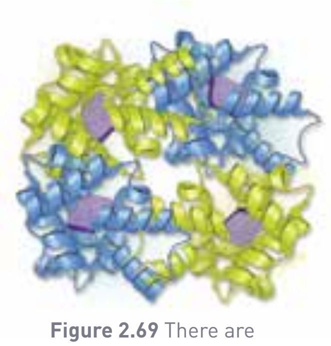


Figure 2.69 There are many different sequences of amino acids that could make a functional haemoglobin molecule. Why might these variations in haemoglobin exist?

Comparing amino acids in proteins

Proteins are coded for by genes and are made up of a string of amino acids (see chapter 1). Proteins range in size from approximately 50 to thousands of amino acids. The characteristics of a protein are determined by the sequence of amino acids from which it is constructed.

All livings things use the same 20 amino acids to make proteins, even though approximately 250 amino acids occur naturally. If life evolved from a common ancestor with only these 20 amino acids, we may expect that these same 20 amino acids are always used.

Protein sequences also show remarkable similarities. A number of different genetic codons can code for the same amino acid, and small changes in some of the amino acids that make up a protein may have little effect on the functioning of the protein. So, we can have a set of proteins that do essentially the same thing but are not identical.

Haemoglobin is an example of variation in amino acid sequences. Several types of haemoglobin molecules are found among different vertebrates and invertebrates. These haemoglobin molecules are all very similar in structure and all serve the function of binding oxygen in the blood, yet they differ in their amino acid sequences.

Insulin is another example. All mammals produce insulin, which helps cells to absorb sugar, but there are slightly different versions among different species. People with insulin-dependent diabetes used to use insulin from animals such as pigs and cows. This substitute insulin worked in the human body, but not as well as human insulin. Since the 1980s, human insulin is produced by genetically engineered bacteria, leading to fewer side effects.

SCIENCE SKILLS

Evolutionary relationships

Cytochrome c is a protein commonly used to identify evolutionary relationships because of its involvement in cellular respiration – a metabolic process common to most organisms.

Table 2.1 shows the number of amino acid differences in a homologous (common) sequence of cytochrome c from several species. The homologous sequence contains a total of 104 amino acids.

From the information in Table 2.1, relationships can be identified between the species because pairs of species with fewer differences are more closely related.

For example, there are 14 differences between humans and penguins compared with only eight differences between penguins and rabbits; so, penguins and rabbits are more closely related than humans and penguins.

Your turn

1 Which are more closely related: penguins and ducks, or rabbits and monkeys?

2 The relationship between species is considered to be an indication of how recently they shared a common ancestor. A tree diagram is often used to represent evolutionary relationships. Determine which species from Table 2.1 fit the labels in Figure 2.70.

Table 2.1 Number of amino acid differences in cytochrome c between species.

	Human	Penguin	Rabbit	Monkey	Duck
Penguin	14				
Rabbit	9	8			
Monkey	1	13	8		
Duck	11	3	6	10	
Tuna	21	18	17	21	19

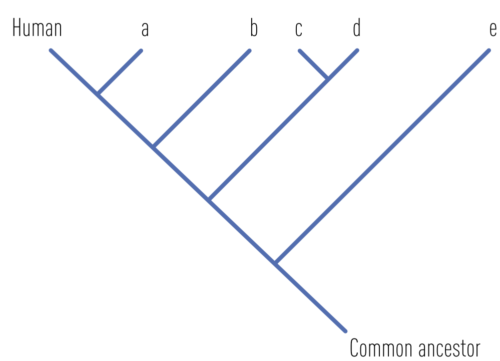
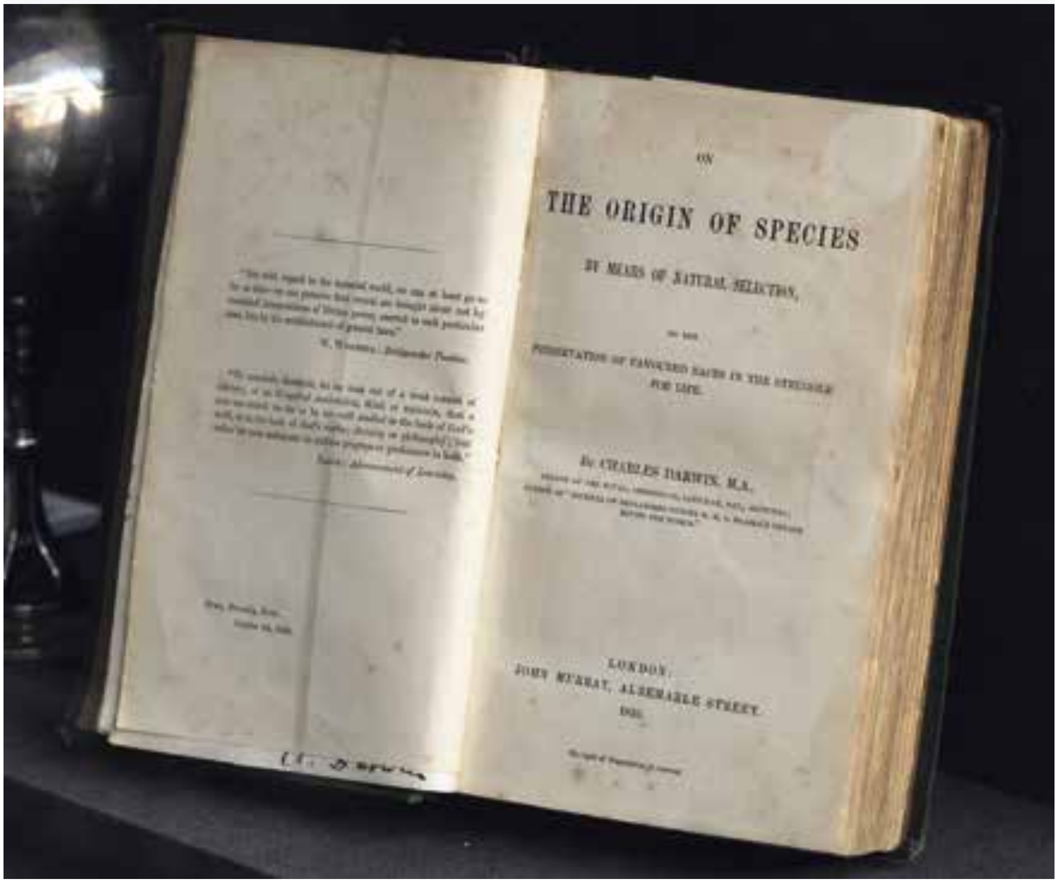


Figure 2.70 Use the data in Table 2.1 to complete this evolutionary tree diagram.

ACTIVITY 2.3.4: EVIDENCE FOR EVOLUTION CONTINUES

When Darwin wrote *On the Origin of Species*, he described evidence available at the time. In the past 150+ years there have been huge advances in our knowledge of the fossil history of life and the biology of organisms.

Divide the class into groups for each line of evidence for evolution (such as the fossil record, and by comparative anatomy, embryology and molecular biology) and debate which evidence is most important. Has all of the evidence been well described or do some areas have the potential for new insights? As a class, decide which evidence is most compelling and which areas offer the greatest possibilities for further discoveries.



QUESTIONS 2.3.3: ANALYSING THE LIVING

Remember

1 Define the term 'homologous structure' in your own words.

2 Define the term 'vestigial structure'.

3 Name the two molecules that are of most interest to biologists studying evolution.

4 Explain how the 20 amino acids used in protein synthesis provide evidence for evolution.

Apply

5 Identify an example of a homologous structure not already mentioned in this chapter.

6 Explain in your own words how DNA sequencing supports the concept of evolution from a common ancestor.

7 Describe the relationships between convergent evolution, divergent evolution, homologous structures, analogous structures and environmental pressures. You may like to use a graphic organiser.

2.3 CHECKPOINT

EVIDENCE FOR EVOLUTION

Remember and understand

1 Identify the type of scientist that studies the fossil record and geological time periods. [1 mark]

2 *Archaeopteryx* had features of both birds and dinosaurs. Recall the term for fossils that show features of two different groups and explain how this provides evidence for evolution. [2 marks]

4 The layering of sedimentary rocks is useful in relative dating. Outline the basic principle of relative dating and describe how layers at different sites may be matched. [3 marks]

5 Explain how fossils provide evidence for evolution. [2 marks]

Apply

6 Distinguish between the terms 'transitional fossil' and 'living fossil'. [2 marks]

7 Suggest why a vestigial structure may not disappear altogether. [2 marks]

8 'Superbugs' are more common in hospitals than in other parts of the community. Propose reasons for this and explain how 'superbugs' provide evidence for evolution. [3 marks]

Analyse and evaluate

9 Discuss methods you could use to investigate the hypothesis that birds are more closely related to reptiles than to mammals. [4 marks]

10 Discuss the role of DNA sequences in providing evidence for evolution. [2 marks]

11 Which evidence for evolution do you find most convincing? Justify your choice. [2 marks]

12 For many years it was thought that the human appendix did not have a purpose. Recent studies suggest it may serve an immune function. Explain how scientists might ascertain whether this immune function is a new purpose for the appendix or simply a long-existing function that had not been identified. [3 marks]

Ethical understanding

13 Through selective breeding, humans can bring about speciation in animals and plants. Provide two positive and two negative examples of selective breeding. Explain your choices. [5 marks]

Critical and creative thinking

14 Analyse the extent to which the theory of evolution is testable. [4 marks]

15 Present the strengths and weaknesses of the various forms of evidence to support evolutionary theory in a clear and attractive format. [5 marks]

TOTAL MARKS
[/40]

1 Fill in the gaps using the words in the Word Bank below:

Explanations for the diversity of living things have led to ideas about _________. Lamarck proposed the theory of inheritance of _________characteristics. Darwin and Wallace proposed the mechanism of _________ selection. In Darwin's book *On the Origin of _________ by Means of Natural Selection*, Darwin proposed that individuals struggled for limited resources and only the _________ survived. This leads to changes in the _________.

The variation in organisms comes from _________ in the DNA, which creates different versions of genes. If these lead to a favourable characteristic, we call it an _________. Populations may evolve different favourable characteristics in different environments, leading to _________ speciation. In _________ speciation, a new species evolves in the same environment.

Evidence for evolution comes from many sources. The Grants collected long-term data on finch evolution in the _________ Islands. _________ study fossils to trace their evolutionary history. Studies of the anatomy, _________ and biochemistry of living organisms provide yet more evidence for evolution.

2 CHAPTER REVIEW

WORD BANK

acquired	evolution	natural	sympatric
adaptation	fittest	palaeontologists	
allopatric	Galapagos	population	
embryology	mutations	species	

Describe scientific evidence of the evolution of present-day organisms

2 Describe an example of evolution that has occurred due to human activity. [2 marks]

3 Describe evidence of evolution that explains the distribution of organisms in the world today. [2 marks]

4 Explain the differences between convergent and divergent evolution using specific examples. [4 marks]

Explain how natural selection can change populations

5 Outline Darwin's theory of natural selection. [2 marks]

6 Compare Darwin and Lamarck's explanations for evolution. [3 marks]

7 The work of Thomas Malthus provided Darwin with a key insight into the mechanism of evolution. Describe the main argument of Malthus and how this relates to natural selection. [2 marks]

8 Both Darwin and Wallace independently proposed the concept of evolution by natural selection. Analyse the importance of the personal observations made during travel in the development of the theory of natural selection. Do you think that Darwin or Wallace would have proposed this theory if they had not made observations of animals and plants in a variety of places? [3 marks]

Outline how genetics and environmental factors influence the survival of individuals and species

9 Create a table to compare the two types of speciation. [4 marks]

10 Cheetahs have very little genetic diversity and, consequently, little variation in the species. Lions have several genetically and physically distinct populations, demonstrating much greater variation. Explain why cheetahs are more at risk of extinction than lions. [2 marks]

11 Linnaeus described his biological classification system based on similarities between organisms in 1735, long before the theory of evolution was developed. He divided organisms into distinct groups such as fish, birds, dinosaurs and mammals, based on their structural similarities. Propose two reasons why Linnaean classification may need to be replaced, using your knowledge of evolution. [2 marks]

12 Geographic isolation is a well-understood and obvious cause of speciation. Analyse the mechanisms of sympatric speciation and explain how it might result in geographic isolation after a long period of time. [2 marks]

Relate the fossil record to evidence of the age of the Earth and evolution

13 List the types of evidence for evolution that may be gained from living organisms and those that may be gained from fossil evidence. Explain how the two types of evidence complement each other. [3 marks]

14 Like all good scientific theories, evolution can be used to make testable predictions. Research the discovery of the transition fossil *Tiktaalik*. Outline the evidence scientists used when deciding where to look for this fossil. What predictions did they make? What did they find? Explain how the story of *Tiktaalik's* discovery demonstrates the scientific method in action. [4 marks]

15 In the movie *Jurassic Park*, dinosaurs were created using DNA from the stomachs of mosquitoes, and gaps were filled in using frog DNA. In reality, there is no DNA left in mosquitoes that have been trapped in amber for millions of years and the frog would be a very bad choice for 'filler' DNA. Propose a better method of investigating the dinosaur genome using living species. Justify your choice based on at least two types of evidence for evolution. [4 marks]

16 The evolution of humans is well documented in the fossil record. Unlike other species, modern humans modify their own environment and avoid most agents of natural selection. Do you think humans are continuing to evolve? Would humans evolve if they colonised another planet? Justify your predictions about the future of humans and present your findings as a poster, short story or comic strip. [5 marks]

17 Australia and New Guinea are the only places in the world where monotremes (egg-laying mammals) are found. Both landmasses sit on the same continental plate and have been connected frequently throughout geologic history. Monotreme fossils are the oldest Australian mammal fossils, dating back 123 million years ago to the Mesozoic Period, better known as the age of dinosaurs. A 61-million-year-old monotreme fossil has also been found in South America. Using this information, propose the site where monotremes first evolved and explain both the fossil and current distributions of these animals. Predict whether other continents might have undiscovered monotreme fossils. [6 marks]

TOTAL MARKS [/50]

RESEARCH

Choose one of the following topics for a research project. Your job is to investigate how evidence for evolution is gathered, analysed and used to predict how species and ecosystems may change over time.

Modern-day evidence for evolution

There is evidence of current populations evolving by natural selection all around us. Research one of the following topics and see whether you can find evidence of evolution by natural selection occurring today. Prepare a case study of your chosen topic.

- Can controlled breeding modify organisms?
- When fewer predators are present, how does brighter coloration evolve?
- How does natural selection lead to pesticide resistance?

Climate change and natural selection

How do you think climate change will affect species on the Earth? Which species do you think will be most affected? Why is this? How might species avoid becoming extinct as a result of changing habitats? Would all species be able to avoid the effects of climate change? Do you think new species may evolve as a result of climate change? Outline the effect of climate change on a named species.

Real-time evolution

Significant advances in our understanding of evolution by natural selection have been vital to the study of diseases and pests. Antibiotic resistance in bacteria and the tolerance to herbicides in crops and pesticides in general agriculture are monitored closely. Why are these examples important? Why do they need close monitoring? Why do these organisms demonstrate evolution at such a fast rate? Describe an example of how our understanding of natural selection in bacteria and pests has changed the permitted use of pesticides or antibiotics.

REFLECT

Me

1 What new science skills have you learned in this chapter?

2 What was the most surprising thing you found out about evolution?

3 What was the most difficult aspect of this topic?

4 How has your understanding of how scientific theories are developed improved?

My world

5 Why is it important to understand evolution and natural selection?

6 What is being done in the world to better understand the process of evolution?

7 Which technologies have helped us understand the process of evolution?

My future

8 What career paths could a study of evolution lead to?

KEY WORDS

absolute dating
allopatric speciation
analogous structure
artificial selection
biogeography
common descent
convergent evolution
divergent evolution
evolution
extinction
fossil
fossilisation
gene flow
gene pool
geographic isolation
homologous structure
isolating mechanism
living fossil
natural selection
niche
palaeontologist
pentadactyl limb
plate tectonics
population
relative dating
scientific theory
sexual dimorphism
sexual selection
speciation
species
strata
survival of the fittest
sympatric speciation
trace fossil
transitional fossil
vestigial structure

2

MAKING CONNECTIONS

The rise of the bipedal ape

Since the time of Carolus Linnaeus (1700s), scientists had considered the great apes to be the closest relatives of humans because of their physical similarities. In the 19th century, scientists speculated that the closest living relatives of humans were chimpanzees owing to their physical similarities and their natural habitat range. Over time, further evidence emerged that provided more evidence of this close link. More recently, biochemical comparisons have allowed evolutionary biologists to estimate the times at which the ape lineages split from each other, providing a prediction of what rock layers should be searched for transitional fossils.

Our evolutionary history

The incredible story of the evolution of humans from our ape ancestors covers approximately 7 million years. Life has existed for approximately 4 billion years, so 7 million years is really a snapshot in time, but how many years of your own family tree can you trace back in time? Maybe a couple of hundred if you are lucky.

Darwin's *On the Origin of Species*, published in 1859, suggested that humans were descended from African apes. With no fossils of our ancestors discovered until 1924, Darwin's suggestion was considered ridiculous and insulting to the human race. In 1924, Raymond Dart dug up the Taung child in Africa, a 3–4-million-year-old Australopithecine and our distant ancestor (Figure 2.71).

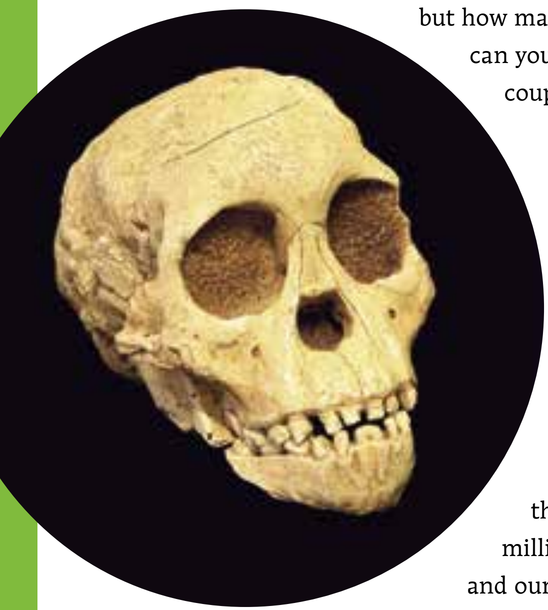


Figure 2.71 The skull of the Taung child, a distant ancestor that is 3–4 million years old.

Since Dart's discovery nearly a century ago, approximately 12–19 different species of human ancestors have been identified, although scientists are continually arguing and modifying their stance on the relationships between the fossil finds. As more fossils are uncovered, and more analyses performed, it is expected that the story of human evolution will continue.

Your task

Many pieces of evidence have formed the puzzle pieces that tell the story of human evolution. Fossils are the most obvious, but the level of detail they can provide requires specialists to analyse the information. Consequently, many palaeontologists will specialise in the analysis of skulls or leg bones. Other forms of evidence, such as comparative biochemistry, require their own specialists.

1 Define the term 'hominid'.
2 Find a selection of images of hominid skulls to analyse. (You may be lucky enough to have access to replicas.)

Figure 2.72 One of the most famous fossils is the remarkably complete 'Lucy', dug up in Ethiopia in 1974. Although her scientific name is *Australopithecus afarensis*, her discoverers named her 'Lucy' in honour of the Beatles song they were listening to at the time – *Lucy in the Sky With Diamonds*.

3 Without looking at any of the data that may accompany these images, make careful observations of the various facial, cranial and even brain-case features. Measurements could be made of lengths, diameters or even volumes. Use these observations to suggest a timeline from most recent (most like modern humans) to most distant relative. Record your reasoning, and then present it to the class.

4 As a group, discuss the:
   a different features that each person observed. What did most people notice?
   b similarities and differences between the skulls.

5 Conduct further research to find out whether you placed the skulls in the correct order.

6 What additional information would palaeontologists have access to? What additional information would they find useful?

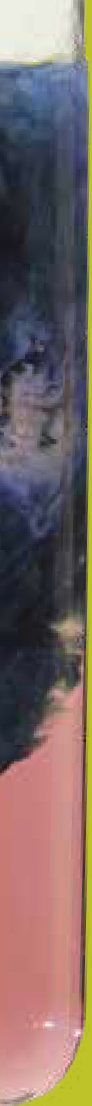
7 Present your information as an informative multimedia presentation, or in some other format as discussed with your teacher. Remember to include a full bibliography of your sources.

Figure 2.73 The astonishing 'hobbit' species, *Homo floresiensis*, found on an Indonesian island in 2003. Some scientists believe it is simply a dwarf form of modern *Homo sapiens*, but further analysis will be required to determine whether this is true.

3

CHEMICAL REACTIONS

We know that substances can change. We can freeze water to form ice, and we can melt that ice to form water again. This is a physical change. If you place some sodium metal (Na) in water (H_2O), hydrogen gas is released. This change is different; a chemical reaction has occurred. During chemical reactions, substances interact to form different substances. How are new substances produced from existing materials? What is happening at an atomic level that we cannot see?



CHANGING MATTER WITH CHEMICAL REACTIONS 3.1

A chemical change is defined by the formation of a new substance, but that new substance is produced from the existing atoms available in the reactants. No atoms are destroyed or created in a chemical reaction. Chemical formulas are used to explain the composition of substances, whereas word and chemical equations demonstrate the changes in arrangement of atoms during a chemical reaction.

Students:

- » recall that matter is composed of atoms which have mass
- » identify the names and chemical formulas of some common compounds
- » construct word equations to describe chemical reactions
- » deduce that atoms of reactant substances are rearranged during chemical reactions to produce new substances
- » balance chemical equations (additional content)

CLASSIFYING CHEMICAL REACTIONS 3.2

When one or more substances interact to produce one or more new substances, a chemical reaction is said to have occurred. The types of reactants and products, or the manner in which the reactants interact, enable chemists to classify chemical reactions and predict the outcome of similar reactions.

Students:

- » classify compounds based on common chemical properties
- » investigate the characteristics of the main types of chemical reactions including combustion, reactions between acids and metals and carbonates, corrosion, precipitation, neutralisation and decomposition

CHEMICAL REACTIONS IN LIFE 3.3

Chemical reactions are not just activities within scientific laboratories; they happen naturally in both living and non-living systems. Photosynthesis and respiration are spontaneous chemical reactions that are key fuels for life on the Earth. But humans also use chemical reactions to extract, refine and use other fuels for heat and electricity.

Students:

- » identify the importance of the chemical reactions involved in photosynthesis, respiration and digestion

3.1 CHANGING MATTER WITH CHEMICAL REACTIONS

For several thousand years, until the 17th century, alchemists tried to produce valuable substances such as gold from less valuable materials, such as lead. The word 'alchemy' comes from an Arabic word meaning 'value'. Without knowledge of what happens to atoms during a chemical reaction, early alchemists were attempting the impossible. Modern chemists still use some of the language and equipment of alchemy, but they can now consider what is really happening to the 'invisible' particles in chemical reactions.

CHEMICAL REACTIONS AND CHEMICAL FORMULAS

All matter is made up of atoms. Some of these atoms join together to form molecules or three-dimensional lattice structures. Sometimes different types of atoms or elements join together to form compounds. Atoms join together in different ways to produce all the different substances on the planet.

Every atom is made up of protons and neutrons in the nucleus, which are surrounded by layers of orbiting electrons in electron shells. The number and arrangement of the subatomic particles determine the element and the properties of that element.

We are still discovering new things about the atom. In July 2012, the physics world was in a state of excitement. A new type of subatomic particle had been confirmed by CERN, the European Organization for Nuclear Research.

The Standard Model, which describes the particles, forces and interactions of the universe, is supported by the existence of a subatomic particle called the Higgs boson. Until July 2012, that particle was predicted but undiscovered. Discovery of the Higgs boson is proof of a force that gives particles their mass. If particles had no mass, they would travel through the universe without attracting each other and so would never form into bodies such as planets and stars.

CERN's observations are important for areas other than physics. You will find out in this chapter just how vital the idea of mass is to chemical reactions.

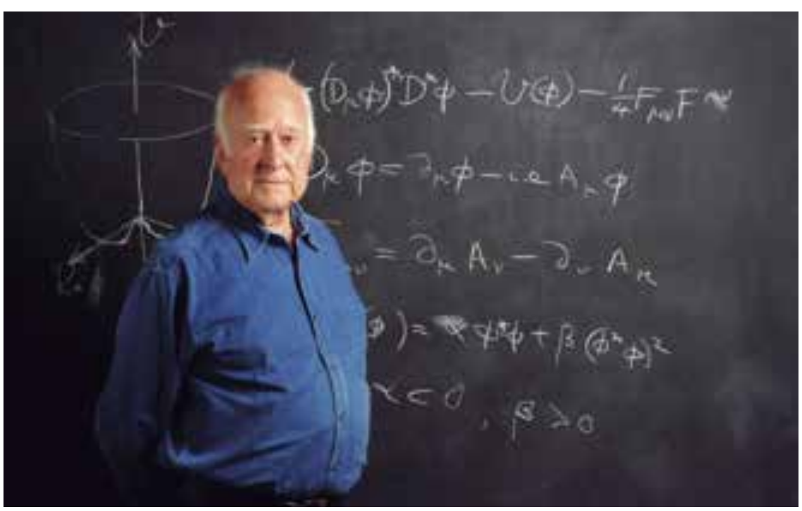


Figure 3.1 British theoretical physicist Peter Higgs predicted the existence of an additional subatomic particle in 1964 and called it the Higgs boson. The Higgs boson was finally discovered in 2012.

Chemical reactions

Chemical change is defined as the production of a new substance from existing substances. All chemical reactions start with one or more reactants (ingredients) and result in one or more new products. The products are formed from the atoms of the reactants. No atoms are destroyed and no new atoms are created by the reaction. It is simply a rearrangement of the atoms that are already there.

Atoms can be thought of as being like Lego© blocks that can be clicked together and taken apart, over and over, in many different ways, to form different things.

ACTIVITY 3.1.1: THE ALCHEMIST'S DESIRE

Imagine that you and your friends are approached by an alchemist claiming to be able to change lead into gold. You know that the claims are an attempt to trick you, but your friends are tempted to believe the alchemist, because they think they could become incredibly wealthy.

Your task is to convince your friends that the alchemist is a fraud and that alchemy simply doesn't work. You have the following pieces of evidence.

- Elements always behave predictably in chemical reactions.
- All elements have physical properties that appear to be consistent.
- When chemicals react with each other, the total amount of mass of the chemicals does not change.
- Pure metals don't change in terms of physical properties unless they're mixed with other metals or form compounds.

1 Do you think any of these pieces of evidence would be useful in persuading your friends to ignore the alchemists? If so, why?

2 Choose three of the points and explain why you think you could use them as evidence to support your opinion that alchemy is more of a trick than a scientific endeavour.

Figure 3.2 Alchemists did not have an understanding of the structure of atoms or the nature of chemical reactions and were never successful in converting lead into gold.

Describing chemical reactions

Figure 3.3 shows sodium metal reacting with water. Perhaps you have seen this reaction at school or on the Internet.

There are different ways to describe this reaction.

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

  sodium + water → sodium hydroxide + hydrogen

- Using a chemical equation: The ratio in which they react, and the formulas and states (solid, liquid or gas) of each substance are described by a balanced **chemical equation**:

  $2Na(S) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$

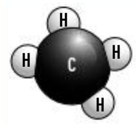
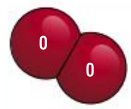
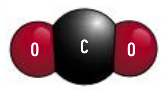
Figure 3.3 Sodium metal reacts spectacularly with water.

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

ACTIVITY 3.1.2: REPRESENTING CHEMICALS

Table 3.1 represents four chemicals in different ways.

Table 3.1 Representations of four chemicals.

Chemical name	Formula/symbol	Diagram
Methane	CH_4	
Oxygen	O_2	
Argon	Ar	
Carbon dioxide	CO_2	

1 Identify:

- **a** an element composed of molecules
- **b** a compound composed of molecules
- **c** an element composed of atoms.

2 Which representation tells us the most about the chemicals: the formula or the diagram? Explain your reasoning or discuss your answer with others.

3 Which substance will burn in air and produce heat energy?

Did you remember these key facts about chemicals?

- Elements are made up of one type of atom.
- Compounds are combinations of different atoms.
- Molecules are atoms bonded together.

ACTIVITY 3.1.3: OBSERVING A CHEMICAL REACTION

What you need: candle, matches, range of measuring devices such as a stopwatch, thermometer etc.

1 A burning candle is an example of a common chemical reaction. Light a candle and spend 5 minutes listing as many observations about what happens as you can. Remember to use observational tools other than your eyes. Share your list with a partner.

2 Would any of your observations help to classify what type of reaction this is? Answer the following questions.

- Was energy released in the reaction?
- If so, what forms of energy? How do you know?
- Was it a fast reaction?
- What was used up in the reaction? What was produced?
- Did the reaction start on its own? (Was it spontaneous?)

Chemical formulas

To be able to understand the atoms contained in a substance and involved in chemical reactions, scientists use **chemical formulas**. A chemical formula is made up of letters and numbers. The letters are element symbols and tell us which elements are present. The subscript numbers tell us how many atoms of that element are present in each molecule, or in the case of lattice structure, the ratio of atoms of each element.

You were introduced to ionic and covalent compounds in *Oxford Insight Science 9*.

Ionic compounds

Ionic compounds contain both metal and non-metal elements. The metal atoms donate their valence electrons to the non-metal atoms, causing the metal atoms to form positively charged cations. Accepting the electrons causes the non-metal atoms to form negatively charged anions. The difference in charge forms ionic bonds between ions. Ionic bonds are relatively weak and often break when the compound is dissolved in water. The number of electrons donated or accepted determines the charge of the ion, which in turn influences the ratio of atoms in the compound.

Ionic compounds list the metal element first in the name, followed by the non-metal element name. However, the non-metal name is altered slightly so that it always ends in 'ide'. For example, oxygen becomes oxide; chlorine becomes chloride; and sulfur become sulfide. Polyatomic ions (ions made up of a combination of more than one atom and usually more than one element) take on their own specific name, which may not necessarily end in 'ide'.

Ionic compounds usually form hard and brittle crystal lattices. The chemical formula of an ionic compound indicates the ratio of different elements in the compound.

Molecular compounds

Molecular compounds contain two or more different non-metal elements. The different atoms share electrons in their valence shells and form strong covalent bonds. The number of electrons required to make the valence shell of each atom stable determines the number of electrons shared and the ratio of elements involved in the compound.

Molecular compounds form discrete molecules, so the numbers in the chemical formula indicate the exact number of atoms required for each molecule.

Molecular compounds are named according to the number of each element in the compound. There are a number of rules involved in naming molecular compounds.

- The element listed first is found further left on the periodic table than the other element. For example, carbon is listed first in any compound containing carbon and oxygen.
- The ending of the second element name is changed to 'ide'.
- Numerical prefixes indicate the number of atoms of each element (see Table 3.2).
- If there is only one atom of the first listed element, the prefix 'mono' is dropped.

Some everyday molecular compounds have a common name as well as a scientific name (see Table 3.2).

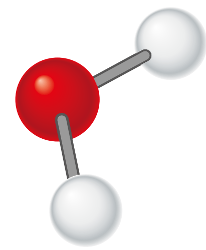


Figure 3.5 Covalent bonds, such as those in H_2O, are formed when valence electrons are shared between two atoms.

Table 3.2 Some common molecular compounds.

Chemical formula	Scientific name	Common name
H_2O	Dihydrogen monoxide	Water
NH_3	Nitrogen trihydride	Ammonia
CH_4	Carbon tetrahydride	Methane
H_2O_2	Dihydrogen dioxide	Hydrogen peroxide
HCl	Hydrogen monochloride	Hydrochloric acid

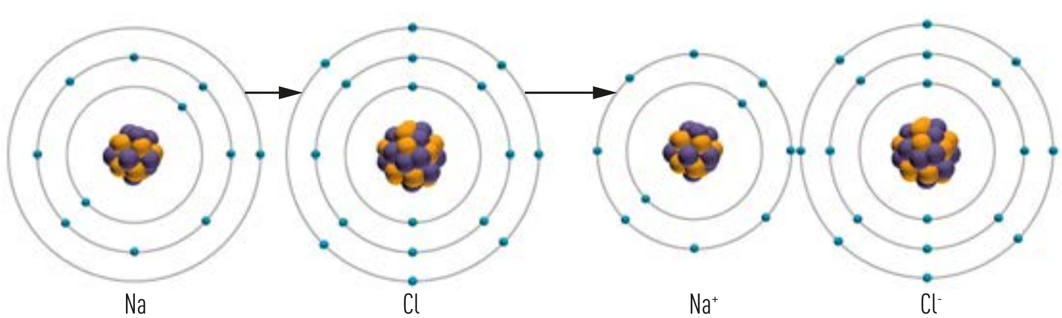


Figure 3.4 Sodium chloride (NaCl) forms a 3D lattice made up of one positively charged sodium cation for every negatively charge chlorine anion.

SCIENCE SKILLS

Naming compounds and writing chemical formulas

Part A: Ionic compounds

Ionic compounds are always written and named with the metal element before the non-metal element, which always ends in 'ide'. The ratio of cations and anions must result in a substance without charge. That is, the positive charges must cancel out the negative charges. Table 3.3 lists some common ions.

Table 3.3 Some common ions.

Cations		Anions	
Element	**Formula**	**Element**	**Formula**
Lithium	Li^{+}	Fluorine	F^{-}
Sodium	Na^{+}	Chlorine	Cl^{-}
Potassium	K^{+}	Bromine	Br^{-}
Magnesium	Mg^{2+}	Iodine	I^{-}
Calcium	Ca^{2+}	Oxygen	O^{2-}
Zinc	Zn^{2+}	Sulfur	S^{2-}
Aluminium	Al^{3+}	Nitrogen	N^{3-}

Example

1 What is the name and formula for the compound of zinc and sulfur?
- The ions are Zn^{2+} and S^{2-}.
- Because the charges 2+ and 2– are equal, the ions need to be in the ratio of 1:1.
- Therefore the formula is ZnS.
- The compound is called zinc sulfide.

2 What is the name and formula for the compound of aluminium and oxygen?
- The ions are Al^{3+} and O^{2-}.
- Because the charges 3+ and 2^{-} are unequal, the ions need to be in the ratio of 2:3 (2 × 3 = 6, 3 × 2 = 6).
- Therefore the formula is Al_2O_3.
- The compound is called aluminium oxide.

Your turn

1 Write the chemical formula and the name for the compounds of:
   a calcium and bromine
   b sodium and nitrogen.

Part B: Molecular compounds

Molecular compounds are named using numerical prefixes to identify the number of atoms for each element involved. The second element always ends in 'ide'. Table 3.4 lists the numerical prefixes.

Example

1 Identify the name of the compound, NF_3.
- Identify the element symbols: N = nitrogen, F = fluorine.
- Because nitrogen does not have a subscript number, it doesn't require a prefix.
- Fluorine has the subscript number 3, so needs the prefix 'tri' and must end in 'ide'.
- The compound is called nitrogen trifluoride.

2 Identify the formula of the compound, phosphorus pentachloride.
   - Identify the element symbols: phosphorus = P, chlorine = Cl.
   - Because phosphorus doesn't have a prefix, there must only be one atom, and so no subscript number is needed.
   - Chlorine has the prefix 'penta', so must have the subscript number 5.
   - The chemical formula of the compound is written as PCl_5.

Your turn

1 Name the compound S_2F_{10}.

2 Write the chemical formula for sulfur hexafluoride.

Table 3.4 Numerical prefixes for naming molecular compounds.

Number of atoms	Prefix
1	mono
2	di
3	tri
4	tetra
5	penta
6	hexa
7	hepta
8	octa
9	nona
10	deca

QUESTIONS 3.1.1: CHEMICAL REACTIONS AND CHEMICAL FORMULAS

Remember

1 Define the terms 'reactant' and 'product' in relation to chemical reactions.

2 Identify which way of describing a chemical reaction tells us most about what is happening to the atoms.

3 Identify the differences between ionic and molecular compounds. You may like to use a table or graphic organiser.

Apply

4 Identify what you think the '(s)', '(l)', '(g)' and '(aq)' stand for in the chemical equation for the reaction of sodium metal with water (see page 107).

5 Name the following compounds.

   a N_2H_4

   b Na_2O

6 Identify whether the compounds in question 5 are ionic or molecular. Justify your decisions.

7 Write the chemical formula for dinitrogen tetraoxide.

Analyse

8 Suggest an advantage of using chemical formulas over compound names.

CONSERVATION OF MASS

While a chemical reaction produces a new substance, only the atoms present in the reactants are used. Chemical bonds between atoms may be broken and re-formed between different atoms, but no atoms are destroyed or created in the process. This means that all the atoms that were present at the start of the reaction are still present at the end. They have simply been rearranged into something new.

The **law of conservation of mass** explains this phenomenon by stating that the total mass of the reactants must be equal to the total mass of the products of a chemical reaction.

EXPERIMENT 3.1.1: COMPARING MASS BEFORE AND AFTER A CHEMICAL REACTION

Aim

To determine if mass is conserved in a chemical reaction.

Hypothesis

Predict whether you think the mass of the products of this reaction will be the same as the mass of the reactants consumed in this reaction. Rewrite your prediction as a hypothesis using an 'If … then …' statement.

Materials

- Balance
- Measuring cylinder
- 2 conical flasks
- Sodium bicarbonate
- Watch glass
- Vinegar
- Gas jar and cover
- Limewater
- Spatula
- Balloon
- Thermometer

WARNING

> Make sure that you have discussed any possible risks to yourself or others with your teacher and members of your investigation team. Identify how you could minimise or eliminate any anticipated risks.

Part A

Method

1 Copy the results table on page 113 for part A to record your results.
2 Add 20 mL of vinegar to a flask.
3 Use a thermometer to measure the temperature of the vinegar.
4 Ensure the balance is reading zero. Weigh the vinegar and flask. Record this mass (m_1).
5 Predict whether the mass of the flask and vinegar after the reaction with the sodium bicarbonate will be more, the same or less than the initial mass.
6 Measure 2.0 g of sodium bicarbonate (m_2) and place it on a watch glass. Add the sodium bicarbonate to the flask containing the vinegar and swirl the solution until the bubbling stops.
7 Measure the temperature of the solution in the flask.
8 Weigh the flask after the reaction has stopped. Record the final mass (m_3).

Figure 3.6 Add the sodium bicarbonate to the vinegar.

Results

Mass of flask and vinegar (m_1)	Mass of sodium bicarbonate (m_2)	Total mass before reaction ($m_1 + m_2$)	Mass after reaction (m_3)

Part B

Method

1 Copy the results table below for part B to record your results.

2 Add 20 mL of vinegar to the clean flask.

3 Ensure the balance is reading zero. Weigh the vinegar, flask and a balloon. Record this mass (m_1).

4 Predict whether the mass of the flask, vinegar and balloon after the reaction with the sodium bicarbonate will be more, the same or less than the initial mass.

5 Measure 2.0 g of sodium bicarbonate (m_2) on a watch glass. Add the sodium bicarbonate to the balloon then stretch it over the neck of the flask to collect any gas produced.

6 Invert the balloon so its contents empty into the flask and vinegar.

7 Weigh the flask after any reaction ceases, with the balloon still attached. Record the final mass (m_3).

8 Pour limewater into a gas jar to a depth of around 2 cm.

9 Pinch the balloon and remove it from the flask. Release the gas in the balloon into the gas jar and limewater. Put the lid on the gas jar and gently swirl the limewater in the jar, noting what happens. If the limewater turns milky, it suggests that carbon dioxide was produced in the reaction of vinegar and sodium bicarbonate. This gas has then reacted with the limewater to produce white calcium carbonate.

Figure 3.7 Quickly stretch the balloon over the flask to collect any gases produced.

Results

Mass of flask, vinegar and balloon (m_1)	Mass of sodium bicarbonate (m_2)	Total mass before reaction ($m_1 + m_2$)	Mass after reaction (m_3)

Discussion

1 Compare the initial and final masses for each part of the experiment. Is this what you expected? Explain why or why not.

2 Did you identify that a gas was produced in the reaction between sodium bicarbonate and vinegar? How did you know?

3 Describe whether the temperature of the vinegar solution was the same, lower or higher after the reaction with sodium bicarbonate.

4 Identify the gas produced.

5 Identify the purpose of the balloon.

6 Was carbon dioxide gas produced in the reaction? Describe how you know this.

7 Explain how the design of this experiment and the reliability of your results could be improved.

Conclusion

- Describe the evidence you observed that tells you that a chemical reaction did occur.
- Describe your evidence that indicates mass was conserved in this chemical reaction.
- Was your hypothesis supported or not supported by your observations?

Chemical reactions and mass

What happens to the mass of chemicals during chemical reactions? To find out, we can gather some evidence by experimenting. Consider the reaction of acid in vinegar with sodium bicarbonate. This reaction produces carbon dioxide gas, and it can be represented as:

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

Experiment 3.1.1 showed that when the products of a chemical reaction are not allowed to escape, the mass of the products after the observed reaction is the same as the mass of the reactants at the start. This is a very important observation. It shows that the total mass of the chemicals is not changed in a chemical reaction and supports the law of conservation of mass.

Atoms in a chemical reaction

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

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Figure 3.8 shows what is happening to the atoms during this reaction. Different atoms are represented by different colours. One methane molecule combines with two oxygen molecules to produce one carbon dioxide molecule and two water molecules.

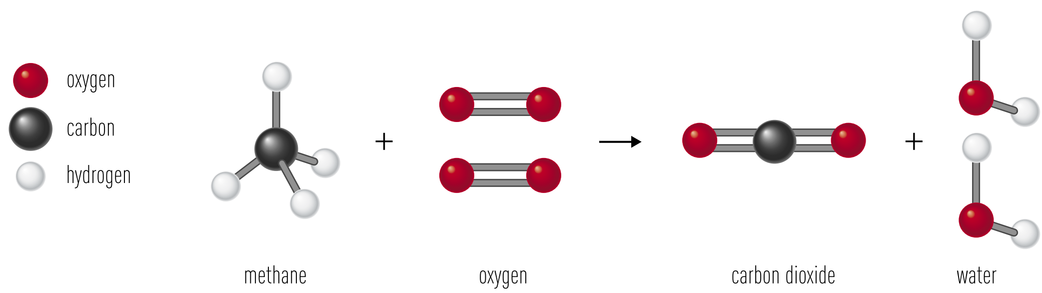


Figure 3.8 Atoms are rearranged during a chemical reaction.

When the methane gas is burning, this reaction is happening between millions of molecules, but for each and every reaction between methane and oxygen, the atoms always rearrange in this way, if there is plenty of oxygen.

Writing chemical equations

Hydrogen combines with oxygen to produce water. The equation can be written using the following steps.

1 Write the word equation for the reaction.

hydrogen + oxygen → water

2 Write a chemical equation using the formulas of the substances involved.

$$H_2 + O_2 \rightarrow H_2O$$

3 Work out the number of each type of atom in the reactants (left-hand side) and in the products (right-hand side) by looking at the subscript numbers.

4 Compare the number of each type of atom in the reactants with the number in the products. In this case, the number of atoms in the products of the reaction (2 + 1 = 3) is different from the number of atoms in the reactants (2 + 2 = 4). This doesn't fit the law of conservation of mass. We can't have 'lost' an oxygen atom.

5 The equation needs to show that the numbers of each atom in the products are the same as they were in the reactants, according to the law of conservation of matter. We do this by including whole numbers (called coefficients) in front of the formulas of the elements or molecules, where necessary. The coefficient is a multiplier and applies to each different type of atom within a molecule. Coefficients are added to the chemical formulas until the equation is balanced; the number of reactant atoms equals the number of product atoms for each element.

6 To balance the equation for the reaction between hydrogen and oxygen molecules, the hydrogen molecule in the reactants and the water molecule in the products each have a coefficient of 2. The oxygen molecule has a coefficient of 1, but a coefficient of 1 doesn't need to be shown.

$2H_2 + O_2 \rightarrow 2H_2O$

	Reactants		→	Products	
Type of atom	H	O	→	H	O
Number of atoms	2	2	→	2	1

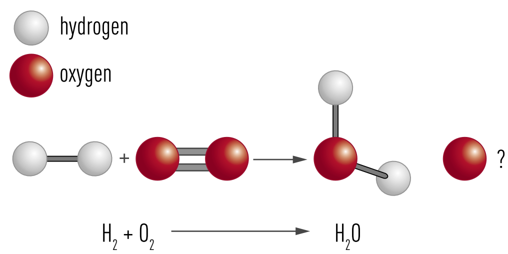


Figure 3.9 An atom of oxygen can't have 'magically' disappeared. This reaction is not yet balanced.

	Reactants		→	Products	
Type of atom	H	O	→	H	O
Number of atoms	2 × 2 = 4	2	→	2 × 2 = 4	2 × 1 = 2

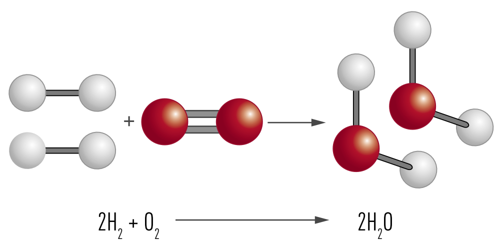


Figure 3.10 The law of conservation of mass means that two molecules of hydrogen must react with one molecule of water to produce two molecules of water.

SCIENCE SKILLS

Balancing chemical equations (additional content)

When an airbag from an older car activates, the atoms in a chemical called sodium azide (NaN_3) separate to form sodium metal and nitrogen.

Your turn

Follow these steps to write and balance the equation for airbag activation.

1 Write the word equation for the reaction.

2 Write the word equation as a chemical equation using the formulas of the substances involved.

3 Work out the numbers of each type of atom in the reactants (left-hand side) and in the products (right-hand side).

4 Compare the number of each type of atom in the reactants with the number of each type of atom in the products and use coefficients to balance the number of atoms on both sides.

QUESTIONS 3.1.2: CONSERVATION OF MASS

Remember

1 What are the key feature of a chemical change compared to a physical change?

2 If no mass is lost or gained in a chemical reaction, outline what this tells you about the atoms involved in the reaction.

3 What do the following numbers in a chemical formula tell you?

a Subscript numbers

b Coefficient numbers

Apply

4 Explain why the products of a reaction have very different properties from those of the reactants, even though the total mass remains the same.

5 Explain why chemical reactions that are not 'balanced' are always incorrect.

Analyse

6 Balance the following equations by adding numbers.

a __ Na + __ $H_2O \rightarrow$ __ NaOH + __ H_2

b __ H_2 + __ $O_2 \rightarrow$ __ H_2O

c __ CH_4 + __ $O_2 \rightarrow$ __ CO_2 + __ H_2O

d __ Mg + __ HCl $\rightarrow$ __ H_2 + __ $MgCl_2$

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

7 Rewrite all of the equations in question 6 as word equations. Identify the common names for NaCl and H_2O.

CHANGING MATTER WITH CHEMICAL REACTIONS

3.1 CHECKPOINT

Remember and understand

1 Describe what all substances are made from. [1 mark]

2 State the law of conservation of mass. [2 marks]

3 Describe what happens to atoms during a chemical reaction. [2 marks]

4 Identify how many atoms of each element in total are present in:

- **a** a molecule of citric acid ($C_6H_8O_7$). [3 marks]
- **b** six water molecules ($6H_2O$). [3 marks]

Apply

5 Identify three things you could observe that would indicate a chemical reaction has taken place when chemicals are mixed or burned. [3 marks]

6 In the car airbag described in the Science Skills: Balancing chemical equations (see page 115), other chemicals are present in the bag to react with the sodium metal after it is produced. Apply your knowledge of sodium to explain why you think that this is necessary. [2 marks]

Analyse and evaluate

7 Outline the advantages and disadvantages of using a balanced chemical equation to describe a chemical reaction. [2 marks]

Critical and creative thinking

8 Think back to the work of the early alchemists. Outline why they thought they could create new substances from old materials. Use your knowledge from this unit to explain why their efforts to produce gold from other substances were futile. [2 marks]

9 The law of conservation of mass states that the total mass of substances is the same before and after a chemical reaction. Explain why the following observations do not contradict (go against) the law of conservation of mass.

- **a** An iron nail becomes heavier as it rusts. [2 marks]
- **b** When a piece of magnesium is mixed with acid in a beaker to produce hydrogen gas, the combined mass of the beaker and its contents decreases. [2 marks]

Making connections

10 The main idea that you have been considering in this section is that when substances interact and change, atoms within the substances are rearranged. LPG (liquefied petroleum gas), which is used in barbecues, contains propane (C_3H_8). When propane gas burns in air, it reacts with oxygen to produce carbon dioxide and water.

The reaction can be represented by a chemical equation:

propane + oxygen → carbon dioxide + water vapour

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

The molecules involved in the reaction can be represented as shown in Figure 3.11.

- **a** Describe what happens to a carbon atom (black) during this reaction. [2 marks]
- **b** Explain why three molecules of carbon dioxide are produced for each molecule of propane reacted. [2 marks]
- **c** Use this reaction to explain the law of conservation of mass in a chemical reaction. [2 marks]

Figure 3.11 Molecules involved when propane burns in air.

TOTAL MARKS
[/30]

3.2 CLASSIFYING CHEMICAL REACTIONS

All chemical reactions begin with reactants and result in products. However, reactions can be classified according to particular interactions between reactants and the products they produce. Descriptions of reactions may focus on observation, such as the production of gas or heat. Alternatively, they may name the chemicals involved, writing word equations or chemical equations with symbols and formulas to demonstrate the rearrangement of atoms during the reaction.

REACTIONS INVOLVING ACIDS AND BASES

Acids are commonly found around us. Unripe fruit tastes sour because of the presence of acid. Weak acids in fruit include citric acid in oranges and lemons, tartaric acid in grapes, malic acid in green apples and oxalic acid in rhubarb. Vitamin C is ascorbic acid. Sour milk and yoghurt contain lactic acid. Vinegar is acetic acid. Fizzy soft drinks contain carbonic acid.

Acids are a group of chemical compounds with similar properties. As well as tasting sour, all acids produce a prickling or burning sensation if they contact skin. All common acids contain at least one hydrogen atom. They tend to react with many metals.

Some acids are strong and some are weak. Strong acids are dangerous because they can react continuously and can 'eat' their way through objects. Very strong acids such as concentrated sulfuric acid can dehydrate (remove water from) carbohydrates such as sugar to leave behind carbon. This gives an appearance of burning. Weak acids are usually much safer and we can eat and drink some of them. Most of us enjoy the sour taste of weak acids in foods or condiments such as vinegar or in citrus fruits.

Bases can be described as the chemical opposites of acids. They are bitter and feel slippery or soapy to touch. A base that dissolves in water is called an **alkali** and solutions that are formed by these soluble bases are described as **alkaline** solutions.

Both acids and bases can be very dangerous. It is important to remember not to taste or touch any chemicals in a laboratory!

DEEPER UNDERSTANDING

Treating the sting of ant bites

What happens when an ant bites you? Most ants release a toxin that includes methanoic acid (sometimes called formic acid), which is released into the skin when they bite. Methanoic acid causes the stinging sensation. A preparation that contains baking soda works quite well to reduce the stinging sensation. This is because baking soda is a base, so it neutralises the acid in the toxin, thus taking away the sting.

Not all insect stings are acidic. Fire ants release an alkaline compound. Treating fire ant stings with a base such as baking soda will not ease the pain because one base will not neutralise another base. What do you think would neutralise the effect of a sting from a fire ant?

Figure 3.12 A scanning electron microscope image of a fire ant. Unlike many ant species, fire ants release a strong base when they bite.

Identifying acids and bases

Acids and bases can be identified by taste, touch and smell, but it's often not safe to do so. A safer alternative is to use an indicator.

An **indicator** is a substance that changes colour in the presence of an acid or a base. Some plants naturally contain pigments that are examples of these substances.

The coloured chemicals in many flowers and fruits can be extracted with hot water, and then used as an indicator for acids and bases. Red cabbage contains a water-soluble pigment called flavin, which is also found in plums, poppies, grapes and apple skin. Very acidic solutions will become red when flavin is added, neutral solutions become a purplish colour and alkaline solutions appear greenish yellow.

Figure 3.13 Some vegetables, such as red cabbage, can be used to make pH indicators.

In the laboratory, scientists commonly use **litmus paper** and **universal indicator** as indicators. Litmus paper is the most commonly used indicator for quickly testing whether a substance is an acid or a base. Litmus paper becomes red in acidic solutions and blue in basic solutions.

Universal indicator is a mixture of different indicators. It is more accurate than litmus paper, because it also indicates the strength of the acidic or the basic solution that is being tested.

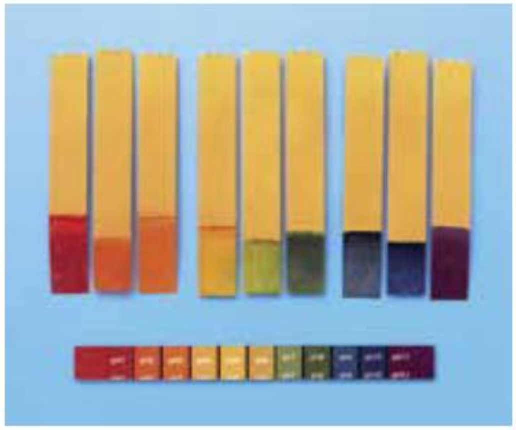


Figure 3.15 Universal indicator paper will turn a range of different colours depending on the strength of the acid or base. Reds and oranges are typically acids, blues and purples are bases, while neutral is usually green.

Figure 3.14 Blue litmus paper turns red to indicate the presence of acid.

The pH scale

The **pH scale** describes the relative acidity or alkalinity of a solution. If a solution is **neutral** – that is, it is neither an acid nor a base – it has a pH of 7. Pure water has a pH of 7 because it is neutral.

Acids have pH values of less than 7. The higher the acidity of a solution, the lower the pH of the solution. A pH of 1 or less indicates a very acidic solution.

Bases have pH values greater than 7. Strong bases, such as caustic soda (sodium hydroxide), can form solutions with a pH of up to 14.

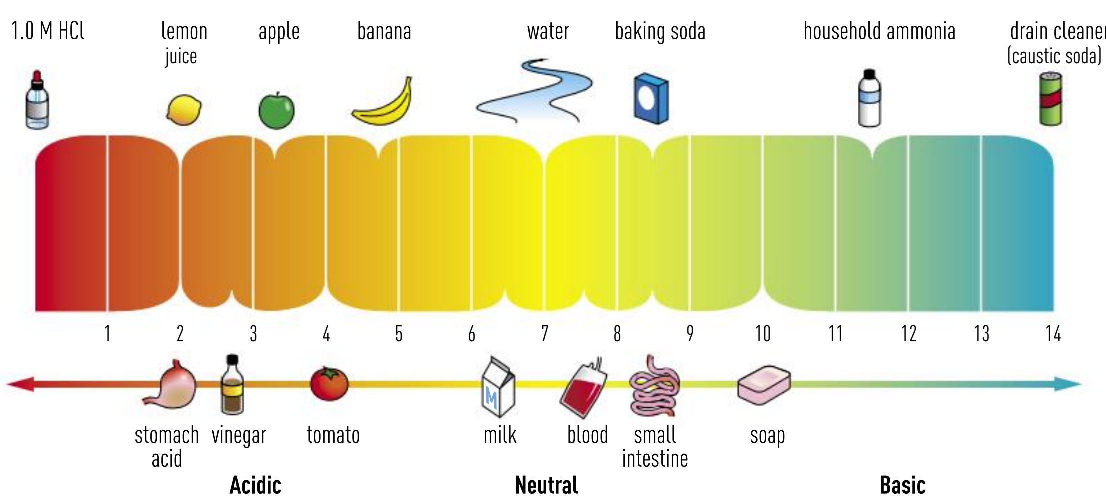


Figure 3.16 The pH scale and the relative pH of various substances.

ACTIVITY 3.2.1: TESTING WITH pH PAPER

What you need: pH paper and pH colour chart, white tile, variety of laboratory acids and bases, vinegar, milk, toothpaste, lemon juice

1. Tear off about 1 cm of pH paper and place it on a white tile.
2. Place a drop of a laboratory acid on the paper.
3. Compare the colour of the wet spot on the pH paper with the pH colour chart.
4. Repeat for the laboratory bases and the other substances.
5. For each substance, record the pH colour and number, and note whether the substance is an acid, a base or neutral.
6. Dilute some of the substances in water and measure the pH of the diluted solutions with more indicator paper.
   - Which was the most acidic solution that you tested (lowest pH)?
   - Which was the most basic solution that you tested (highest pH)?
   - What happens to the pH of an acid when the acid is diluted in water? Is it more or less acidic?
   - Using your answer to the previous question, suggest a way of treating a burn caused by acid.

EXPERIMENT 3.2.1: CREATING AN INDICATOR WITH RED CABBAGE

Aim
To make an indicator from red cabbage, and to demonstrate how it can be used to identify acids and bases.

Materials
- 2 leaves from a fresh red cabbage (shredded)
- Stirring rod
- Water
- Beaker (250 mL)
- Strainer
- Hotplate or Bunsen burner, tripod and gauze mat
- Test tubes and test tube rack
- Hydrochloric acid (0.1 M)
- Sodium hydroxide (0.1 M)

Method
1. To make the indicator:
   a. Cut a few red cabbage leaves into smaller pieces and place them in the beaker.
   b. Cover the cabbage leaves with water and boil the mixture until the water is purple.
   c. Cool the liquid and then strain it, discarding the cabbage leaves.
2. To test the indicator:
   - Add a small amount of hydrochloric acid to a test tube and then add a few drops of red cabbage indicator. Record any colour change in a results table.
   - Add a small amount of water (neutral solution) to a test tube and then add a few drops of red cabbage indicator. Record any colour change in your table.
   - Add a small amount of sodium hydroxide (basic solution) to a test tube and then add a few drops of red cabbage indicator. Record any colour change in your table.
   - Add a few drops of red cabbage indicator solution to a variety of products, such as shampoo, vinegar and baking soda. Record the colour changes and determine which products are acids and which are bases.

Results

Present your observations in a table.

Discussion

1 What colour is the extract from red cabbage?

2 What colour does the extract become in:
  a an acid **b** a base **c** water?

Conclusion

Identify whether the red cabbage solution is a suitable acid–base indicator.

Extension

Plan an investigation to discover what other plants, flowers or fruits could be used to create an indicator to test for the presence of an acid or a base.

Reactions involving acids

A general reaction for an acid is a word equation that summarises a reaction, without naming the particular acid. General reactions help you to learn the common reactions involving acids. You can also use them to predict the products of a reaction if you know the reactants being used.

Acids reacting with bases

When an acid and a base react, they neutralise each other to form a **salt** and water. This type of reaction is called a **neutralisation** reaction.

acid + base → salt + water

Different acids will produce different salts in neutralisation reactions. For example, sulfuric acid will produce salts called sulfates. When hydrochloric acid reacts with sodium hydroxide, the salt sodium chloride (common table salt) and water are produced.

sodium hydroxide + hydrochloric acid → sodium chloride + water

The chemical equation is: $NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O$

Acids reacting with metals

When an acid reacts with a metal, hydrogen gas is produced, as well as a salt.

metal + acid → salt + hydrogen

Some metals, such as magnesium, react rapidly with acids. Magnesium reacts with hydrochloric acid to produce magnesium chloride and hydrogen gas.

magnesium + hydrochloric acid → magnesium chloride + hydrogen

The chemical equation is: $Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$

Less reactive metals, such as lead, need to be heated to get them to react with acids such as hydrochloric acid. Other metals, such as gold, will not react with typical acids found in school science labs.

Acids reacting with metal carbonates or bicarbonates

When an acidic solution reacts with a metal carbonate or bicarbonate, a salt, carbon dioxide and water are produced. The general reaction is:

metal carbonate + acid → salt + carbon dioxide + water

The reaction of citric acid ($C_6H_8O_7$) with sodium bicarbonate ($NaHCO_3$) is used in sherbet to produce the fizzy sensation in your mouth.

EXPERIMENT 3.2.2: NEUTRALISATION REACTIONS

Aim
To investigate neutralisation reactions.

Materials
- Hydrochloric acid (1 M)
- Sodium hydroxide (1 M)
- Test tubes and test tube rack
- Dropping pipettes
- 10 mL measuring cylinder
- Universal indicator solution
- 100 mL beaker
- Petri dish
- Microscope or magnifying glass

WARNING

> Ensure that you wear safety goggles at all times during this experiment and avoid skin contact with the hydrochloric acid and the sodium hydroxide solutions.

Method
1. Using the measuring cylinder, transfer 5.0 mL of hydrochloric acid into the beaker. Rinse out the measuring cylinder with water.
2. Add 2 drops of universal indicator solution to the acid.
3. Pour 10 mL of the sodium hydroxide into the measuring cylinder.
4. Using the dropping pipette, add the sodium hydroxide from the measuring cylinder to the acid in the beaker.
5. Stop adding the sodium hydroxide when the acid has been neutralised. (The indicator will turn green.)
6. Record how much sodium hydroxide you needed to add.
7. Carefully empty and rinse out your glassware and repeat the experiment. This time, do not add any universal indicator but use the same amount of sodium hydroxide as you did before.
8. Pour the solution into a Petri dish until full and leave the dish open in a safe warm place in the laboratory for a few days. As the solution evaporates, record your observations.

Results
Present your results in a table.

Discussion
1. Why was it essential to rinse the measuring cylinder with water after it was used?
2. Outline why the experiment was repeated without the indicator.
3. Outline how you could produce the solid salt more quickly in the last step of the method.
4. Should you taste the product of this reaction to check whether salt has been produced? Explain your reasoning.

Figure 3.17 Compare the colour of the solution to the universal indicator pH scale to determine when it is neutral.

5. Describe what you notice about the shape of the salt crystals produced. What can you infer about the arrangement of the particles inside the salt crystals?

Conclusion
What have you observed about neutralisation reactions?

EXPERIMENT 3.2.3: REACTION BETWEEN AN ACID AND A METAL AT DIFFERENT TEMPERATURES

Aim
To investigate the rate at which a metal reacts with an acid at different temperatures.

Hypothesis
Predict the effect of an increased or a decreased temperature on the reaction between magnesium and hydrochloric acid. Write this prediction as a hypothesis using an 'If … then …' statement.

Materials
- Hydrochloric acid (1 M)
- 3 test tubes and test tube rack
- 3 beakers
- 10 mL measuring cylinder
- Ice slurry
- 3 pieces of magnesium ribbon of identical length
- Stop watch with lap timer capacity

Method
1. Add 5 mL of hydrochloric acid to each test tube.
2. Place one test tube in a beaker of ice water, one in water at room temperature and one in hot water. Leave the acid to reach the same temperature as the beaker in which it is sitting (5–10 minutes). This is called equilibrating.
3. Add a strip of magnesium to each test tube and commence timing the reaction in each test tube.
4. Record the time at which the reaction is no longer observed; that is, when all magnesium is reacted.

Results
Present your results in a table.

Conclusion
Identify which reaction was fastest and which was slowest. What does this suggest about the effect of increased temperature on the rate of this reaction? How accurate was your hypothesis?

ACTIVITY 3.2.2: MAKING SHERBET

What you need: small zip-lock sandwich bag, 1 tablespoon icing sugar, ¼ teaspoon sodium bicarbonate (baking soda), ¼ teaspoon citric acid, 1 teaspoon flavoured jelly crystals

WARNING

> Do this activity in a food preparation area using food preparation implements so that the sherbet is safe to eat. Remind your teacher if you have food allergies or diabetes – you may not be able to taste the sherbet.

1. Make sure the utensils are clean and dry.
2. Mix all the ingredients in the sandwich bag.
3. Dip a clean spoon into the mixture and put a small amount on your tongue.
   - What happened to the sherbet when it mixed with the saliva in your mouth?
   - What three substances were formed?
   - How did the sherbet feel on your tongue? What differences in tastes did you observe?
   - Do you think that carbonates and bicarbonates should be described as bases? Explain your answer, carrying out research if required.

Figure 3.18 Sherbet fizzes in a chemical reaction involving saliva.

ACTIVITY 3.2.3: METALS AND ACIDS

What you need: hydrochloric acid (1 M), test tubes and test tube rack, small pieces of metals (e.g. aluminium, copper, iron, magnesium, tin and zinc) to fit into test tubes

WARNING

> Wear safety goggles at all times and avoid skin contact with the acid.

1. Add a small piece of one metal to a test tube and pour in enough acid to cover it.
2. Observe what happens (e.g. bubbling, metal dissolving, colour change, test tube warming) and record your observations in a table.
3. Repeat steps 1 and 2 for each metal.
4. If one of the test tubes bubbles vigorously, collect some of the gas from the bubbles by holding an empty inverted larger test tube over the top of the reaction test tube. Test to see whether that gas is hydrogen by keeping the collection test tube inverted and holding a lighted match near the mouth of the test tube. If the gas is hydrogen, you will hear a popping sound.
   - What observations did you make about how the metals reacted with the acid?
   - Which metal was the most reactive with the acid?
   - Which metal was the least reactive with the acid?

QUESTIONS 3.2.1: REACTIONS INVOLVING ACIDS AND BASES

Remember

1. List the main properties of acids and bases. You could use a table or graphic organiser to help you.
2. Identify the pH that would indicate a strong base. What about a strong acid?
3. Identify the nature of a substance with a pH of 7.
4. Describe the colour of litmus paper in a solution of:
   a. an acid
   b. a base.
5. Identify the general terms to describe the two products of a neutralisation reaction between an acid and a base.
6. Identify the gas produced when an acid and a carbonate react.

Apply

7. Leo spilled some acid on his laboratory coat. What should he do? Explain your answer.
8. Write the word and chemical equations for two of the reactions you have investigated in this section.

Analyse

9. Count the number of each type of atom on both sides of the equations you wrote in question 8. Describe what you notice about the numbers of atoms. Are the equations balanced? What does this tell you about what is happening to atoms in these reactions?

REACTIONS INVOLVING OXYGEN

When you see something burn, you are witnessing a substance reacting with oxygen in a chemical reaction. The amount of energy released can be huge. It is in the form of heat energy and light energy, which we see as a flame, and sometimes sound energy. Chemists classify these as **combustion** reactions.

Not every substance reacts with oxygen in this way. For example, iron reacts with oxygen quite slowly at room temperature. There are no flames, just gradual corrosion of the metal. This type of reaction with oxygen is not classified as combustion.

Figure 3.19 Oxygen is a key reactant in all combustion reactions.

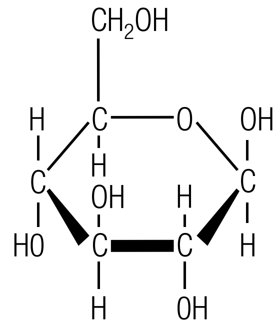


Figure 3.20 Glucose ($C_6H_{12}O_6$) reacts with oxygen in living systems.

Metals reacting with oxygen

When metal elements react with oxygen, a metal oxide is formed.

metal + oxygen → metal oxide

In the case of very reactive metals, this reaction is rapid and produces a lot of heat. For example, if magnesium metal is briefly exposed to a flame or is heated, it will start to react with the oxygen in the air, producing a brilliant white light. This reaction should never be watched directly because the light can damage your eyes.

The word equation for this reaction is:

magnesium + oxygen → magnesium oxide

The chemical equation is:

$$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$$

For moderately reactive metals like iron, the reaction still produces heat but it is slow.

Figure 3.21 Burning magnesium produces a dangerously intense white light.

Corrosion

Corrosion reactions are most commonly seen as metals reacting with the oxygen and moisture in their surroundings to produce metal oxides.

Corrosion costs the Australian economy billions of dollars each year. Metal roofs, cars, metal pipelines, metal bridges such as the Sydney Harbour Bridge and steel ships all corrode, at great expense. Maintenance is constant and expensive.

Corrosion is generally associated with a metal reacting with oxygen and water. The corrosion you will be most familiar with is the corrosion of iron or steel known specifically as rusting.

The word equation for this reaction is:

iron + water + oxygen → rust

The chemical equation is:

$$4Fe(s) + 6H_2O(l) + 3O_2(g) \rightarrow 4Fe(OH)_3(s)$$

The rate of corrosion is different for different metals. For example, zinc corrodes much more quickly than iron, whereas gold corrodes much more slowly. The rate of corrosion of a metal will also change depending on the conditions. Understanding corrosion means that we can come up with methods to prevent it or reduce the damage it can cause to structures.

Figure 3.22 All metals corrode, but only iron forms rust. The corrosion of this copper pipe produced copper oxide, which then reacted further with carbon dioxide to form green copper carbonate.

ACTIVITY 3.2.4: RUSTING AWAY

When iron 'rusts away', it is undergoing a corrosion reaction. But is it actually losing mass?

What you need: balance, pair of similar clean iron nails, pair of test tubes, test tube rack

1. Predict whether a nail will weigh more or less when it is not corroded. Write your prediction as a hypothesis.
2. Accurately weigh both nails and record their masses.
3. Add water to one test tube and place both test tubes in the test tube rack.
4. Add a nail to each test tube, noting the mass of each nail in each test tube.
5. Leave the nails for a week.
6. Take both nails out of their test tubes and leave them in a dry environment for 24 hours. Note any difference in appearance in the nails.
7. Reweigh both nails. Compare the masses of both nails with that of 8 days before.
   - Has the corroded nail decreased in mass, increased in mass or stayed the same?
   - Has the law of conservation of mass been compromised? Explain based on your observations.
   - Was your hypothesis supported or not supported? What evidence did you use to decide this?
   - Corrosion occurs in many metals. Outline why in some situations, such as the corrosion of a metal boat, the corroded metal seems to have disappeared.

STUDENT DESIGN TASK

Investigating corrosion prevention

Challenge

Your task is to investigate the conditions required for the corrosion of iron and to determine the best conditions to prevent corrosion. You may like to refer back to the results of Experiment 5.1.2 you did in *Oxford Insight Science 8* on page 214.

Questioning and predicting

- Choose one variable to focus your investigation on (e.g. oxygen availability, salt concentration, temperature, surface covering).
- Predict which condition will best prevent corrosion and write your prediction as an 'If … then …' statement.

Figure 3.23 Some possible conditions you may like to test.

Planning and conducting

- State the aim of your experiment. During your planning, refer to your aim continually to ensure your method is valid.
- Identify which variables will need to be kept constant and explain why this is the case.
- Describe a logical method for your experiment, making sure to specifically identify equipment needed.
- Identify how you will take your measurements and specify the units to be used.

- Assess any risks associated with your method and determine how to minimise them.
- Show you teacher your method before carrying it out.

Processing data and problem solving

- Collect, collate, summarise and present your data appropriately.
- Apply numerical procedures as appropriate (e.g. finding the average of data sets).
- Identify the data that supports or disproves your hypothesis.
- Describe ways to improve your method and your data.
- Describe relationships between variables.
- Determine the reliability and validity of your data.
- Based on your results, suggest a method of preventing corrosion of iron.

Communicating

Present your findings as scientific evidence to support your proposal for corrosion prevention.

Non-metals reacting with oxygen

Some non-metal elements react with oxygen, which is also a non-metal. The result is generally a molecular compound. Consider the following reactions.

hydrogen + oxygen → water

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$$

carbon + oxygen → carbon dioxide

$$C(s) + O_2(g) \rightarrow CO_2(g)$$

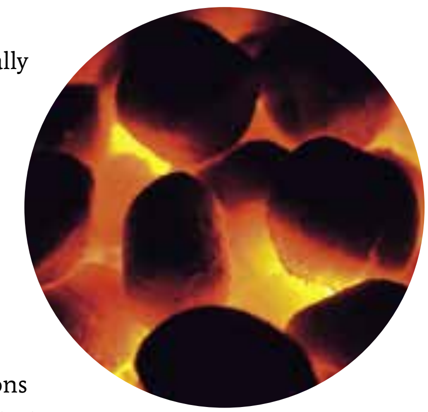


Figure 3.24 Burning charcoal heat beads produces carbon dioxide.

Both of these reactions give out a lot of heat energy. The first reaction can cause explosions and the second is what happens when coal burns. The products of these reactions are described as non-metal oxides.

Carbon dioxide, like the oxides of most non-metals, is an acidic substance. When non-metal oxides dissolve in water, they form acidic solutions, so they are called **acidic oxides**. Other acidic oxides are sulfur dioxide (SO_2) and nitrogen dioxide (NO_2).

DEEPER UNDERSTANDING

Acid rain

One problem caused by carbon dioxide and certain other gases in the atmosphere is acid rain (see *Oxford Insight Science 8*, page 233).

As rainwater condenses from water vapour in the air and falls to the ground, it can dissolve carbon dioxide from the atmosphere. A product of this reaction is a weak acid called carbonic acid (H_2CO_3). As a result, fresh rainwater usually has a pH of 5–6.

Cars, other vehicles, factories and power plants all give off pollutants that enter the atmosphere. These pollutants include sulfur dioxide (SO_2) and nitrogen dioxide (NO_2), which may also dissolve to produce the much stronger acids, such as sulfuric acid (H_2SO_4) and nitric acid (HNO_3). The result is known as acid rain, which can have a pH as low as 3.

Acid rain is corrosive to building materials, marble and limestone, and much corrosion has been found on buildings and statues due to acid rain. It kills wildlife in lakes and rivers, and has destroyed vast areas of forest throughout the world.

One way to prevent acid rain is to treat waste gases so that acid-causing pollutants are reduced in the atmosphere. Another way is to reduce the use of fuels containing carbon and sulfur.

Figure 3.25 This stone lion has been heavily corroded by acid rain.

Combustion of fuels

Figure 3.26 The reaction of hydrogen with oxygen caused the *Hindenburg* airship to explode and burn.

When hydrogen gas burns in oxygen, large amounts of heat energy are produced. If this reaction happens in uncontrolled conditions, then it is very dangerous. It caused the destruction of the *Hindenburg* airship in 1937 when a spark set a huge amount of hydrogen gas ablaze. Thirty-five of the passengers died. Under controlled conditions, hydrogen can be used safely as a fuel.

In science, a **fuel** is a substance that will undergo a chemical reaction in which a large amount of useful energy is produced at a fast but controllable rate. Fuels are the substances we use to produce heat and/or electricity, and to run engines and motors.

Many fuels consist of compounds of carbon and hydrogen, which are known as **hydrocarbons**. When hydrocarbons burn in unlimited air, carbon dioxide and water are produced. When the air supply is more limited, which occurs when the combustion happens in a confined space, carbon monoxide can be produced.

hydrocarbon + excess oxygen → carbon dioxide + water

hydrocarbon + limited oxygen → carbon monoxide + water

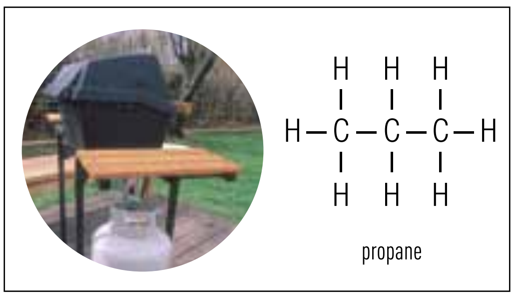


Figure 3.27 Household barbecues use LPG, which is mainly propane (C_3H_8).

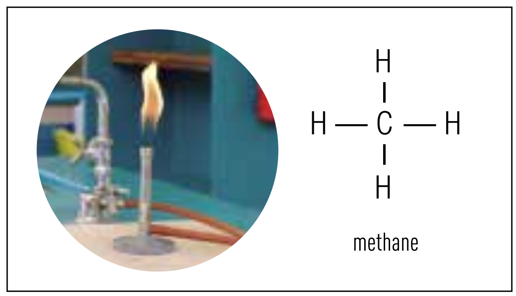


Figure 3.28 Bunsen burners use natural gas, which is mainly methane (CH_4).

The combustion of fuels is the most important chemical reaction to produce energy for industry and transport in modern societies. You will cover more about combustion in chapter 4.

Figure 3.29 Oil and gas are hydrocarbon fuels that can be found under the sea floor, and are extracted at offshore rigs.

QUESTIONS 3.2.2: REACTIONS INVOLVING OXYGEN

Remember

1 Identify the gas essential for combustion reactions.

2 Identify the two elements always present in hydrocarbons.

3 Identify the other two reactants (i.e. besides a metal) that are vital for corrosion reactions.

Apply

4 Carbon dioxide (CO_2) and sulfur dioxide (SO_2) are both acidic oxides produced during combustion of carbon- or sulfur-containing compounds. Explain what you think the 'di' in their names relates to.

5 When carbon dioxide reacts with water, the product is carbonic acid (H_2CO_3), which is a weak acid.

- **a** Write a word equation for this reaction.
- **b** Write the chemical equation for the reaction.
- **c** Estimate the pH of a solution of carbonic acid.
- **d** Carbonic acid reacts with metals to produce carbonates. Identify the carbonate that would be produced when zinc from galvanised iron reacts with carbonic acid in rain.

Analyse

6 When sulfur dioxide reacts with water vapour, it produces an acidic solution. Would you expect this to accelerate metal corrosion? Explain your answer.

7 There are numerous errors in the equations below, including incorrect balancing and incorrect products. Rewrite the equations correctly.

- **a** $C_4H_8 + 6O_2 \rightarrow 4CO_2 + 3H_2O$
- **b** $C_5H_{12} + 5O_2 \rightarrow 5CO_2 + 6H_2$

8 Ethene gas, C_2H_4, is the gas from which polyethene (a type of plastic sometimes called polyethylene) is produced. The trouble is that it is highly flammable. Set out the steps for writing a balanced equation for the combustion of ethene in excess air.

9 People sometimes describe corrosion as 'rusting away to nothing'. From a scientific perspective, discuss the correctness of this statement.

10 The fuels used in cars, trucks and buses are generally liquefied petroleum gas (LPG), petrol or diesel. These fuels are mainly hydrocarbons.

- **a** Predict the main two substances present in vehicle exhaust gases.
- **b** Explain why scientists are warning that excessive use of these vehicles is contributing to the enhanced greenhouse effect.

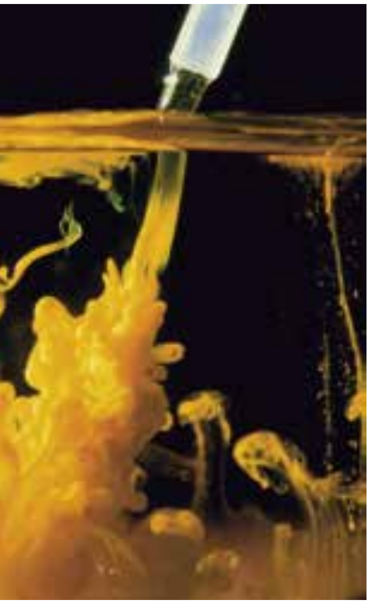


Figure 3.30 A solution of lead nitrate mixed with a solution of potassium iodide produces a yellow precipitate of lead iodide.

DISPLACEMENT AND DECOMPOSITION REACTIONS

Some reactions are classified, not according to their specific reactants, but according to how the reactants interact.

Displacement and precipitation reactions

When salts dissolve in water, the ionic bonds between the metal and non-metal parts of the salt are broken down and the positively charged ion (cation) and negatively charged ion (anion) are released. Sometimes, when separate solutions of two soluble salts are mixed, ion pairings are swapped and one or more insoluble salts are produced. This swapping of ions in the compounds is called **displacement** and can be generalised as:

$$AB + CD \rightarrow AD + CB$$

Sometimes one of the new salts formed is insoluble. Insoluble salts that are heavier than their solution 'fall out' of solution; fine particles appear and settle at the bottom of the solution. This is called **precipitation**, the solid particles that form are called the **precipitate** and the reaction that made the insoluble salt is a precipitation reaction.

Lead salts are toxic. If a water supply contains lead, this is a big problem. A simple test for lead in the water supply is a precipitation reaction test (see Figure 3.30).

EXPERIMENT 3.2.4: PRECIPITATION AND CONSERVATION OF MASS

Aim

To observe a precipitation reaction and determine whether it is described by the law of conservation of mass.

Hypothesis

Read the aim and method, and write a hypothesis for this experiment as an 'If … then …' statement.

Materials

- Balance
- 2 small beakers (150 mL)
- Sodium iodide solution
- Lead nitrate solution
- Thermometer

WARNING

> The chemicals involved in the experiment are dangerous so wear gloves and safety glasses at all times. Clean up any spills immediately and notify your teacher.

Method

1 Add sodium iodide to one beaker and add lead nitrate solution to the other beaker, both to a depth of around 2 cm.

2 Measure the temperature of each solution and record it.

3 Accurately weigh each beaker with solution and record its mass.

4 Add the contents of the sodium iodide solution to the lead nitrate solution, taking care not to spill any liquid. If a spill occurs, clean it up with paper towel and dispose of the paper towel immediately.

5 Note any change that occurs in the mixed solution.

6 Measure and record the temperature of the combined solutions.
7 Reweigh the empty beaker accurately.
8 Add the mass of both beakers and solutions before reaction, and then compare the total mass to that of both beakers and the solutions after reaction.

Results

Record your observations in an appropriate format.

Discussion

1 What observations did you make that suggested a chemical reaction had taken place?
2 Was the temperature of the solutions before reaction the same as the temperature of the reactions immediately after reaction? Was it higher or lower? If the temperature of the solution increased, then energy was released by the reaction. If the temperature fell, then energy was absorbed during the reaction. This energy change is the result of breaking or forming new bonds between particles.

Conclusion

Was your hypothesis supported or not supported? Was the law of conservation supported by this reaction? Was energy produced or absorbed?

Decomposition reactions

In **decomposition**, the atoms of a compound are separated to form two or more products. The reaction can be generalised as:

$$AB \rightarrow A + B$$

Decomposition reactions are important in the industrial smelting of metal sulfide ores and metal oxide ores. For example, copper sulfide, when roasted at high temperatures, will produce copper metal and release sulfur dioxide gas as the sulfur reacts with oxygen from the atmosphere.

When water undergoes electrolysis (the breaking of chemical bonds using an electric current), it produces hydrogen gas and oxygen gas. Similarly, when aluminium oxide undergoes electrolysis, it produces aluminium metal and oxygen.

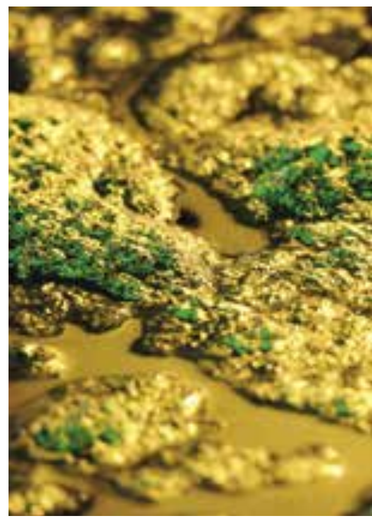


Figure 3.31 Copper sulfide decomposes when it is heated strongly.

EXPERIMENT 3.2.5: DECOMPOSITION AND CONSERVATION OF MASS

Aim

To observe a decomposition reaction and determine whether the law of conservation of mass has been obeyed in the reaction.

Hypothesis

Write a hypothesis about what you think will happen as an 'If ... then ...' statement.

WARNING

> This experiment involves strong heating. Read through the method carefully, considering any foreseeable risks. Take steps for their prevention.

Materials

- Balance
- Large test tube
- Test tube holder
- Copper carbonate
- Limewater
- Bunsen burner
- Balloon
- Gas jar

Method

1 Weigh a test tube and record its mass. Add about 2 g of copper carbonate to the test tube and record its mass. Calculate the mass of copper carbonate by finding the difference in the masses.

2 Collapse a balloon and fit it over the neck of the test tube.
3 Accurately weigh the test tube, balloon and copper carbonate. This is the system mass before decomposition.
4 Heat the copper carbonate in the test tube. Take care not to heat the opening of the test tube so that the balloon bursts, melts or catches on fire. Note any changes in colour of the copper carbonate you observe. If it turns black, you have produced copper oxide. Note what happens to the balloon.
5 Accurately weigh the test tube with the products and the balloon, then record their masses. This is the system mass after the decomposition reaction.
6 Compare the system mass before decomposition and after decomposition.
7 Pour limewater into a gas jar to a depth of about 2 cm.
8 Pinch the balloon and remove it from the test tube, then pour the gas inside into your gas jar and limewater. Immediately put the gas jar lid on and gently swirl the limewater in the jar, noting what happens. If the limewater turns milky, it suggests that carbon dioxide gas was produced in the reaction.

Results

Record your observations in an appropriate format.

Discussion

1 Identify the reactant in this experiment.
2 Identify the products of this decomposition reaction.
3 Write a word equation for the decomposition reaction you observed.
4 Was mass conserved in this experiment? How can you tell?

Conclusion

- Was your hypothesis supported or not supported by your observations? Justify your answer based on the results of this experiment.
- Identify whether the law of conservation of mass was obeyed.
- Outline how this experiment might be improved.

QUESTIONS 3.2.3: DISPLACEMENT AND DECOMPOSITION REACTIONS

Remember

1 Identify the most important property that determines whether or not a precipitate will form from the mixing of two soluble solutions.
2 Describe the characteristic features of a displacement reaction.
3 Describe the characteristic features of a decomposition reaction.

Apply

4 Some ores of zinc are carbonates. Outline one way to extract the zinc from these ores.

CLASSIFYING CHEMICAL REACTIONS

3.2
CHECKPOINT

Remember and understand

1 Identify whether the following statements are true or false. Rewrite the false statements to make them true. [4 marks]

- **a** Reactants are made in chemical reactions.
- **b** Oxygen is a fuel.
- **c** Hydrocarbons require oxygen to burn.
- **d** Sulfur dioxide will dissolve in water to form an alkali.

2 Identify the products when methane burns in an excess supply of oxygen. [2 marks]

3 Write down the chemical formula of:

- **a** carbon dioxide [1 mark]
- **b** carbon monoxide [1 mark]
- **c** sulfur trioxide. [1 mark]

4 Identify whether the chemicals in question 3 are acidic or basic substances. Explain how you know. [4 marks]

Apply

5 Consider the following equation:

potassium hydroxide + sulfuric acid → potassium sulfate + water

- **a** Identify the reactants and the products in this reaction. [2 marks]
- **b** Identify the type of reaction. [1 mark]
- **c** Identify what you could add to the reaction mixture to show whether all of the acid has been used up in the reaction. [1 mark]

6 'You should never drink orange juice because it contains acid.' Evaluate the accuracy of this statement. [2 marks]

7 Consider the following chemical reactions.

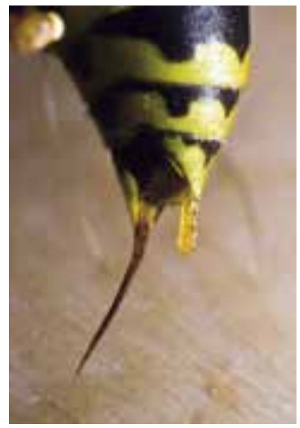
- **a** Carbon in brown coal reacts with oxygen in the air to form carbon dioxide.
- **b** Carbon dioxide dissolves in water (containing universal indicator) to form a solution of carbonic acid (H_2CO_3).

For each reaction:

- **i** describe the expected observation of the reaction [3 marks]
- **ii** write the word equation [2 marks]
- **iii** write a balanced chemical equation. [2 marks]

Critical and creative thinking

8 Some insect stings are acidic and some alkaline; however, it might not always be possible to know what insect caused the bite. Imagine you are asked to design a treatment that would reduce the pain of all insect stings. Identify the chemicals it would need to contain. Suggest a short descriptive name for your product that identifies how the product works. Present your ideas in the form of an information pamphlet or an advertisement for your 'anti-sting' treatment. [4 marks]



Research

9 Research ways that are used to restore or prevent the corrosion of objects. [5 marks]

10 Investigate the activity series of metals. What is it? What does the order of the metals mean? Which metals are high on the list? Which are low? Compare this list to the galvanic series of metals. [5 marks]

TOTAL MARKS
[/40]

3.3 CHEMICAL REACTIONS IN LIFE

Chemical reactions are happening all around us, all the time. They affect living and non-living systems, and involve acids and bases, metals and gases – all sorts of substances. Some chemical reactions improve our lives, keeping our bodies healthy, homes clean and food tasting good, while others can harm us. Understanding these chemical reactions allows us to control some of them, start others, or use them to our advantage.

USING ACIDS AND BASES

A lot of chemical reactions that take place naturally and spontaneously involve acids and bases. Acids and bases are important in our everyday lives; they are found within our bodies, in foodstuffs, in cleaning products and in a range of industrial applications.

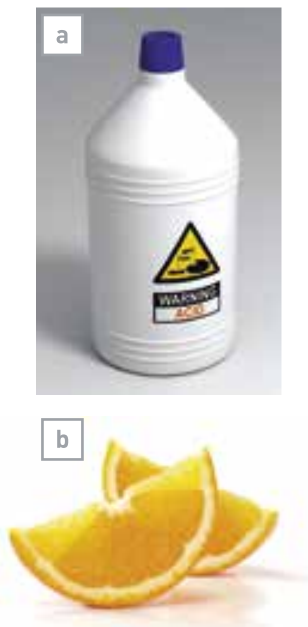


Figure 3.32 (a) Strong acids are dangerous and corrosive (b) Weak acids are often found in the foods we eat.

Acids

You have seen that acids are a group of chemicals with similar properties. Strong acids are dangerous because they are corrosive and can cause severe burns, even when they have been diluted. Weak acids are much less reactive and many are in the foods we eat, and in drinks, such as lemonade. Even so, many of them are corrosive and can cause bad burns when in concentrated form.

We use acids for many purposes. For example, sulfuric acid is used extensively in industry and to make other acids. It is used in car batteries and to clean oxide layers off metals before they are plated with other metals. Nitric acid is used to manufacture fertilisers, plastics, dyes and explosives. Hydrochloric acid is used to clean metals, bricks and tiles.

Phosphoric acid (H_3PO_4) is an ingredient of some cola drinks, but its main industrial use is in the production of fertilisers. It is also used as a rust remover or rust converter. Only a very small amount of phosphoric acid is added to cola drinks, so the concentration of the acid in these drinks is very low. Small amounts of phosphoric acid are enough to give the drinks a distinctive tangy taste. The acid also acts as a preservative by preventing the growth of microorganisms.

Bases

Bases have many uses. They react with fats and oils to produce soaps. Some bases, such as ammonia solution, are used in cleaning agents. One that is very effective is household cloudy ammonia. Sodium hydroxide is used in the manufacture of soap and paper. It is also used in drain cleaner and oven cleaner. Calcium hydroxide is used to make plaster and mortar.

Figure 3.33 Many cleaning products are alkaline solutions (bases).

Figure 3.34 Sodium hydroxide, a base, is used to make soap.

Table 3.5 Examples of common acids and bases.

Strong acids		Strong bases	
Hydrochloric acid	HCl	Sodium hydroxide	$NaOH$
Nitric acid	HNO_3	Potassium hydroxide	KOH
Sulfuric acid	H_2SO_4	Barium hydroxide	$Ba(OH)_2$
Weak acids		**Weak bases**	
Ethanoic acid	CH_3COOH	Ammonia	NH_3
Carbonic acid	H_2CO_3	Sodium carbonate	Na_2CO_3
Phosphoric acid	H_3PO_4	Calcium carbonate	$CaCO_3$

Acids and bases in digestion

Have you ever had heartburn? Has somebody in your family complained of having indigestion? One of the causes of that burning feeling is gastric reflux, a failure of the ring muscle at the top of the stomach to keep gastric acids where they belong, in the stomach.

Gastric acid is mostly hydrochloric acid (HCl), potassium chloride (KCl) and sodium chloride (NaCl). It has a pH of 1.4–3.5. The hydrochloric acid has several important jobs, including reducing the number of bacteria in the food, and dissolving leftover nutrients.

The main role of the stomach is to digest proteins. In the acidic environment produced by gastric acid, a substance called pepsin digests most proteins. After spending some time in the stomach, food is mixed by muscle contractions and the gastric juices, turning it into chyme. Muscle contractions lower in the stomach push chyme into the small intestine where the hydrochloric acid is neutralised. The next stage of digestion, the breakdown of fats, happens in a basic environment.

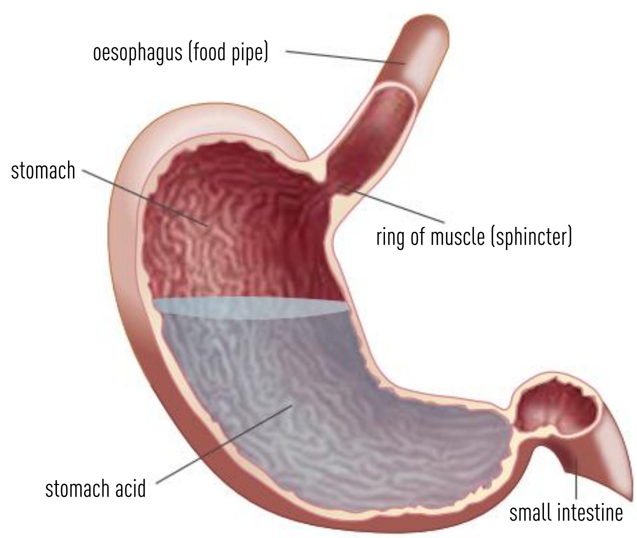


Figure 3.35 The ring of muscle at the top of the stomach works to keep gastric acid in the stomach. A burning feeling in the chest can result when the muscle doesn't work as it should.

ACTIVITY 3.3.1: INVESTIGATING ACIDS

1. Choose one strong acid and one weak acid from Table 3.5.
2. Find out about some of the key uses of the two acids and describe examples of their use, if possible using situations that affect your own life.
3. Explain how the strength of the acids influences what they are used for, and how they need to be handled by the people using them.
4. Find out the difference between the strength of an acid or a base and its concentration. Draw a diagram to explain your findings.
5. Present your information as an informative pamphlet, a comparative graphic organiser or some other appropriate format.

DEEPER UNDERSTANDING

Acidic oceans

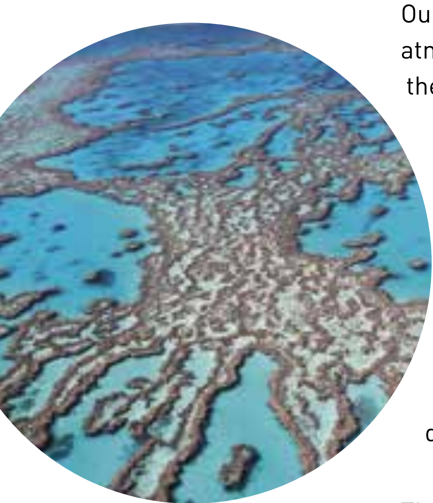


Figure 3.36 Coral reefs are made of the weak base calcium carbonate, which dissolves in acid.

Rising carbon dioxide levels in the atmosphere have caused the oceans to become acidic. Our oceans are a major carbon 'sink' and absorb much of the carbon dioxide (CO_2) in the atmosphere. When carbon dioxide dissolves in water, it forms carbonic acid (H_2CO_3). Before the Industrial Revolution, the oceans were in equilibrium with the atmosphere, absorbing as much carbon dioxide as they released.

Since the beginning of the Industrial Revolution, carbon dioxide levels have increased in our atmosphere due to large-scale burning of fossil fuels and industrial processes in which carbon dioxide is produced (e.g. the production of steel, aluminium and cement).

The oceans have responded by absorbing more carbon dioxide, thus increasing their acidity. Scientists estimate that the oceans now absorb 30 million tonnes of carbon dioxide every day.

As the oceans become increasingly acidic, the effect on marine ecosystems is devastating.

Coral reef ecosystems rival rainforests in terms of the huge diversity of species present. They also help protect coastlines from erosion. But coral reefs across the world are now under threat. One problem is that the coral itself is built up from calcium carbonate ($CaCO_3$), which is a weak base. This reacts with the weakly acidic seawater, causing the calcium carbonate to slowly dissolve and crumble.

The ability of molluscs, such as sea snails, to produce adequate protective shells, which are also made from calcium carbonate, is also greatly affected. The lower pH of the water affects many species of marine organisms that reproduce by ejecting their sperm and eggs into the water. If the number of successfully fertilised eggs decreases and some of these species die out, this will affect the entire food chain and hence the diversity of species that can survive.

QUESTIONS 3.3.1: USING ACIDS AND BASES

Remember

1 Describe the difference between an acid and a base.

2 Identify which acid and/or base you would be likely to find in:

- **a** cleaning products
- **b** alcoholic drinks
- **c** insect stings.

3 Identify the major cause of the increase in acidity of the oceans.

4 Describe how pH changes as the acidity of the oceans increases.

Apply

5 Outline why acids used in foods are always weak acids.

6 Part of the human digestive system in the mouth treats food with saliva, which is basic. The stomach then produces acids, including the strong acid hydrochloric acid, to mix with the food. The small intestine adds basic chemicals to the chyme it receives from the stomach. At both ends of the stomach, a biological valve called a sphincter stops excessive amounts of liquids travelling back along the digestive tract. Outline how these changes in the type of chemicals are important for health and well-being.

7 Plants growing in soils that are too acidic have difficulty in taking up nutrients. Adding a small amount of lime to the soil is one suggested solution. Describe the nature of lime and identify why it works.

CELLULAR REACTIONS

Two chemical reactions essential to life are **respiration** and **photosynthesis**. The interdependence of these reactions maintains a balance of carbon dioxide and oxygen in ecosystems.

Chemistry of respiration

During respiration, energy stored in the chemical bonds of fuel molecules is changed to a usable form of energy. The fuel is usually a carbohydrate such as glucose ($C_6H_{12}O_6$); however, fats and proteins can also be used. The fuel molecule is converted in a series of steps into a chemical called adenosine triphosphate (ATP), which is essential for cell function. This molecule is the biological energy-storage molecule. ATP then undergoes other reactions that release energy as required.

When enough oxygen is present, **aerobic** respiration occurs in plant and animal cells. The word and chemical equations are:

glucose + oxygen → carbon dioxide + water + energy (stored in an ATP molecule)

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

When you exercise strenuously, your muscle cells don't have enough oxygen for aerobic respiration. The cells quickly produce energy anaerobically (without oxygen) and make lactic acid ($C_3H_6O_3$) as a waste product. The build-up of lactic acid is thought to make your muscles feel sore and causes you to breathe very heavily. The word and chemical equations for the overall reaction are:

glucose → lactic acid + energy

$$C_6H_{12}O_6 \rightarrow 2C_3H_6O_3 + \text{energy}$$

Some organisms are capable of **anaerobic** respiration. This is known as fermentation and produces alcohol. The word and chemical equations are:

glucose → ethanol + carbon dioxide + energy

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 + \text{energy}$$

Some organisms, such as certain types of bacteria, survive on anaerobic respiration alone.

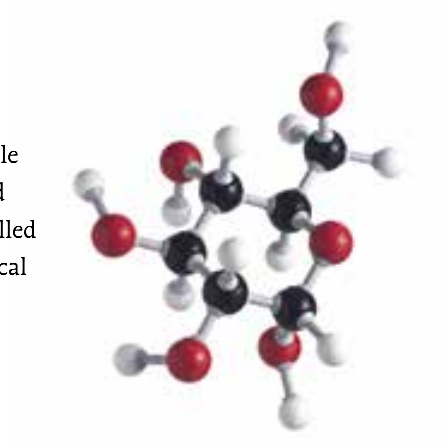


Figure 3.37 Glucose is the most common source of energy in aerobic respiration.

Figure 3.38 The fermentation of yeast is what causes bread to rise and produces the alcohol in beer.

ACTIVITY 3.3.2: TESTING FOR CARBON DIOXIDE

Limewater is a saturated solution of calcium hydroxide ($Ca(OH)_2$).

What you need: limewater, large test tube, straw

1. Pour approximately 10 mL of limewater into the large test tube.
2. Gently blow into the limewater through the straw, making sure that you do not suck the limewater through the straw. Observe the changes in the appearance of the limewater.
   - Write word and chemical equations for the reaction of limewater with carbon dioxide.
   - Explain the change to the limewater, in terms of producing a new substance.

Figure 3.39 Limewater can be used to test for the presence of carbon dioxide.

EXPERIMENT 3.3.1: THE PRODUCTS OF CELLULAR RESPIRATION

Aim

To determine what is produced in cellular respiration.

Hypothesis

Construct a hypothesis to describe what you think will be produced during respiration in this experiment. Remember to write your hypothesis as an 'If ... then ...' statement.

Materials

- 3 test tubes
- Test tube rack
- Yeast
- Sugar
- Stirring rod
- Incubator (set at 37°C)
- Single-hole rubber stopper with glass connection to flexible tubing about 20 cm long
- Distilled water and bromothymol blue indicator
- Spatula
- Measuring cylinder

Method

1. To a test tube add half a large spatula each of yeast and sugar, and 20 mL of warm (not hot) distilled water. Stir gently.
2. To the second test tube add 20 mL of distilled water and a few drops of bromothymol blue indicator.
3. Set up the apparatus by connecting the rubber stopper and tubing to the yeast mix (ensure no leaks). Ensure that the outlet hose is under the level of distilled water and bromothymol blue indicator.
4. Set up a third test tube of distilled water and bromothymol blue indicator that is not connected to the yeast.
5. Leave the apparatus set up in a warm place overnight. An incubator set at 37°C can be used. If an incubator is used, put test tube racks in a tray because the yeast may leak out of the test tube.

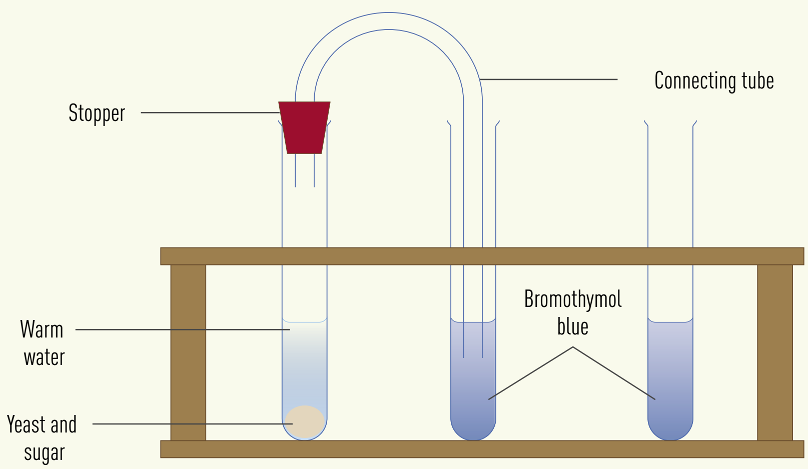


Figure 3.40 Experimental set-up.

Results

Record your observations. Distilled water and bromothymol blue indicator is blue and is slightly alkaline (base). Carbon dioxide gas is slightly acidic. Bromothymol blue indicator will change to either green or yellow in the presence of an acid.

Discussion

Compare and contrast your observations of the test tube of bromothymol blue indicator and distilled water connected to the yeast, and the unconnected bromothymol blue indicator and distilled water. Draw on your understanding of the reactants and products of respiration and limewater. Cover the following in your discussion.

- Identify the purpose of the third test tube that was not connected to the yeast.
- Describe what happened to the test tube containing bromothymol blue indicator and distilled water that was connected to the yeast.
- Identify why bromothymol blue indicator was used.
- Describe the evidence of water being produced.
- Identify the process that was happening in the yeast cells. Write an equation for this process.
- Identify how this experiment could be modified to test respiration in plants.

Conclusion

Was your hypothesis supported or not supported? Justify your answer using the evidence of your data.

Chemistry of photosynthesis

Living things need energy to grow, to move around and to reproduce. Plants, some algae and some bacteria are able to produce this energy by photosynthesis. In this process, glucose, a chemical with a high level of stored energy, is made from water and carbon dioxide. Oxygen is also produced as a by-product.

Photosynthesis occurs within plant cells in organelles called chloroplasts. Chloroplasts are mainly found in the leaf cells of plants, and in some algae and some bacteria. One plant leaf, on average, has tens of thousands of cells, and a single cell may contain about 40–50 chloroplasts.

The overall word and chemical equations for photosynthesis are:

carbon dioxide + water → glucose + oxygen

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

Energy from sunlight is transformed into chemical energy, stored in the chemical bonds of the glucose product. ATP, the energy-storage molecule in biological organisms, is also involved in the process.

Figure 3.41 Sunlight is essential to photosynthesis.

QUESTIONS 3.3.2: CELLULAR REACTIONS

Remember

1. Where does photosynthesis occur in plants?
2. Outline why plants require energy from the Sun in the form of light for photosynthesis to occur.
3. Identify the source of energy for cellular respiration.
4. Write the general word equation for cellular respiration.

Apply

5. Explain why cellular respiration constantly happens in cells.
6. Identify the raw materials needed for photosynthesis. How do they enter the plant?
7. Draw a flowchart showing the inputs and outputs of respiration.

3.3 CHECKPOINT

CHEMICAL REACTIONS IN LIFE

Remember and understand

1 Identify the products when methane burns in an excess supply of oxygen. [2 marks]

2 Identify and give the formulas of two gases that contribute to the formation of acid rain. [2 marks]

3 Outline how the cells of animals get their energy. Consider an oxygen-rich and an oxygen-poor environment. [4 marks]

Apply

4 Carbon dioxide (CO_2) is produced when hydrocarbons burn in oxygen. Outline why carbon monoxide (CO) can be produced when the supply of oxygen to the fuel is reduced. [2 marks]

5 Advertisements claim that antacids, which are weak bases, act fast to relieve heartburn and acid reflux. Describe how antacids work. [3 marks]

6 In the photosynthesis reaction that occurs in plants, glucose ($C_6H_{12}O_6$) and oxygen (O_2) are produced from carbon dioxide (CO_2) and water (H_2O).

a Write a chemical equation for this reaction. [1 mark]

b Identify how many molecules are required to produce each molecule of glucose. [1 mark]

c Outline why this reaction is important to most life on the Earth. [2 marks]

Analyse and evaluate

7 Conduct a PNI ('positive', 'negative', 'interesting') analysis on the effect of acids on our lives. [5 marks]

8 If the carbon dioxide levels in our atmosphere stopped increasing and became stable, predict whether acidity levels in the oceans would change back to the levels they were at before the Industrial Revolution. Explain your answer. [4 marks]

Critical and creative thinking

9 Use a table to describe the similarities and differences between respiration and photosynthesis. [4 marks]

Making connections

10 Imagine all the chemical interactions and changes that occur during the baking of a loaf of bread in an oven fuelled by LPG gas. Describe, in fewer than 100 words, the chemical changes that will occur in this process. Include the processes that produce the heat for the oven and the chemical processes within the food itself. You may need to carry out some additional research. [5 marks]

TOTAL MARKS
[/35]

3 CHAPTER REVIEW

1 Fill in the gaps, using the words in the Word Bank below:

Chemical reactions rearrange the atoms in the ________________ to form new substances called ________________. The law of ________________ of mass states that the total mass of the reactants must equal the total mass of the products because no atoms are ________________ or created during the reaction.

Chemical ________________ outline the arrangement of atoms in each reactant and product, while word and chemical ________________ outline the interaction between the reactants and the production of new substances.

Chemical ________________ can be classified into distinct types depending on key reactants or key products. For example, ________________ reactions involve a ________________, oxygen and water; whereas a reaction between an acid and a ________________ salt will always produce carbon dioxide and water.

While many chemical reactions happen ________________ in nature, we can use controlled chemical reactions to produce useful substances like ________________ and other resources.

WORD BANK

carbonate	equations	products
conservation	formulas	reactants
corrosion	fuels	reactions
destroyed	metal	spontaneously

Recall that matter is composed of atoms which have mass

2 Outline the nature of matter. [3 marks]

3 Corrosion of iron increases the mass of the substance. Explain how this is possible. [3 marks]

Identify the names and chemical formulas of some common compounds

4 Write the chemical formulas and name the following ionic compounds.

a Potassium bonds with iodine. [2 marks]

b Calcium bonds with nitrogen. [2 marks]

5 Identify the chemical formulas for the following molecular compounds.

a Trioxide [2 marks]

b Nitrogen trihiydride [2 marks]

Construct word equations to describe chemical reactions

6 Recall the word equations for respiration and photosynthesis. [2 marks]

7 Use a word equation to describe the production of water and carbon dioxide from the interaction between methane and oxygen. [1 mark]

Deduce that atoms of reactant substances are rearranged during chemical reactions to produce new substances

8 A neighbour says that she is going to get rid of a large pile of combustible rubbish by burning it. Describe whether the rubbish has really disappeared after burning. Explain any scientific principle that supports your answer. [2 marks]

9 Describe how you know that a chemical reaction has occurred. [1 mark]

Classify compounds based on common chemical properties

10 Identify two key differences between ionic and molecular compounds. [2 marks]

11 Compare the nature and properties of acids and bases. [2 marks]

3 CHAPTER REVIEW

12 A student, when asked about antacids to stop indigestion and acid reflux, suggested that the best way to improve the action and reaction time of the antacids is to use a concentrated base. Explain why this would not be a practical solution. [2 marks]

Identify the importance of the chemical reactions involved in photosynthesis, respiration and digestion

13 A man with indigestion takes two indigestion tablets. He then belches a large burp. Describe why this probably happened and what the nature of the gas probably was. [2 marks]

14 Explain why digestion is mostly about chemical reactions that produce small molecules such as glucose, to provide cells with energy through respiration. [2 marks]

15 Plants take up carbon dioxide and release oxygen through photosynthesis. Animals and plants consume oxygen and produce carbon dioxide through respiration. Carbon dioxide is much lower in concentration at less than 0.04% of the atmosphere than oxygen at 21%. Predict what would happen to these concentrations if the amount of photosynthesis occurring was significantly reduced. [2 marks]

Investigate the characteristics of the main types of chemical reactions including combustion, reactions between acids and metals and carbonates, corrosion, precipitation, neutralisation and decomposition

16 Neutralisation reactions always produce water. Explain why. [2 marks]

17 Identify a key feature that would enable you to classify a reaction as being a:

a combustion reaction [1 mark]

b precipitation reaction [1 mark]

c decomposition reaction [1 mark]

d acid and metal reaction. [1 mark]

Balance chemical equations (additional content)

18 Balance the following chemical reactions:

a ___ Zn + ___ $HCl \rightarrow$ ___ $ZnCl_2$ + ___ H_2 [2 marks]

b ___ $C_{10}H_8$ + ___ $O_2 \rightarrow$ ___ CO_2 + ___ H_2O [2 marks]

TOTAL MARKS [/42]

RESEARCH

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

Phosphoric acid

Phosphoric acid has a wide variety of uses – as a fertiliser, rust remover and food additive. It is even an ingredient of cola drinks. Describe how it is produced and identify more about its uses.

pH of blood

Identify the name given to the conditions under which the pH of blood becomes too low or too high, and the effects on people who have these conditions.

Explosives

The history of the development of explosives is fascinating. Identify who discovered them. When were explosives first used? How do they work? Describe the main chemicals used and their types. Outline the part Alfred Nobel played.

REFLECT

Me

1 What new science laboratory skills have you learned in this chapter?

2 What was the most surprising thing that you found out about chemical reactions?

3 What were the most difficult aspects of this topic, and why?

My world

4 Why is it important to know about chemical reactions?

5 What changes have the products of chemical reactions made to how we live?

6 What are the risks of using some chemicals?

My future

7 How are chemists trying to minimise the negative effect of some chemicals on the natural environment?

8 What more can be done to ensure the sustainable use of certain chemicals?

KEY WORDS

acid
acidic oxide
aerobic
alkali
alkaline
anaerobic
base
chemical equation
chemical formula
combustion
corrosion
decomposition
displacement
fuel
hydrocarbon
indicator
law of conservation of mass
litmus paper
neutral
neutralisation
pH scale
precipitate
precipitation
photosynthesis
respiration
salt
universal indicator
word equation

3

MAKING CONNECTIONS

Iron and steel

Steel, which is an alloy of iron, is produced in vast quantities from iron ore. Australia is the second biggest producer of iron ore in the world. Steelworks such as the Port Kembla steelworks in New South Wales generate huge amounts of steel from this ore, although Australia exports most of its supplies of iron ore. The origin of iron dates back to the beginning of the Earth.

When it was a molten ball hurtling through space, the early Earth contained vast amounts of molten iron, as well as oxygen. The atoms of these elements rearranged in spontaneous reactions and produced oxides of iron such as ferric oxide (or iron(III) oxide, Fe_2O_3). The reaction to form iron(III) oxide is:

iron + oxygen → iron oxide

$4Fe(l) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$

As the crust cooled, the minerals such as iron oxide were embedded in rocks in various crystalline arrangements. Iron oxide is not soluble and, in some areas, including vast regions of Australia, these minerals became concentrated in the rocks.

The first metals used by humans that were not simply dug out of the ground, included alloys of copper and iron. No doubt their discovery was accidental. As people sat around their fires at night, in some places they noticed molten metal trickling out of the rocks. Some thought the rocks were 'bleeding'. The metal was extracted from certain minerals present in the rocks by exposing them to high temperatures and hot charcoal. Before long, when people realised the metals were very useful materials, they started to build furnaces to obtain more metal.

When European settlers in Australia brought their knowledge of how to extract iron from rocks, and when iron-rich rocks with their red–brown colour were discovered, our iron and steel industry was born.

The extraction of iron from its oxide involves separating the iron and oxygen atoms from one another, reversing the reactions that formed the iron oxides in the first place.

Generally, iron is extracted from its oxides in a huge furnace known as a blast furnace. Given that we are trying to remove oxygen from iron, not oxidise it, why do we need all this hot air?

Consider four chemical reactions that occur in the blast furnace. One of the raw materials added to the blast furnace, along with crushed iron oxide (Fe_2O_3), is coke, which is mostly carbon (C). The coke undergoes a combustion reaction with the hot air.

Reaction 1

carbon + oxygen → carbon dioxide

$C(s) + O_2(g) \rightarrow CO_2(g)$

This is a highly exothermic (produces lots of heat) reaction. It produces enough heat to help break down the iron ore.

Another raw material added to the furnace is limestone, which is mostly calcium carbonate ($CaCO_3$). As it gets very hot, it breaks down.

Reaction 2

calcium carbonate → calcium oxide + carbon dioxide

$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

This is a decomposition reaction. The calcium oxide produced in this process helps to remove some of the other materials contained in the iron ore by reacting with them. The carbon dioxide reacts with some of the coke to produce carbon monoxide (CO).

Figure 3.42 Iron ore.

Figure 3.43 Steel is produced in huge blast furnaces.

Reaction 3

carbon + carbon dioxide → carbon monoxide

$C(s) + CO_2(g) \rightarrow 2CO(g)$

The carbon monoxide then reacts with the iron ore and takes the oxygen.

Reaction 4

carbon monoxide + iron oxide → iron + carbon dioxide

$$3CO(g) + Fe_2O_3(s) \rightarrow 2Fe(s) + 3CO_2(g)$$

Objects made from steel will often rust as the iron reacts with oxygen in the air to form iron(III) oxide. This reaction occurs more quickly in the presence of water because the water helps the oxygen atoms (which dissolve in the water) and the atoms of iron to be in contact so that there is a greater chance of a reaction occurring.

There are a number of ways that we can prevent items made from iron or steel from corroding and forming rust. Tin cans are tin-plated steel. Being a less reactive metal than iron, the tin coating is like paint, helping protect the iron from corrosion. So that the tin sticks properly to it, the steel used must be very clean. If a can is dropped and dented, the tin coating may crack and expose the iron inside to corrosion.

Figure 3.44 Tin cans are steel cans plated with tin to help protect the steel from corroding.

The problem is that when hot steel is produced, it reacts with the air and produces a surface coating of iron(III) oxide, or rust. This is insoluble in water, so it can't be simply washed off. But it is a basic oxide, so it will react with acid. The reaction is:

iron(III) oxide + sulfuric acid → iron(III) sulfate + water

$$Fe_2O_3(s) + 3H_2SO(aq) \rightarrow Fe_2(SO_4)(aq) + 3H_2O(l)$$

So, the steel sheeting is dipped into a tank of sulfuric acid on its way to the cell in which it is plated with tin.

Your turn

Create a poster, animation, video or other presentation format that explains one or more aspects of the above information about iron and steel. Consider using graphic representations of the atoms and reactions, and including labels and other notes. You may need to do some further research. Remember to cite all your resources, including any images you may use, in a bibliography.

4

USING CHEMISTRY

Our society relies on the ability to convert the finite resources of our planet into useful materials, including modern materials such as polymers, medicines, composite materials. Chemists know how to manufacture a wide range of useful substances, but managing the by-products of these processes is increasingly important. If the chemical processes used in industry are not managed correctly, the by-products may become pollutants and present a threat to the environment and to our health and safely. The role of chemical engineers is to apply chemical reactions to make quality substances at affordable prices with no harmful effects on the environment.

CHEMICAL REACTIONS AND ENERGY 4.1

Different types of matter can react. The atoms within the matter rearrange and form new substances. These reactions either require energy or release energy.

Students:

» identify that chemical reactions transfer energy and can be classified as either exothermic or endothermic

» construct simple electrochemical cells to describe energy transfer (additional content)

RATE OF REACTIONS 4.2

The rate of a reaction is a measure of how quickly a product is made. Changing the conditions of the reaction can alter the rate of a reaction. Knowledge of rates of reactions and how to speed them up or slow them down can be used to control and improve chemical reactions.

Students:

» compare combustion and respiration as exothermic reactions of different rates

» describe the effects of changes in temperature, surface area and catalysts on the rate of chemical reactions

CHEMISTRY AND INDUSTRY 4.3

Understanding of different chemicals, how they react, the rates of reaction and the products they make is vital for industry. New materials can be made, old ones improved and the methods of production made more efficient, cheaper, safer or cleaner.

Students:

» analyse how the development of new materials can be influenced by social, ethical and environmental considerations

» describe examples where advances in science and technology generate new career opportunities

» investigate the process involved in the production of synthetic fibres (additional content)

» balance chemical equations (additional content)

4.1 CHEMICAL REACTIONS AND ENERGY

We use chemical reactions all the time and all chemical reactions that result in the formation of products. Sometimes the chemical reactions are used because they give off energy, such as the combustion of fuels, including oil and gas, but often, it is the products of the reactions that are the most important. Examples of how humans have learned to use the power of chemistry include the production of metals from metal ores, and the manufacture of fertilisers from acids and bases. In nature, organisms have evolved to use chemical reactions to combine the elements carbon, oxygen, hydrogen and nitrogen into products, such as proteins (for growth) and carbohydrates (for the storage of energy).

ENERGY CHANGES IN CHEMICAL REACTIONS

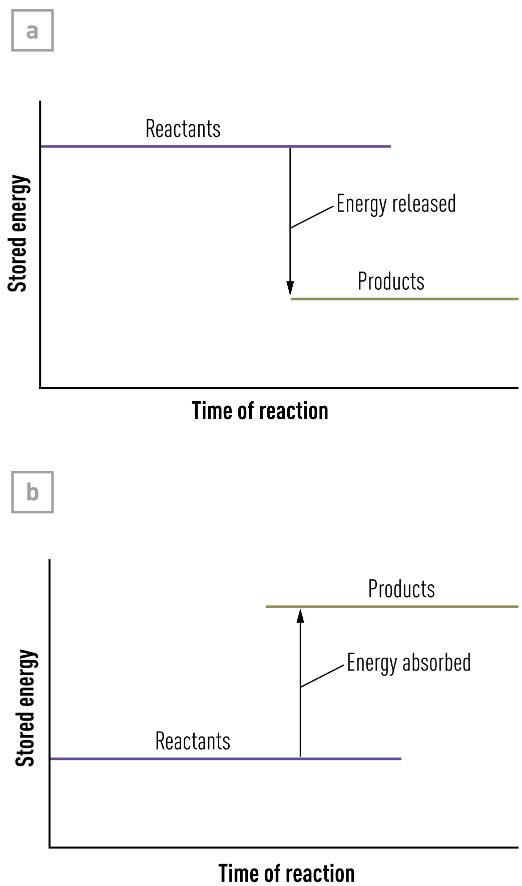


Figure 4.1 (a) In an exothermic reaction, energy is released and the products have less stored energy than the reactants. (b) In an endothermic reaction, energy is absorbed and the products have more stored energy than the reactants.

You may have noticed that a test tube or beaker sometimes feels warmer after a chemical reaction. All chemicals contain a certain amount of stored energy. Reactions that release energy are called **exothermic** reactions (exo = 'to give out', thermic = 'heat'). The energy released is usually heat energy but can also be light or electrical energy. An exothermic reaction can be as fast as a match burning or as slow as the rusting of iron.

Reactions that absorb energy are called **endothermic** reactions. For example, for photosynthesis to happen, plants need energy from the Sun to produce glucose and oxygen from carbon dioxide and water.

In an exothermic reaction, the products have less stored energy than the reactants at the start of the reaction (see Figure 4.1a). This energy is released from the chemicals and goes into the surroundings, usually causing the temperature to rise.

In an endothermic reaction, energy is taken from the surroundings and the products have more energy than the reactants (see Figure 4.1b). Because energy is being removed from the surroundings, endothermic reactions will often cause the temperature of the surroundings to drop.

ACTIVITY 4.1.1: COMMON ENERGY TRANSFERS

1. In pairs or small groups, brainstorm as many different chemical reactions as you can.
2. Classify your reactions as natural (happen spontaneously in nature) or industrial (deliberately used by people to produce something useful).
3. Then classify your list of reactions as being either endothermic (uses up energy) or exothermic (produces excess energy).
4. Combine your group's lists with those of another group or the rest of the class.
   - Did you come up with more natural or more industrial reactions?
   - Did you come up with more endothermic or more exothermic reactions?
   - Discuss whether natural reactions are more likely to be endothermic or exothermic reactions. Suggest why this may have been the case.
   - Discuss whether industrial reactions are more likely to be endothermic or exothermic reactions. Suggest why this may have been the case.

Figure 4.2 Do you think that digestion is an endothermic or exothermic reaction?

Energy changes and particles

Compounds contain atoms held together by chemical bonds. Chemical reactions involve the breaking and making of these chemical bonds.

Reactions and processes that involve the breaking of strong chemical bonds tend to be endothermic. The energy absorbed by the chemicals is required to break the bonds.

Reactions that involve the formation of strong chemical bonds tend to be exothermic. The strongly bonded products have less energy than the reactants, and that difference in energy is released, often in the form of heat.

Some types of cold packs used for injuries (see Figure 4.3) work with the help of an endothermic reaction. They usually contain ammonium nitrate. When the inner bag is broken, the ammonium nitrate dissolves in the water, absorbing heat as it does so. Thus, the bag feels cold.

Figure 4.3 Instant ice packs use endothermic reactions to absorb energy in the form of heat from the surroundings, and feel cold.

EXPERIMENT 4.1.1: ENERGY CHANGES

This experiment could may be carried out using a temperature probe and datalogging equipment instead of a thermometer.

WARNING

> Check the safety data sheets to see how to handle the chemicals in this experiment safely.

> Wear your lab coat, safety goggles and plastic gloves.

Aim

To investigate and compare an exothermic process with an endothermic process.

Materials

- Sealed bottle containing potassium nitrate (KNO_3)
- Sealed bottle containing calcium chloride ($CaCl_2$)
- Measuring cylinder
- Water
- Stirring rod
- Thermometer (or temperature probe)
- 2 polystyrene cups
- 2 spatulas
- Stopwatch
- Wash bottle
- Residue bottle

Method

1. Prepare an appropriate table to record the times and temperatures.
2. Measure 50 mL of water into a polystyrene cup.
3. Measure the temperature of the water and record it.
4. Place three heaped spatulas full of calcium chloride into the water and immediately commence stirring and timing.
5. Record the temperature every 15 seconds for 3 minutes.
6. Dispose of the solution into the container provided and carefully rinse the thermometer with the wash bottle, ensuring the rinse water is also added to the residue bottle. Dispose of the cup as directed by your teacher.
7. Repeat steps 2–6 using potassium nitrate.

Results

Record your data in an appropriate table.

Draw a graph of temperature against time and plot your results for the two chemicals on the same graph. Make sure that you label both axes and use the correct units.

Discussion

1. Which reaction was endothermic and which was exothermic? How did you reach this conclusion?
2. In which reaction did the products have less energy than the reactants?
3. In which reaction did the products have more energy than the reactants?
4. Use the graphs to describe how quickly the temperature rose or fell.
5. Did the temperature reach a steady value after some time? Discuss why you think this is the case.
6. Suggest how the method used in this experiment could be changed to improve the accuracy of the results.

Conclusion

Write a paragraph that uses your experimental evidence to compare endothermic and exothermic reactions.

Activation energy

A chemical reaction occurs when the particles of the reactants collide in the correct ratio. However, not every collision results in a reaction. The particles must collide with enough energy to cause the bonds to break and form to allow the atoms to rearrange. This energy is called the **activation energy** (E_a) and is required even if there is an overall net release of energy (exothermic reactions). You can think of the activation energy as like giving the reactants a little push to get the reaction going.

Like all forms of energy, activation energy is measured in joules (J). Activation energy is commonly in the form of heat, but can be in many different forms like electrical or kinetic energy. In the case of photosynthesis, the activation energy is provided by sunlight.

The activation energy of a reaction and the net change in energy between reactants and products (ΔH) can be shown as a line graph. Figure 4.4 shows the changes in energy during endothermic and exothermic reactions.

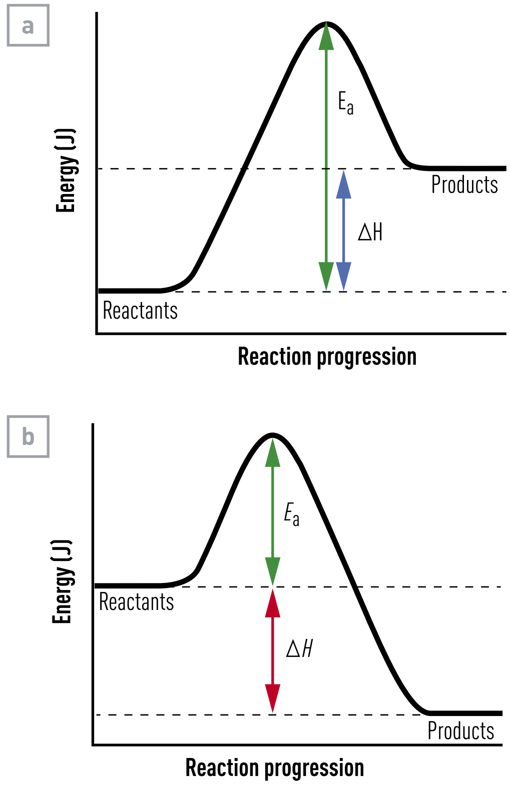


Figure 4.4 Change in energy during an (a) endothermic and (b) exothermic reaction.

QUESTIONS 4.1.1: ENERGY CHANGES IN CHEMICAL REACTIONS

Remember

1 Give three examples of exothermic chemical reactions.

2 In your own words define the term 'activation energy'.

3 The following statements are false. Rewrite them to make them true.

  a The energy released in exothermic reactions is always heat.

  b Chemical reactions that form chemical bonds tend to be endothermic reactions.

4 Recall the difference between E_a and ΔH.

Apply

5 Complete the following sentences:
During an endothermic reaction, the temperature of the surroundings ______________________ . The energy of the products is ______________________ than the energy of the reactants. An example of an endothermic reaction is ______________________ .

6 Classify the following as exothermic or endothermic processes. Justify your answers.

  a A candle burning

  b Ice changing to water

  c A cake baking

7 Explain why a reaction that produces excess energy requires an energy input to start.

ENERGY TRANSFERS IN SYNTHESIS AND DECOMPOSITION

Most endothermic and exothermic reactions involve the breaking and making of chemical bonds, respectively.

Synthesis reactions

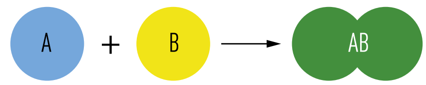


Figure 4.5 A generalised synthesis reaction.

Synthesis is the building up of compounds by combining simpler substances, normally elements. As new bonds are formed, excess energy is released, often in the form of heat. Synthesis reactions are generally exothermic.

Metals can join with non-metals to form ionic compounds or salts. Ionic bonds are usually weak and easily formed and therefore do not release much energy.

metal + non-metal → salt

Example:

sodium + chlorine → sodium chloride

$2Na + Cl_2 \rightarrow 2NaCl$

Non-metals can bond with other non-metals to form covalent or molecular compounds. Covalent bonds are much stronger than ionic bonds and are harder to form, so tend to release much more energy.

non-metal + non-metal → covalent compound

Example:

carbon + oxygen → carbon dioxide

$C + O_2 \rightarrow CO_2$

Quicklime, or calcium oxide (CaO), is an important industrial product generated by a synthesis reaction. It is used in agriculture as a fertiliser and to neutralise acidic soils. It is also a key component in building materials, such as mortar. The ability of quicklime to absorb other chemicals enables it to be used in the preparation and purification of a range of chemicals. When added to water, quicklime produces calcium hydroxide ($Ca(OH)_2$), which is known as slaked lime. This compound is a base and is a key component in whitewash, as well as being used in the treatment of drinking water.

quicklime + water → calcium hydroxide

$CaO + H_2O \rightarrow Ca(OH)_2$

EXPERIMENT 4.1.2: POP SYNTHESIS

Aim

To synthesise water.

Materials

- 2 test tubes
- Test tube rack
- Rubber stopper
- Wooden splint
- Matches
- Magnesium ribbon
- Dilute hydrochloric acid (1 M)

WARNING

- Wear safety glasses and protective clothing.
- Avoid contact with the hydrochloric acid.

Figure 4.6 (a) Add dilute HCl to a magnesium strip; (b) quickly invert a second test tube over the first to catch the hydrogen gas formed.

Method

Preparing the hydrogen gas

1. For this reaction you require a test tube containing hydrogen gas. The easiest way to produce this is to place three 1 cm length pieces of magnesium ribbon into 10 mL dilute hydrochloric acid in a test tube.
2. Place another test tube (make sure it is dry) over the top of the first test tube so that any hydrogen gas produced is collected in the second test tube.
3. After 15 seconds, lift the second test tube up vertically and place a rubber stopper over the end to trap the hydrogen gas. You now have a test tube of hydrogen gas.

Synthesising water

1. Place the sealed test tube containing your hydrogen gas into a test tube rack.
2. Light the wooden splint. Remove the rubber stopper and carefully hold the burning splint close to the top of the test tube.
3. Observe the reaction that occurs and examine the inside of the test tube closely.

Results

Record your observations in an appropriate format. You could photograph or video your experiment.

Discussion

1. What evidence was there that water was formed in the reaction?
2. Write a chemical equation for the reaction that occurred, ensuring that no atoms are created or destroyed in the process, i.e. write a balanced chemical equation.
3. Why do you think that heat was required to start the reaction?
4. Apart from synthesis, what other ways could this reaction be classified? (Hint: Think about the energy involved in this reaction – what evidence do you have that energy was absorbed or released?)

Conclusion

Write a short paragraph that uses scientific evidence to classify the reaction as a synthesis reaction and either an endothermic or an exothermic reaction.

Decomposition reactions

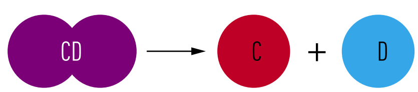


Figure 4.7 A generalised decomposition reaction.

In chapter 3 you learned about decomposition reactions, where the chemical bonds in the reactants are broken down to produce two or more different products, usually simpler compounds or basic elements. Energy is required to break these bonds and so decomposition reactions need to absorb energy from their surroundings and are usually endothermic reactions. The stronger the chemical bonds, the harder they are to break and the more energy is required.

Decomposition reactions typically use energy in the form of heat or electricity to break the bonds in the reactants.

Figure 4.8 (a) A lime kiln being used to produce quicklime. (b) A modern furnace used to decompose limestone.

Thermal decomposition

Thermal decomposition uses heat to provide energy for the reaction. For example:

copper(II) carbonate → copper(II) oxide + carbon dioxide

$$CuCO_3 \rightarrow CuO + CO_2$$

Calcium oxide (CaO) is produced by the thermal decomposition of calcium carbonate ($CaCO_3$).

calcium carbonate → calcium oxide + carbon dioxide

$$CaCO_3 \rightarrow CaO + CO_2$$

The most common and cheapest naturally occurring form of calcium carbonate is limestone. Calcium oxide was produced from limestone for many centuries in lime kilns. These stone structures were fuelled by coal, with blocks of limestone having to be broken up, often by hand, and added to the kiln, where the temperatures could reach close to 1000°C.

Nowadays limestone is roasted in more modern furnaces, often fuelled by gas, where the temperature is regulated by controlling the flow of gas and air into the furnace.

EXPERIMENT 4.1.3: THERMAL DECOMPOSITION OF A CARBONATE

Aim

To use heat to decompose copper(II) carbonate to produce copper oxide and carbon dioxide.

Materials

- Pyrex (high-strength) test tube
- Test tube holder
- Bunsen burner
- Matches
- Spatula
- Copper(II) carbonate
- Copper(II) oxide
- Calcium carbonate powder

WARNING

> Wear safety glasses throughout this experiment.
> Make sure that the open end of the test tube is facing in a safe direction while heating.

Method

1 Describe the appearance of copper(II) carbonate and copper(II) oxide.

2 Place one spatula of copper(II) carbonate into the test tube.

3 Hold the test tube at an angle of approximately 45° and gently heat the bottom of the test tube by moving it carefully in and out of a Bunsen burner flame.

4 Carefully observe the changes that occur.

Figure 4.9 Make sure to point the test tube away from you and other students while heating.

Results

Record your observations in an appropriate format.

Discussion

1 What evidence is there that copper(II) oxide was formed in the reaction?

2 What evidence is there that a gas was given off in the reaction?

3 Write a chemical equation for the reaction that and include the states (solid, liquid or gas).

4 Apart from decomposition, what other ways could this reaction be classified?

Conclusion

Use your experimental evidence to describe thermal decomposition.

Further investigation

How could you redesign this experiment to provide evidence that it is carbon dioxide gas that is produced in the reaction? Write an experimental method, including labelled diagrams, and list any additional equipment you will need. Show your design to your teacher and, if it is safe, try your method using copper(II) carbonate and then repeat using calcium carbonate.

Electrolytic decomposition

Electrolytic decomposition or **electrolysis** uses electricity to provide energy for the reaction. For example:

aluminium oxide → aluminium + oxygen

$$2Al_2O_3 \rightarrow 4Al + 3O_2$$

Aluminium is used extensively in food packaging, buildings, casings for computers and electric cabling. Aluminium is produced by electrolysis. The raw material for this process is bauxite, an ore of aluminium mined extensively in Australia. The bauxite provides the aluminium oxide (Al_2O_3), an ionic solid. This solid is heated to high temperature and then separated into aluminium and oxygen by electrolysis. Very high temperatures are required for this process because the pure aluminium oxide needs to be in a liquid form for electrolysis to work.

The combination of maintaining high temperatures and the use of electricity in production means that aluminium remains a relatively expensive metal, despite the fact that bauxite, and other aluminium-containing compounds, are very common in the Earth's crust.

Figure 4.10 Aluminium is produced by electrolysis in a smelter.

EXPERIMENT 4.1.4: ELECTROLYSIS

Background

Copper sulfate ($CuSO_4$) is an ionic substance containing copper(II) ions (Cu^{2+}) and sulfate (SO_4^{2-}) ions combined in an ionic network.

Aim

To use electricity to produce copper metal from copper(II) sulfate.

Materials

- 100 mL beaker
- Stirring rod
- Spatula
- Copper(II) sulfate
- DC power supply
- 3 leads
- One 6 V globe and globe holder
- 2 carbon (graphite) electrodes
- Alligator clips

WARNING

> Wear safety glasses throughout this experiment.
> Do not let the carbon rods touch when they are in the beaker.

Method

1. Add one spatula of the copper(II) sulfate to the beaker and half fill it with water.
2. Stir until the crystals are all dissolved.
3. Set the power supply to a maximum of 6 volts and connect the circuit as shown in Figure 4.11.
4. Touch the carbon electrodes together to check the circuit works and then place the carbon electrodes in the beaker with a 1 cm gap between them.
5. Hold the electrodes in place for 30 seconds and observe any changes that occur.
6. Turn the power supply off.

Results

Record your observations in an appropriate format.

Figure 4.11 Use alligator clips to connect the electrodes to the power supply and the globe.

Discussion

1. What evidence was there that copper was formed in the reaction?
2. Considering the structure of copper sulfate, describe the:
   - role of the water in the process
   - role of the electric circuit
   - reason that the copper was only found on one of the carbon electrodes.
3. Do you think that a usable amount of copper could be produced this way? If not, what changes would need to be made to the set-up to produce more copper?

Conclusion

Use your experimental evidence to describe electrolysis.

QUESTIONS 4.1.2: ENERGY TRANSFERS IN SYNTHESIS AND DECOMPOSITION

Remember

1. Describe the key characteristic(s) of a synthesis reaction.
2. Do decomposition reactions make or break chemical bonds?
3. Are synthesis reactions usually endothermic or exothermic reactions?

Apply

4. Suggest a reason why decomposition reactions always produce at least two products.
5. Define the term 'by-product' and, using one of the reactions in this section, provide an example of a by-product.

Analyse

6. Why is energy required in:
   a. decomposition reactions
   b. direct synthesis reactions?

ELECTROCHEMICAL TRANSFER OF ENERGY

An **electrochemical cell** is a device that produces electricity from an exothermic chemical reaction or uses electricity to drive an endothermic chemical reaction. Electrochemical cells that produce electricity are called voltaic or galvanic cells, and cells that use electricity are called electrolytic cells.

Both types of electrochemical cells are made up of two half-cells (see Figure 4.12). Each half-cell contains an **electrode**, which is usually made of metal, partially submerged in a liquid **electrolyte**. The electrolyte contains a dissolved ionic substance, which separates into its positive cations and negative anions. Half-cells may contain the same or different electrolytes. A porous membrane or 'salt-bridge' joins the two half-cells and allows the ions to pass between the cells.

Figure 4.12 This voltaic cell has a manganese electrode in a beaker of manganese sulfate on the left and a copper electrode in a beaker of copper sulfate on the right. A salt bridge of filter paper connects the two half-cells.

The reactions in voltaic cells occur spontaneously between the electrode and the electrolyte. At one electrode, positive metal cations are released from the electrode into the electrolyte. This causes the electrode to have a negative charge and it is now called the **anode**. At the other electrode, the metal cations bond to the electrode, forming a new layer of metal. The addition of cations causes the electrode to become a positively charged **cathode**.

The movement of the cations results in the movement of electrons in the opposite direction. This movement of electrons between the two half-cells is what causes the electric current. Electricity will continue to flow until one half-cell runs out of the substances needed for its reaction.

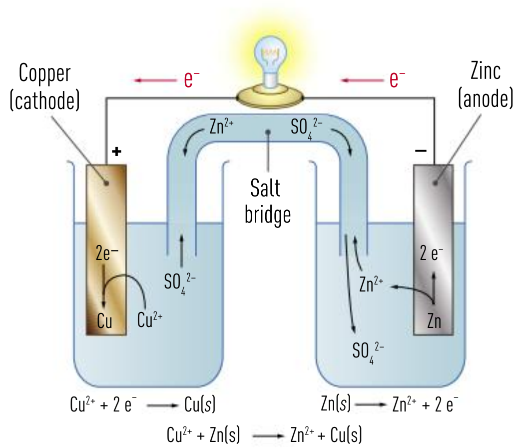


Figure 4.13 The movement of ions in a voltaic cell.

In *Oxford Insight Science 8*, you constructed an electrochemical battery using lemons. In the following experiment, you will investigate how energy is transferred in an electrochemical cell.

EXPERIMENT 4.1.5: ELECTROCHEMICAL FRUIT CELLS

Aim

To construct a simple electrochemical cell to describe the transfer of energy.

Materials

- Copper metal (foil or uninsulated wire)
- Galvanised nail (untarnished) or zinc strip
- 1 large fresh lemon per group
- Alligator clip leads (short)
- LED (or small light globe)
- Multimeter (optional)

Method

1 Roll the lemon and squeeze gently to soften the skin and make sure it is juicy on the inside.
2 Slit the lemons and insert a strip of copper foil. Mark the electrode with a positive sign.
3 At the opposite end, insert the galvanised nail or zinc strip, making sure that the nail is not touching the copper. Mark the electrode with a negative sign.
4 Connect an alligator clip to the copper foil and another clip to the nail.
5 Connect the copper lead to the long arm of the LED (light-emitting diode) and the zinc lead (from the galvanised nail) to the short arm of the LED. The LED will not work if connected incorrectly.
6 Darken the room and look carefully at the LED. It should have a faint glow.

Discussion

1 Identify the anode and the cathode in this cell.
2 What role does the lemon play in this cell?
3 Describe the movement of the electrons through this circuit.
4 Explain the link between the transfer of electrons and the transfer of energy.
5 Suggest a method of confirming which electrode was the anode and and which was the cathode.
6 Suggest a method of increasing the amount of electrical energy being released.

Conclusion

Write a statement that uses your experimental results to explain the aim.

Figure 4.14 Adding appropriate electrodes and connecting wires to a lemon can produce an electrical current.

QUESTIONS 4.1.3: ELECTROCHEMICAL TRANSFER OF ENERGY

Remember

1 Name the type of electrochemical cell in which endothermic reactions take place.
2 Draw and label a generalised voltaic electrochemical cell.
   a Include the following terms: electrolyte, salt bridge, connecting wire, globe, anode and cathode.
   b Draw and label an arrow to indicate the direction of electron movement.
   c Draw and label an arrow to indicate the direction of cation movement.
3 Identify the charges on the anode and cathode in voltaic cells.

Apply

4 Propose how electrochemical cells could be used to determine whether a reaction was endothermic or exothermic.
5 Evaluate whether the following food items could be used to make an electrochemical cell. For each item, explain why they would or would not be suitable.
   a Tomato
   b Banana
   c Potato
   d Sponge cake

CHEMICAL REACTIONS AND ENERGY

4.1 CHECKPOINT

Remember and understand

1 The following statements are false. Rewrite them to make them true.

   a The anode of a voltaic cell is positively charged and attracts electrons. [1 mark]

   b The electrolyte of an electrochemical cell is made up of dissolved molecular compounds. [1 mark]

   c Energy, in the form of electricity, is produced by the exothermic reactions in an electrolytic electrochemical cell. [1 mark]

2 In exothermic reactions, the products contain less stored energy than the reactants. Explain what happens to the energy during the reaction. [1 mark]

3 Recall the purpose of the salt bridge in an electrochemical cell. [1 mark]

4 Photosynthesis is an endothermic reaction. Recall the type of energy input. [1 mark]

Apply

5 A burning candle requires a flame (e.g a lit match) to start the reaction. Identify whether this is an example of an endothermic or an exothermic reaction. Justify your answer. [2 marks]

6 Relate endothermic and exothermic processes to the making and breaking of chemical bonds. [2 marks]

7 All endothermic and exothermic reactions eventually stop absorbing and producing heat. Explain why this is the case. [2 marks]

Analyse and evaluate

8 Explain why exothermic reactions have an activation energy even though they have a net release of energy. [2 marks]

9 Describe how chemical reactions transfer energy. [3 marks]

10 Compare and contrast electrolysis with an electrolytic electrochemical cell. [3 marks]

Research

11 Choose one of the following electrochemical cells to research. Construct an annotated poster of your chosen cell, clearly outlining the structure and chemical processes of the cell. Indicate its common uses. Make sure to include a bibliography of your sources. [5 marks]

- Mercury cells
- Rechargeable batteries
- Alkaline batteries
- Nickel–cadmium cells
- Zinc–carbon cells
- Dry–cell batteries

Making connections

12 Imagine all the chemical reactions that take place when baking bread in an oven fuelled by LPG gas. Describe in around 100 words, the many chemical changes that would occur in this process, including the production of heat in the oven as well as the changes in the bread. Identify each reaction as being either endothermic or exothermic. You may need to carry out some additional research to fully answer this question. [5 marks]

Figure 4.15 Which reactions in the process of baking bread are endothermic, and which are exothermic?

TOTAL MARKS [/30]

4.2 RATE OF REACTIONS

How fast a chemical reaction happens can be a life or death issue. The rapid combustion reactions occurring in a bushfire can easily get out of control as the fire spreads, turning wood to ash and producing vast amounts of heat energy as the fire proceeds. Our bodies rely on chemical reactions that convert the glucose in our blood to glycogen. If this process is too slow, as is the case in some types of diabetes, high levels of blood sugar ensue, a condition called hyperglycaemia. This has the potential to result in heart disease or other serious medical conditions. Controlling the rate of chemical reactions is vital in industry, our environment and in our bodies.

THE IMPORTANCE OF REACTION RATE

A **reaction rate** is how fast a reaction proceeds. A fast reaction has a high reaction rate; a slow reaction has a low reaction rate.

The reaction rate is very important. Explosions must have a high reaction rate if they are to be useful. The rusting of iron has a slow reaction rate. Imagine what would happen to iron if it rusted at the same rate as an explosion.

Chemists have a role to ensure that reactions occur quickly enough to be useful, but not so quickly as to be explosively dangerous.

In the chemical industry, controlling the rate of a reaction is vital. Reactions that are too slow are not economic, because equipment is tied up for a long time. Reactions that are too fast need to be controlled, or contained in strong reaction vessels. The containment vessels cost a lot of money to build and maintain. Chemists and chemical engineers have the role of making chemical reactions as cheap as possible. A large part of this is achieved by controlling the rate of the reaction.

Figure 4.16 Some slow reactions include (a) the rusting of iron and (b) the baking of muffins. Fast reactions include (c) fuel combustion in rocket launches and (d) controlled explosions.

ACTIVITY 4.2.1: FAST OR SLOW?

We are surrounded by chemical reactions. Some are fast, like the gas burning in a barbecue, and some are slow, like the corrosion on the outside of the barbecue. Sometimes we want reactions to occur quickly, but sometimes a fast reaction may not be required or may, in fact, be dangerous.

1. For each of the following situations, describe whether you think a fast or slow chemical reaction is preferred. Discuss your thoughts with others.
   - **a** The rusting of an iron bridge.
   - **b** The reaction in the baking of bread that produces carbon dioxide (which makes the bread rise).
   - **c** The oxidation of alcohol in wine to form vinegar.
   - **d** The combustion of a fuel in a rocket engine.
   - **e** The chemical processes involved in the action of a pain-killing drug.
2. For each situation, write down ways in which we can control the rate of the reaction, either to slow down or speed up the production of products.
3. For one of the reactions you chose to speed up, think about what is happening to the particles (atoms or molecules) during the reaction. Explain how your chosen method of speeding up the reaction would enable the particles to interact and change more quickly.

Rates of exothermic reactions

Exothermic reactions release energy, usually in the form of heat, light and sound. This energy causes increased temperatures, sparks and flames, and the sounds of crackling or explosions.

The amount of energy released and the rate or speed at which it is released varies between the different forms of exothermic reactions.

Figure 4.17 Combustion is a fast reaction that releases energy in the form of heat, light and sound.

Combustion

Combustion reactions require a fuel to react with oxygen. Fuels can be solids, liquids or gases. Solid fuels include coal, wood and metals; liquid fuels include petrol and diesel; gaseous fuels include methane, propane (LPG) and hydrogen.

fuel + oxygen → oxide

Example:

magnesium + oxygen → magnesium oxide + energy (heat, light and sound)

$$2Mg(s) + O_2(g) \rightarrow 2MgO(s) + \text{energy}$$

All combustion reactions require ignition. Ignition is the activation energy of the reaction. Ignition is often in the form of friction (e.g. striking a match) or electrical energy (e.g. an electrical spark or lightning strike).

Combustion is considered to be a fast reaction, quickly releasing energy as the oxides, or oxygen-based compounds, are formed. Very fast combustion reactions result in explosions.

Respiration

Respiration is an exothermic reaction that releases energy from glucose to be used by the cell for its many different functions. There is so much energy in glucose that if it were all released at once, the heat produced would be enough to cook the cell. So respiration releases the energy in stages and at a rate that allows the energy to be converted into ATP molecules (the body's energy molecules). The rate at which the energy is released during respiration is slower and much more controlled than the energy released during a combustion reaction.

sugar + oxygen → carbon dioxide + water + energy

Example:

glucose + oxygen → carbon dioxide + water + energy

$C_6H_{12}O_6(aq) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l) + ATP$

Figure 4.18 All combustion reactions require ignition.

Figure 4.19 Mitochondria are the site of cellular respiration.

QUESTIONS 4.2.1: THE IMPORTANCE OF REACTION RATE

Remember

1 Provide the specific name for the activation energy of a combustion reaction.

2 List three reactions that need to proceed at a fast rate and three that need to proceed at a slow rate.

Apply

3 Identify whether respiration or combustion has the fastest rate of reaction. Justify your decision.

4 Provide two explanations for why all the energy from glucose is not released at once.

Analyse

5 Propose two advantages and two disadvantages of increasing the speed of reactions in industry.

6 Zinc is more reactive than iron, which is more reactive than tin. Assuming that all other conditions were the same, suggest which metal would corrode the slowest.

COLLISION THEORY

For a chemical reaction to occur, the atoms or ions or molecules must collide together, in the right orientation and with enough energy for that reaction to occur. This concept is known as **collision theory**. The energy required for the reactants to interact is the activation energy.

For example, hydrogen iodide (HI) decomposes according to the following chemical reaction:

$$2HI(g) \rightarrow H_2(g) + I_2(g)$$

Hydrogen iodide is a gas and its molecules travel quickly. Each hydrogen iodide molecule must collide with another hydrogen iodide molecule in the correct orientation and with enough energy to provide the activation energy for the reaction to proceed.

Many collisions do not result in a reaction. In these collisions, the hydrogen iodide molecules bounce apart with no reaction, as shown in Figure 4.20.

In the collision shown in Figure 4.21, there is a reaction. A weak chemical bond forms between the iodide ions and the hydrogen ions. This intermediate complex is unstable and only exists for a short period of time, before it breaks apart to form the final products.

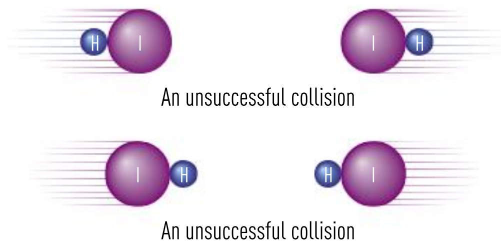


Figure 4.20 If the particles are not in the correct position when they collide, or if they don't collide with enough energy, then they will not react.

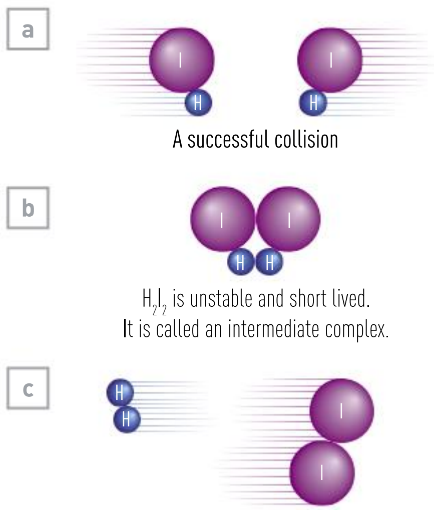


Figure 4.21 (a) When the particles are aligned correctly and collide with enough energy, a reaction will occur. (b) The intermediate complex H_2I_2 is unstable and short lived. (c) It breaks down into the final products, which separate partly due to electrostatic repulsion.

Reversible reactions

Many reactions can occur in reverse and these sorts of reactions are called **reversible** reactions. For example, the decomposition of hydrogen iodide can be reversed. This would then be called the synthesis of hydrogen iodide.

Decomposition of hydrogen iodine:

$$2HI(g) \rightarrow H_2(g) + I_2(g)$$

Synthesis of hydrogen iodine:

$$H_2(g) + I_2(g) \rightarrow 2HI(g)$$

A reversible reaction can be written with a double-headed arrow, showing that the reaction can proceed in both directions.

$$2HI(g) \rightleftharpoons H_2(g) + I_2(g)$$

In the case of photosynthesis, while the reactants of respiration are the products of photosynthesis (in the overall reaction), and vice versa, they cannot be written as a reversible reaction. Both respiration and photosynthesis are actually a series of smaller reactions that involve very different intermediate products and enzymes. They are very different processes and neither is reversible.

Collision theory and rates of reaction

Collision theory tells us that reactant particles only react when they collide in the correct ratio and orientation, and with energy equal to or greater than the activation energy. Increasing the rate of successful collisions increases the overall rate of the reaction.

The factors that control the rate of a reaction in industry are the same as the factors that control reactions in your school laboratory. You can therefore investigate each factor and then relate it to a chemical process in industry. Table 4.1 lists a number of variables that could affect reaction rate and a brief description of the change to the particles. The table also suggests some reactions that could be used to test a hypothesis about each variable.

Table 4.1 Factors affecting reaction rate.

Variable	Particles	Suggested chemicals and reactions suitable to test the hypothesis
Surface area	The larger the surface area, the more particles available for collisions.	Calcium carbonate and dilute hydrochloric acid.
Concentration	The more particles in a solution, the more likely it is that collisions will occur.	Powdered $CaCO_3$ and different concentrations of hydrochloric acid. *or* Magnesium ribbon and different concentrations of hydrochloric acid (in both cases, the volume of gas produced can be measured).
Heat or temperature	The higher the temperature, the more energy the particles have, so the more they move around and the more likely they are to collide.	A solution of potassium permanganate mixed with a solution of oxalic acid. (The purple permanganate solution becomes colourless when the reaction is complete.) The solutions can be warmed before mixing to investigate the effects of changes in temperature.
Mixing or stirring	Mixing or stirring increases movement of the particles, making them more likely to collide.	A solution of potassium permanganate mixed with a solution of oxalic acid – the amount of stirring of the reaction mixture can be varied.
Presence of a catalyst	A catalyst is a 'helper' molecule that brings the reactant particles together in the correct orientation, but is not actually a part of the reaction itself. It can be reused over and over. While a catalyst does not increase the rate of reaction, it does lower the activation energy, which means the reaction will take place at a lower temperature.	Dilute hydrogen peroxide (H_2O_2) solution decomposes slowly and can be used to investigate the effect of the catalyst manganese dioxide.

STUDENT DESIGN TASK

Investigating the effect of surface area on reaction rate

Before you start

- The reaction that you are investigating is between calcium carbonate and hydrochloric acid. The equation for this reaction is:

  $CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$

- Decide on the best way to measure the rate of this reaction. This may involve some preliminary trials to test whether your method will work.

Questioning and predicting

Write an appropriate aim and hypothesis for your experiment.

Planning and conducting

- Use the guide in chapter 8 to plan an appropriate method for your experiment.
- Consider the dependent, independent and controlled variables.
- Consider safety equipment and perform a risk assessment for your method.
- Carry out your experiment as you have outlined in your method.

Suggested materials

- Pieces of calcium carbonate (limestone, chalk or marble)
- Dilute hydrochloric acid (1.0 M)
- Test tubes
- Test tube rack
- Stopwatch
- Electronic balance
- Measuring cylinder
- Safety glasses
- Hammer or mortar and pestle

(Note: you may be able to access other equipment depending on your experimental plan.)

Processing, analysing and problem solving

- Construct an appropriate table to collate your results. You may like to present your data as a graph to make it easier to identify trends.
- Identify the links between the sizes of the pieces of calcium carbonate and surface areas.
- Determine whether or not your hypothesis was supported. Use evidence to support your claims, or suggest alternative explanations for your results.
- Identify what your results can tell you about other similar reactions.
- Suggest ways to improve your original method if you felt it was flawed. If your experiment was successful, suggest a new experiment to extend the depth of your investigation.

Communicating

Present your investigation as a formal scientific report, or in another format as negotiated with your teacher.

Figure 4.22 Which form of calcium carbonate has the highest surface area? Which will react the fastest?

EXPERIMENT 4.2.1: EFFECT OF CONCENTRATION ON REACTION RATE

Aim
To investigate the effect of concentration on reaction rate.

Hypothesis
Read the method of this experiment and write an appropriate hypothesis as an 'If … then …' statement.

Materials
- 20 mL of 0.5 M HCl (hydrochloric acid)
- 20 mL of 1.0 M HCl
- 20 mL of 2.0 M HCl
- 30 g small marble chips of similar size
- 3 × 100 mL conical flasks
- Electronic balance
- Stopwatch
- 25 mL measuring cylinder

WARNING
> Avoid contact with the acid solutions because they are corrosive.
> Wear protective gloves, lab coats and safety glasses.
> Wash off with water immediately if contact is made.

Method
1 Prepare a table for your results as shown below.

2 Place a conical flask on the digital balance and tare the balance so it reads zero. Weigh approximately 10 g of marble chips into the flask.

3 Use a measuring cylinder to add 20 mL of 0.5 M hydrochloric acid to the conical flask still sitting on the digital balance. Immediately tare the balance once so that it returns to zero briefly, and start the stopwatch. The numbers on the balance will move into negative readings from zero, as gas is released.

4 In your results table record the mass loss in grams at 30 seconds, 1 minute and then every minute for 8 minutes.

5 Repeat steps 2–4 using 1.0 M HCl and then 2.0 M HCl.

6 Plot a graph of the mass loss against time. Plot all three acid concentrations on the same graph for comparison.

Figure 4.23 Marble reacts with hydrochloric acid: calcium carbonate + hydrochloric acid → calcium chloride + water + carbon dioxide

Results

HCl concentration (M)	Time								
	30 s	1 min	2 min	3 min	4 min	5 min	6 min	7 min	8 min
0.5									
1.0									
2.0									

Discussion
Write a couple of paragraphs about the key findings of your experiment and any trends in the data, and evaluate of the method used to produce the data. Suggest solutions to these issues or propose a new experiment to extend the investigation.

Conclusion
Write a conclusion for your experiment that includes a statement about the validity of your hypothesis based on the data from the experiment.

EXPERIMENT 4.2.2: EFFECT OF TEMPERATURE ON REACTION RATE

Aim
To investigate the effect of temperature on reaction rate.

Hypothesis
Read the method of this experiment and write an appropriate hypothesis as an 'If ... then ...' statement.

Materials
- 0.001 M potassium permanganate solution
- 0.005 M oxalic acid solution
- Test tubes
- Stopwatch
- 250 mL beaker
- 10 mL measuring cylinders
- Kettle or access to hot water
- Thermometer

WARNING

> Avoid contact with the potassium permanganate solution and oxalic acid solution.

> Wear protective gloves, lab coats and safety glasses.

Method
1 This experiment can be performed using a water bath to warm or cool specific amounts of the two solutions to the required temperature before they are mixed. Leave the test tube containing the reaction mixture in the water bath while the reaction time is measured. (The reaction is finished when the purple colour of the potassium permanganate disappears.)

2 Consider what different temperatures will be used, how the temperature will be measured, what volumes of solutions should be used and how the results will be best presented.

3 In your report only write the steps of the method that you and your group planned. Include any appropriate units.

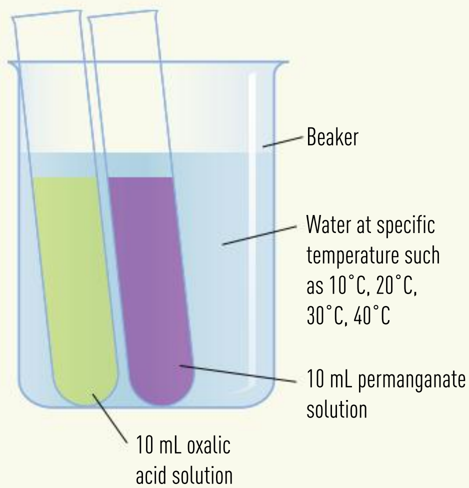


Figure 4.24 A water bath can be used to control the temperature of solutions.

Results
Design an appropriate table to collect and collate your data. You may like to draw a graph of your results to display any trends more clearly.

Discussion
Write a couple of paragraphs about the key findings of your experiment and any trends in the data and evaluate of the method used to produce the data. Suggest solutions to these issues or propose a new experiment to extend the investigation.

Conclusion
Write a conclusion for your experiment that includes a statement about the validity of your hypothesis based on the data from the experiment.

EXPERIMENT 4.2.3: EFFECT OF A CATALYST ON REACTION RATE

Aim

To investigate the effect of adding a catalyst to a reaction. The reaction used in this experiment is the decomposition of hydrogen peroxide.

$$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$$

Hypothesis

Read the method of this experiment and write an appropriate hypothesis as an 'If ... then ...' statement.

Materials

- Hydrogen peroxide solution (H_2O_2) (10 volume)
- Manganese dioxide powder (MnO_2)
- Test tubes and test tube rack

WARNING

> Wear safety glasses and protective clothing at all times. Avoid contact with the hydrogen peroxide.

Method

1 Place 5 mL hydrogen peroxide solution into two separate test tubes.

2 Allow one of the test tubes to stand. Add a small amount of the manganese dioxide to the other test tube using a spatula.

3 Observe and describe the changes that occur in the two test tubes.

Results

Record your observations in an appropriate format.

Figure 4.25 The gas product can be tested with a glowing splint. CO_2 will extinguish the splint, H_2 will cause a 'pop' and O_2 will cause the splint to relight.

Discussion

1 Was there evidence of any reaction in the test tube to which manganese dioxide was not added?

2 Would you say that the manganese dioxide acted as a catalyst in this reaction? Justify your answer.

Conclusion

Write a conclusion for your experiment that includes a statement about the validity of your hypothesis based on the data from the experiment.

Further investigation

For each of the two scenarios below, write a hypothesis and design an experiment to test your hypothesis. You may need to use some additional equipment. Once you have checked with your teacher, you may be able to complete your investigation. Don't forget to write a report of your findings.

1 Is the manganese dioxide used up in the reaction?

2 Does the amount of the catalyst used affect the rate of the reaction?

QUESTIONS 4.2.2: COLLISION THEORY

Remember

1 Explain the main ideas of the collision theory in your own words.

2 Define the term 'reversible reaction'.

3 Explain why photosynthesis and respiration are not a pair of reversible reactions.

Apply

4 Using your knowledge of collision theory, explain activation energy.

5 Describe how collision theory explains the rate of reactions.

6 Explain why it is important to follow the steps of the scientific method.

7 Identify the controlled variables in Experiment 4.2.1.

8 Identify the independent and dependent variables in Experiment 4.2.2.

Analyse

9 Evaluate the following statement: Every time reactant particles collide, they react to form particles of the products.

FACTORS INFLUENCING THE RATE OF REACTION

A chemical reaction proceeds when the reactants interact. The reactants combine to form the products. The more reactants that can interact in a certain amount of time, the faster the products will form and the faster the reaction. A faster reaction has a higher reaction rate.

Collision theory states that the particles of the reactants, such as atoms, ions or molecules, must collide so they can react. In explaining how to make a reaction occur faster, it is best to think of how to make more collisions.

You may have already investigated the effect of some of these factors in the previous section. In the next few pages you will discover why these factors affect reaction rate.

Increased surface area

A metal such as magnesium reacts with dilute hydrochloric acid. A hydrogen ion in the acid has to collide with a magnesium atom in order for the two of them to react. There are more metal atoms exposed to the hydrogen ions if the metal is in small pieces. Because the reaction occurs on the surface of the magnesium, breaking it up into smaller pieces provides a larger surface area on which the reaction can occur.

Powders have a much larger surface area than large-sized pieces of material. Remember, the surface area is not the size of the pieces, but the total area exposed to the surroundings.

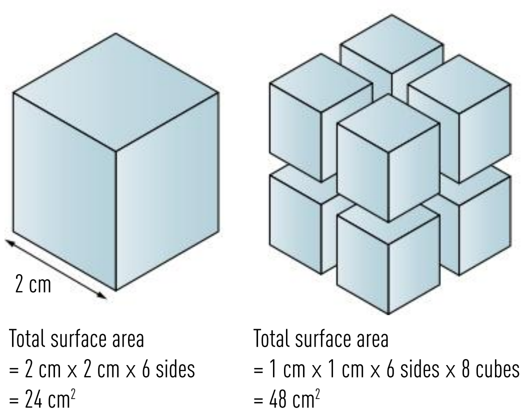


Figure 4.26 Many small particles have a larger surface area than a single large particle of the same volume.

Increased concentration

In a dilute solution, the particles (molecules or ions) of the reactant are spread out in a solvent, such as water. There is a lot of space between the reactant particles. In a concentrated solution, there are many more reactant particles in the same volume, so they are much closer together.

In the reaction between magnesium and hydrogen ions, the reaction will go faster if there are more hydrogen ions. So, using a hydrochloric acid solution with a higher concentration (i.e. when there are more hydrogen ions in a given volume) will speed up the reaction.

To speed up a reaction, it is best to use more concentrated solutions of reactants. This is because, in concentrated solutions, there are more particles available for a given volume that can react. When there are more particles, there are more collisions and therefore a higher reaction rate.

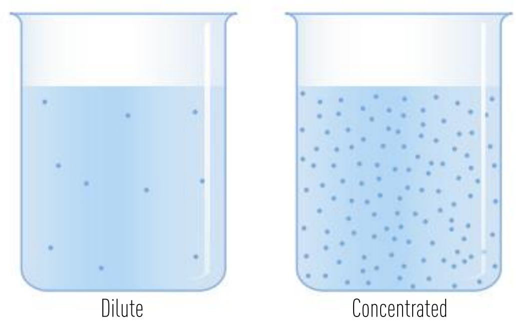


Figure 4.27 A more concentrated solution will contain more dissolved particles than a dilute solution.

Increased temperature

Particles in a hot substance have more kinetic energy than particles in a cold substance. This means that the particles in a hot substance are travelling faster than the same particles in a cold substance.

In a reaction, hotter particles will collide more often and with more energy than cold particles. More collisions, and more energetic collisions (at or above the activation energy), mean a greater proportion of collisions that result in a reaction.

Slow moving molecules will be pushed apart by the repulsion of the electrons that orbit the atoms; they never come close enough to form new chemical bonds. Fast moving molecules can 'push through' the repulsion and their electrons can orbit around a different atom, changing into products.

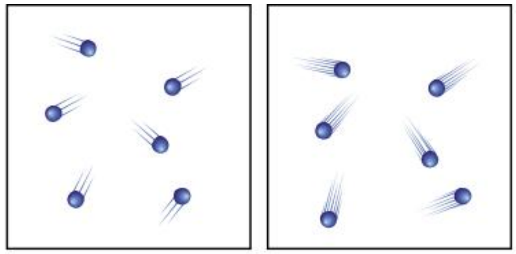


Figure 4.28 At higher temperatures, the average energy of the particles is increased, resulting in more movement and higher energy collisions.

Increased pressure (gases)

For chemical reactions that involve gases, increasing pressure increases the rate of reactions. Gas pressures can be increased in two ways – by increasing the concentration of particles in a fixed volume or by increasing the temperature of the gas. Increasing the number of particles in a volume means more particles are available to collide. Increasing the temperature of a gas means the particles have more kinetic energy, increasing the likelihood of energetic collisions.

Stirring and mixing

As a chemical reaction proceeds, the particles of the reactants get used up. When there are fewer reactants, there are fewer collisions and so the reaction rate slows down. To maintain the reaction rate, the products of the reaction should be removed and replaced with more reactants. A basic way of doing this is by stirring or mixing the reactants.

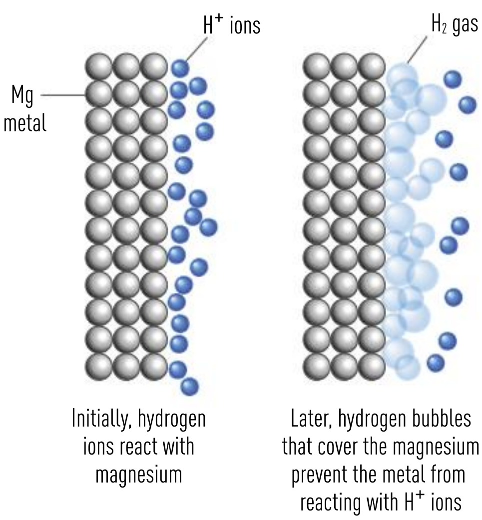


Figure 4.29 Sometimes the presence of the product can slow down a chemical reaction.

In the reaction between magnesium and acid, one of the products is hydrogen gas. The gas forms bubbles that gather on the surface of the magnesium, covering the unreacted magnesium. The bubbles form a barrier that separates the magnesium from the hydrogen ions and prevents the reaction from continuing. Stirring sweeps the hydrogen gas away so that more hydrogen ions can react with the fresh magnesium surface.

Using a catalyst

A **catalyst** is any substance that speeds up a chemical reaction but is itself not used up in the reaction. In other words, a catalyst is a 'helper' particle that is not actually a part of the reaction.

Solid catalysts provide a surface on which the reaction can occur. The particles of reactants **adsorb** (stick) onto the surface, where they react to form the products. The products are then released from the surface of the catalyst. This frees up the catalyst to be used again by other reactant molecules.

This sort of catalyst is used in the catalytic converters of cars. A honeycomb-like grid of metals provides a large surface area. The metals adsorb pollutant gases, but not 'clean' gases, such as nitrogen and carbon dioxide. The pollutant gases are adsorbed onto the catalyst, where they react to form the gases nitrogen and carbon dioxide. These clean gases are passed through the car exhaust.

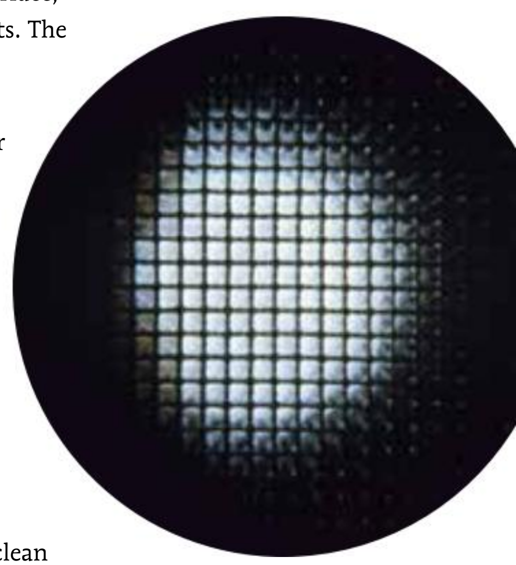


Figure 4.30 Solid catalysts are often used in the form of a grid to maximise the surface area.

An example of a catalyst acting as a 'helper' particle is the destruction of ozone. Chlorofluorocarbons (CFCs), such as CCl_3F (trichlorofluoromethane or freon-11), are broken apart by the UV rays from the Sun, releasing free chlorine atoms. Chlorine atoms catalyse the destruction of ozone and can be reused over and over.

In this way, one chlorine atom from the original CFC can destroy up to 10 000 ozone molecules. The reactions occurring can be shown as follows.

1 UV radiation provides the energy for the decomposition of freon-11.

2 The free chlorine atom forms an intermediate complex with an oxygen atom, catalysing the decomposition of ozone:

$$Cl + O_3 \rightarrow ClO + O_2$$

3 The ClO is destroyed by O atoms, releasing the Cl atom to destroy more ozone:

$$ClO + O \rightarrow Cl + O_2$$

Enzymes as catalysts

An **enzyme** is a catalyst made and used in living cells. Enzymes are made from one or more protein molecules. Enzymes play an important part in all cellular processes. These catalysts increase the rate of the reactions that occur inside a cell. There are numerous different enzymes in our bodies, as each cellular reaction requires its own specific catalyst. For example, enzymes in the digestive system help break down food, while enzymes in mitochondria catalyse respiration. Enzymes only work with specific reactants and so will only catalyse certain reactions.

One model that explains the action of enzymes is the **lock-and-key model**. The enzyme molecule has a specific shape, or active site (the lock), into which only specific reactants (the keys) will fit. The enzyme brings the reactants close together in the correct orientation so that they can react to form the products. The products are slightly different in shape from the reactants and so no longer 'fit' in the active site. So the enzyme releases the products and becomes available to collect more reactants.

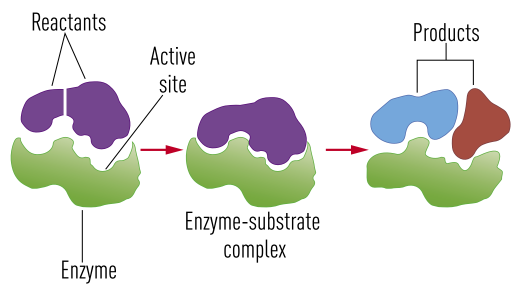


Figure 4.32 The lock-and-key model of enzyme activity.

Figure 4.31 Chlorofluorocarbons (CFCs) were used to pressurise the gas in aerosol cans before it was proven that the CFCs damaged the ozone layer.

QUESTIONS 4.2.3: FACTORS INFLUENCING THE RATE OF REACTION

Remember

1 Six factors affecting reaction rate have been explored in this unit. Identify the one thing they all have in common for increasing reaction rate.

2 Define the term 'catalyst'.

3 Identify why enzymes are considered to be 'biological catalysts'.

Apply

4 Explain why a greater surface area increases the rate of reaction.

5 Explain why a reaction may proceed more quickly when the reactants are stirred.

6 Describe the relationship between the concentration of reactants in solution and the rate of reaction.

7 Using your knowledge of collision theory, explain how decreasing the temperature of the reactants can reduce the rate of reaction.

8 Reactants A and B react to form product C. When catalyst X is added, the reaction rate appears to increase. Propose how you could test that X is really a catalyst and not a new reactant in a different reaction.

Analyse

9 Drying hair is a physical change. But the methods used to dry hair are similar to the methods chemists use to speed up the rate of chemical reactions. Relate each of the methods listed below to methods of increasing reaction rate.

- Blow air over it – moving air carries away water vapour, bringing in dry air to carry away more vapour.
- Heat the air – heat energy is needed to evaporate water, so the water will evaporate faster if the air is heated.
- Spread out or fluff up your hair – this gives a larger surface area for the water to evaporate from so that more water can evaporate at the same time.

Figure 4.33 In what ways does blow-drying your hair increase the rate of drying?

4.2

CHECKPOINT

RATE OF REACTIONS

Remember and understand

1 In terms of particles, identify the key requirements for a chemical reaction to take place. [2 marks]

2 Identify whether respiration is an endothermic or exothermic reaction. Describe the evidence that supports your decision. [2 marks]

3 Name at least four factors that influence the rate of reaction. [4 marks]

4 Describe a situation in which it could be dangerous for a reaction to occur too quickly. [1 mark]

5 Describe a situation in which it could be dangerous for a reaction to occur too slowly. [1 mark]

Apply

6 Describe at least two ways to measure the rate of a reaction. [2 marks]

7 Propose a reason why most food is kept refrigerated. [1 mark]

Figure 4.34 What is the purpose of refrigerating food?

8 In many industrial environments, dust is regarded as an explosion hazard. Explain why a reactive dust is more likely to explode than blocks of the same material. [2 marks]

9 A student wanted to investigate the effect of temperature on the reaction between hydrochloric acid and magnesium metal.

- **a** List four variables that should be kept constant in this investigation. [4 marks]
- **b** For two of these variables, explain how the experimental error would be increased if they were not controlled properly. [2 marks]

Analyse and evaluate

10 Propose how the particle model of matter helps us understand the rate of reactions. [3 marks]

11 The reaction $2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$ is very slow at room temperature. The reaction occurs more quickly in the presence of nitrogen dioxide gas. The reaction occurs in two steps, which are shown below.

Step 1:

$$2SO_2(g) + 2NO_2(g) \rightarrow 2SO_3(g) + 2NO(g)$$

Step 2:

$$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$$

Describe two reasons why the nitrogen dioxide is regarded as a catalyst. [2 marks]

Critical and creative thinking

12 Indigestion tablets often contain carbonates, which take part in neutralisation reactions in our stomach to reduce excess acidity. The general reaction is:

acid + carbonate → salt + water + carbon dioxide

Describe problems that might result if the reaction occurred:

- **a** too quickly [1 mark]
- **b** too slowly. [1 mark]

Making connections

13 Some catalysts work by providing a surface on which reactions can occur. These surface catalysts work by allowing the reacting particles to interact together on the surface of the catalyst.

- **a** Propose a reason why attracting particles onto a surface of another chemical would encourage a chemical change to occur. [1 mark]
- **b** Explain why a substance that actually bonded chemically to the reacting particles would not make a good catalyst. [1 mark]
- **c** Give an example of the use of a surface catalyst, describing in detail the chemical reaction. You may have to do some research to answer this question. [3 marks]
- **d** Use your knowledge of collision theory to explain why most catalysts are used in the form of a powder or fine mesh. [2 marks]

TOTAL MARKS
[/35]

CHEMISTRY AND INDUSTRY

4.3

Chemicals may have a public relations problem. We often see products advertised as 'chemical free' or 'organic'. It is easy to tap into people's fear of chemicals because the word 'chemical' is often associated with substances that are seen to do harm to the environment. Acids, pesticides, chlorofluorocarbons (CFCs), industrial waste and food additives are all chemicals, but chemistry is not just about these types of materials, and even these are safe if their quantities are controlled and their use is monitored. Many chemicals are vital in the production of materials that most of us use in our daily lives. A better understanding of chemistry allows us to predict, manage and reduce the risks of using chemicals in our environment as well as when producing important resources.

INDUSTRIAL CHEMISTRY

Many materials used in industry today are the end products of chemical reactions. Some of the reactions occur naturally, but do not proceed quickly enough to make enough product to be useful. Chemists research new reactions and ways of increasing the rates of reactions to make all sorts of products, from metals, to plastics and fibres.

Industrial chemistry is involved in producing almost all substances that are not found in large quantities in nature.

Oxidation and reduction reactions

As you are reading this book, respiration is keeping you alive. Respiration is an **oxidation** reaction in which oxygen combines with glucose to give our cells the energy they need to stay alive. Many chemical reactions involve bonding oxygen to other substances. Common oxidation reactions are combustion and corrosion. These reactions involve the combination of oxygen with a fuel or a metal.

The opposite process is called **reduction**. Compared with oxidation, reduction is the removal of oxygen from compounds. One such example is the smelting of iron ore (iron(III) oxide Fe_2O_3) into iron metal. Carbon is added to the iron(III) oxide to remove the oxygen. Carbon has a greater attraction for oxygen than does iron. As an equation, this process is written as:

$$2Fe_2O_3(s) + 3C(s) \rightarrow 4Fe(s) + 3CO_2(g)$$

This reduction reaction occurs in the making of iron and steel from iron ore. Carbon, in the form of coke, is added to a blast furnace. Molten iron forms and is drained off to form ingots of iron, or is further purified and alloyed to become steel.

Some chemical jars have a diamond-shaped warning label on the side, with the words 'oxidising agent' or '**oxidant**' (see Figure 4.36 , page 176). These substances can supply oxygen, or take the place of oxygen, in an oxidation reaction. In gunpowder, the oxidant is potassium nitrate, $KNO_3(s)$, which provides the oxygen for the combustion process to

Figure 4.35 The molten iron has been reduced by carbon.

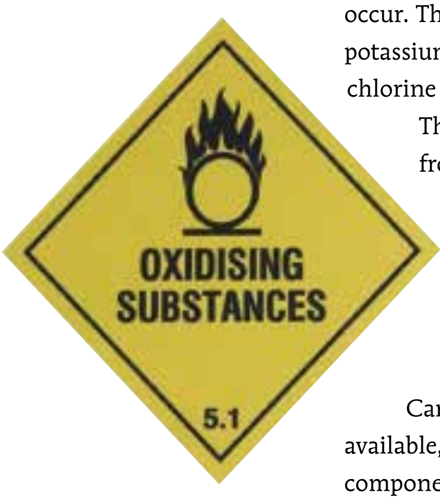


Figure 4.36 Warning label for oxidising agents.

occur. This is why gunpowder burns without air. Similar oxidants are potassium chlorate ($KClO_3$), potassium perchlorate ($KClO_4$) and potassium permanganate ($KMnO_4$). Other oxidants are chlorine (Cl_2) and hydrogen peroxide (H_2O_2).

The opposite of an oxidant is a **reductant** (reducing agent). Reductants remove oxygen from other substances; they combine with the oxygen atoms they have taken. Common reductants are carbon and carbon monoxide. Both of these reductants take oxygen to form carbon dioxide.

$$C(s) + \text{oxygen-containing compound} \rightarrow CO_2(g)$$

$$CO(g) + \text{oxygen-containing compound} \rightarrow CO_2(g)$$

Carbon is the most common reductant in the processing of metals. Carbon is readily available, and cheap, in the form of coal. When coal is heated in the absence of air, the volatile components are released. The solid left behind is called 'coke', which is nearly pure carbon. Coke is porous and ideal for use as a reductant in many chemical processes.

ACTIVITY 4.3.1: PRODUCING IRON

Resource-rich Australia has large deposits of iron, and exports of iron ore bring millions of dollars into the Australian economy. China and other Asian countries rely on iron from Australia to support the development of their industries and infrastructure. One of the major forms of iron ore is iron(III) oxide, known as haematite.

1. Research four uses of iron: one household, one related to infrastructure, one related to transport, and one related to sport or recreation. For each use, explain why the properties of iron make it suitable for use in that particular way.
2. Iron can be produced from haematite by a number of different reduction reactions. One such reaction is called the 'thermite process'. Your teacher may demonstrate this for you.

   The reaction can be described by the following equation:

   $Fe_2O_3 + 2Al \rightarrow Al_2O_3 + 2Fe$

   Describe the role of the aluminium in the process.
3. Why do you think the iron(III) oxide is described as being reduced in the thermite reaction?
4. The thermite process is not used to produce iron on an industrial scale. Rather, carbon monoxide or coke (C) is used to reduce the iron in blast furnaces within iron and steelworks. Carbon dioxide is produced as a by-product in the process. Copy and complete the following equation for the reaction.

   $Fe_2O_3 + 2CO \rightarrow$ ___________ + ___________

   (Hint: Make sure that you have applied the law of conservation of mass when writing the final equation.)

Figure 4.37 Iron ore exports are vital for the Australian economy.

Figure 4.38 Hot iron being roll-pressed into a length of rail.

Plastics and polymers

Plastics are a major part of our lives. They form the wrap we put around our sandwiches and the containers in which we store our food and other products. Recycled plastics are used to make wheelie bins. Plastics are made up of giant molecules called **polymers**. These polymers have been synthesised by chemists. There are also many naturally occurring polymers, including proteins, DNA and cellulose.

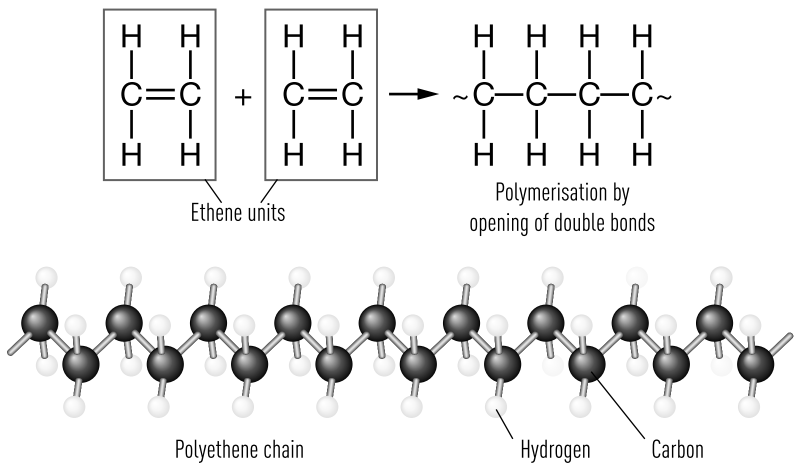


Figure 4.39 The formation of polyethene from ethene molecules.

Formation of polymers

Polymers are formed in **polymerisation** reactions in which smaller molecules (**monomers**) are combined to form long chain molecules. There are many different types of polymerisation reactions, but they all follow the same process: the monomers are placed under reaction conditions (i.e. specific temperature and/or pressure) that encourage them to join together in a chain reaction to form giant molecules that can contain thousands of atoms. Polyethene (also called polythene or polyethylene) is produced in this way: molecules of ethene (C_2H_4) react together to form long chain polymer molecules. This process can be represented using a diagram, as shown in Figure 4.39.

This polymerisation reaction requires high temperature and pressure, as well as a chemical catalyst.

Different types of polymers

DEEPER UNDERSTANDING

A polymer is a giant molecule produced by joining many, many smaller molecules or monomers together – often thousands. Polymer means 'many parts'.

If the polymer has been produced by chemists or chemical engineers, it is termed a 'synthetic' polymer. An example of a synthetic polymer is nylon. Before nylon was made, stockings were made from silk, which is a natural fibre produced by the silkworm. Apart from being expensive, stockings made from silk easily developed holes and 'ladders'. Toothbrush bristles were made from another natural fibre – the fine hairs from boars! Nylon was able to replace both of these because nylon fibre is much tougher and more suitable for these applications.

There are three types of polymer structures: linear polymers, occasionally cross-linked polymers (also known as elastomers) and cross-linked polymers (see Figure 4.40).

Linear polymers are in the form of long chains. Generally, the chains consist of carbon atoms held together by covalent bonding, with other atoms or groups attached to the carbon atoms. In some linear polymers, the atoms of another non-metal are found at regular intervals along the chain of carbon atoms. In nylon, for example, a nitrogen atom is found about every tenth atom along the chain. There may also be 'branches', segments like the main chain, hanging off the main chain.

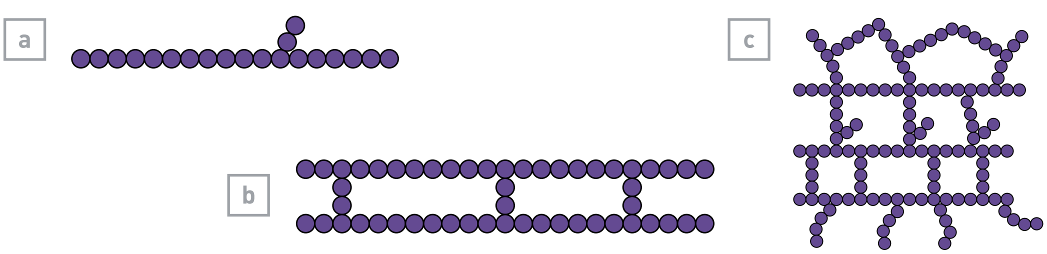


Figure 4.40 The basic structure of (a) a linear polymer, (b) an elastomer and (c) a cross-linked polymer. The circles represent the monomers.

Elastomers are like a ladder. They are in the form of long chains that are connected every now and then with a small chain of atoms. They are termed 'elastomers' because they are elastic – they can be stretched and, when you let them go, they spring back into shape.

Cross-linked polymers are giant covalent lattices. Generally, they are made up of carbon atoms, although the atoms are much more haphazardly arranged than in other covalent lattices, such as diamonds.

Figure 4.41 The cover of a Playstation is made of thermosetting polymers.

Apart from being classified according to their structure, another way in which polymers are classified is according to how they respond to heat. This is a very important property.

Thermoplastic polymers, such as plastic film, soften when heated gently and solidify again when cooled. They can be readily worked into different shapes by warming and pressing them, squeezing them through holes or even blowing them into the required shape. 'Plastic' means being able to have its shape changed. So, these are the only polymers that really should be described as 'plastics'.

Thermosetting polymers do not melt or change shape when heated. If heated very strongly, they may char (turn black). These polymers must be produced in a mould because once they are formed they will not change shape again. Once formed, they are hard and rigid.

EXPERIMENT 4.3.1: TESTING POLYMERS

Aim

To classify polymers based on their thermal properties.

Materials

- Samples of different polymers
- Forceps
- Beaker of very hot water
- Large white ceramic tile

WARNING

> Be very careful not to be burned by the hot water or steam.

Method

1. Drop each of the polymer samples individually into the beaker of hot water using the forceps.
2. After 1 minute, use the forceps remove each sample and place it on the tile.
3. Examine it carefully as you handle it.

Results

Record your observations for each polymer you tested. Did it become softer and more pliable after being dropped in the beaker of hot water? Did it spring back to its original shape as it cooled, or set hard in the new shape?

Figure 4.42 The properties of polymers determine their uses.

Discussion

1. When a polymer softens on heating and can be made to change shape, it is said to be in a plastic state. The softening temperature is the temperature at which this occurs. Did any of the polymers you tested become plastic?
2. From your results, identify whether any of the polymers are thermoplastic.
3. Suggest why this property was not tested by placing the samples in a flame.
4. For a fair comparison, what should have been true of all the samples tested? On the basis of this, did you conduct a fair test? Discuss.

Conclusion

Use your data to write a statement that addresses the aim.

EXPERIMENT 4.3.2: MAKING NYLON (TEACHER DEMONSTRATION)

Aim
To observe the polymerisation reaction used to make nylon.

Materials
- 5% 1,6-diaminohexane solution
- 5% adipoyl chloride solution in cyclohexane
- Distilled water
- Forceps or stirring rod
- 2 × 50 mL beakers
- Glass Petri dish containing 50% alcohol (ethanol)/water mix
- Paper towel or filter paper

WARNING

> This experiment should only be done as a teacher demonstration.
> The preparation of the chemicals, the making of the nylon, and clean-up, must be done in a fume cupboard. Do not breathe in the vapours.
> Wear a lab coat, safety glasses, gloves and closed-in shoes at all times.

Method
1. In a 50 mL beaker, mix 0.5 mL of adipoyl chloride and make up to 10 mL with cyclohexane. Stir.
2. In the other 50 mL beaker place 0.5 g of 1,6-diaminohexane solution and make up to 10 mL with distilled water. Stir until dissolved.
3. Gently pour the 10 mL of 5% 1,6-diaminohexane solution down the side of the second beaker containing the 10 mL of the 5% adipoyl chloride solution. Do not mix.
4. A skin will form between the interface of the two liquids. Lift the skin out with the forceps and gently wrap it around the length of the glass rod. This skin will continue to re-form for quite some time.
5. Unroll the thread into a Petri dish or a beaker containing 50% alcohol and leave it to soak for 10 minutes.
6. Remove the thread from the alcohol solution and dry it between layers of paper towel or filter paper.
7. Examine the thread under a microscope and sketch its appearance.

Results
Record your observations in an appropriate format.

Discussion
1. Describe the reactants used.
2. Describe the product formed.
3. What changes have taken place?
4. State a use for nylon and explain what properties of nylon make it suitable for that use.

Conclusion
Use your data to write a statement that addresses the aim.

Figure 4.43 Tents are made of nylon, which makes them lightweight.

Figure 4.44 Polar fleece has many uses when camping.

Modern uses of polymers

Many different polymers are used today. Designer polymers are being developed and modified to suit particular applications. Before World War II and the invention of nylon, tents were made of canvas. Canvas is a strong, durable, natural fabric. However, it can tear and leak, which is the last thing you want in stormy weather. Moreover, canvas is heavy to carry. Today, many tents are made from nylon, which is used to produce a lightweight, tear-resistant fabric. Bigger tents are made of cotton polyester. The bases of the tents are made of polyurethane, another useful, waterproof polymer.

The downside of using synthetic polymers for tents and other outdoor applications is that, over time, many deteriorate as a result of the action of ultraviolet (UV) radiation from the Sun. Substances known as UV stabilisers can be added to the polymer material to help slow this process.

Most people have at least one piece of clothing made of polar fleece, but do you really know why it is so warm and yet lightweight? Polar fleece is a synthetic wool made from PET, or PETE (polyethylene terephthalate). PET is a thermoplastic polymer and, for polar fleece, is sourced from recycled plastic bottles that have been processed into a clothing fabric. PET gives polar fleece its soft, warm, durable and fast-drying properties, which make it perfect for camping and other outdoor activities.

QUESTIONS 4.3.1: INDUSTRIAL CHEMISTRY

Remember

1 Identify the differences between oxidation and reduction reactions. Give an example of each process.

2 Define the terms 'oxidant' and 'reductant'. Give an example of each.

Apply

3 Identify the oxidant and reductant in the smelting of haematite to produce iron.

4 For each of the following applications, state whether it would be better to make the object from a thermosetting polymer or a thermoplastic polymer.

- a Food wrap
- b Light switch
- c Disposable drinking cup
- d Handles of barbecue tongs
- e Wash bottle for a science laboratory

Analyse

5 Deduce whether a thermosetting plastic is a linear or a cross-linked polymer. Justify your decision.

6 Polythene bags are commonly used throughout Australia, but some companies are now phasing them out or replacing them with other types of bag.

- a Propose reasons why polythene bags became common use.
- b Suggest some materials they may have replaced.
- c Research why Australia is trying to reduce the use of polythene bags.
- d Describe some measures that are being taken to reduce the use and production of polythene bags.

CHEMICALS AND POLLUTANTS

The chemicals we use contribute to the lifestyle we enjoy, but sometimes unwanted substances enter the environment and cause pollution.

Pollutants are chemical substances that are in the wrong place or are present in the wrong amounts and cause harm. Carbon dioxide is not normally a pollutant, but too much in the atmosphere is contributing to climate change.

Chemists are constantly developing new products and processes. New products are often more environmentally friendly than the products they replace. New processes reverse many of the negative environmental effects. Consider the methods used to prevent pollution from cars and the plans to implement carbon capture at coal-burning power stations.

Pollution from fuels

Fuels are the substances we use to produce heat and/or electricity, and to run engines and motors. When choosing a fuel for a particular use, factors such as cost, safety and efficiency are considered. Fuels can also be chosen according to the amount of pollution they release compared to the amount of energy they can produce.

The chemical fuels that our society relies on are based on carbon. Our ancestors burned wood, which is mainly the carbon compound cellulose. Later generations burned coal, which is close to pure carbon. Coal is made by the dehydration and compaction of buried plant remains. We use coal to produce electricity and petroleum as a liquid fuel for transport. Australia has huge supplies of brown coal and a good supply of natural gas.

All these fuels contain molecules made of carbon. Cellulose is a polymer of $C_6H_{10}O_5$ units arranged end-to-end, coal is up to 95% pure carbon (depending on the type) and petroleum is a mixture of hydrocarbons. Petrol is mostly octane (C_8H_{18}), diesel is a mixture with the average formula $C_{12}H_{23}$, natural gas is methane (CH_4) and liquefied petroleum gas (LPG) is propane (C_3H_8).

Petrol, diesel, natural gas and LPG are **fossil fuels**. They are obtained from the Earth and were formed from the fossilised remains of plants and animals. The energy in them was captured by photosynthesis millions of years ago. This carbon has been locked away out of the atmosphere for millions of years. Even renewable fuels, such as biodiesel and ethanol, contain carbon atoms. The carbon atoms in renewable fuels were captured by photosynthesis in the last growing season.

It is fair to say that our society runs on carbon. It is in every important fuel. Carbon is the mainstream of our economy. This is why is it called a carbon economy.

Carbon pollution

Burning carbon fuels provides energy at a relatively low cost, but there is a price to the environment.

Burning carbon fuels in excess oxygen produces carbon dioxide and water. When there is less oxygen available, carbon monoxide and soot (carbon) form. With even less oxygen, unburned hydrocarbons are released, along with water. As an example, the following equations show three possible reactions for the combustion of propane (C_3H_8). Note that as less oxygen is available, the products of the reaction will change.

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

$$2C_3H_8 + 7O_2 \rightarrow 6CO + 8H_2O$$

$$C_3H_8 + 2O_2 \rightarrow 3C + 4H_2O$$

Carbon monoxide (CO) is a poison that binds more tightly onto the haemoglobin in red blood cells than oxygen does. Victims of carbon monoxide poisoning die because of a lack of oxygen to the brain and other body tissues. Small particles of soot cause breathing problems, especially in people with asthma. It is important that all users of fossil fuels burn them 'cleanly' – in enough oxygen so that carbon dioxide, and not carbon monoxide or soot, is formed. In addition to releasing less pollution, burning fossil fuels in excess oxygen provides more energy.

Figure 4.45 Methane is the main component of natural gas, which is used to fuel gas hot water systems and stoves.

Figure 4.46 Carbon is the chemical basis for oils and fuels that we extract from the Earth.

Figure 4.47 Acid rain is caused by non-metal oxides, such as SO_2 and NO.

Other pollutants from burning fuels

Carbon fuels are not pure. Wood contains water and plant oils, whereas coal contains dust, nitrogen, sulfur and tar. Oil refineries now process petroleum to remove the sulfur, but this has not always been the case.

When a fuel is burned, the impurities in it, such as sulfur, are also burned.

$$S(s) + O_2(g) \rightarrow SO_2(g)$$

At high temperatures in an engine or furnace, nitrogen in the air can react with oxygen.

$$N_2(g) + O_2(g) \rightarrow 2NO(g)$$

The gases sulfur dioxide (SO_2), sulfur trioxide (SO_3, made from SO_2 in the atmosphere) and nitrogen monoxide (NO) dissolve in water and form acid. Even small amounts of acid can raise the acidity enough to destroy the ecosystems in forests, lakes and rivers. In cities, acid rain dissolves the limestone and marble on buildings and statues.

Pollution control in cars

Modern cars produce much less pollution than older cars. The pollutants are reduced by computer-controlled combustion in the engine and are removed in the exhaust system by a catalytic converter. As the exhaust gases pass through the converter, they react on the surface of the metals to form harmless gases. The metals that act as catalysts are platinum, palladium and rhodium. While the catalytic converters improve the efficiency of the vehicles and reduce pollution, these metals are very expensive.

The overall reaction that occurs in the catalytic converter is:

$$2CO(g) + 2NO(g) \rightarrow 2CO_2(g) + N_2(g)$$

Figure 4.48 Heavy traffic increases pollution levels.

Figure 4.49 Catalytic converters are used to reduce pollution from exhaust gases.

ACTIVITY 4.3.2: OXYGEN – A TOXIC CHEMICAL?

We all know that the presence of oxygen on the Earth is essential for our survival. But can oxygen be toxic? Can it be considered a harmful substance? In what situations is the presence of oxygen dangerous?

Hyperbaric chambers are often used by sports stars to speed up recovery from injury. It is believed that breathing in an atmosphere of pure oxygen improves wound healing and stimulates the growth of new blood vessels. However, the discovery that oxygen was toxic came through the experiences of early scuba divers, who were breathing pure oxygen for long periods of time at higher than normal pressure. Considering more long-term effects, it is thought that oxygen in our bodies causes the formation of reactive particles called 'free radicals'. These free radicals cause the tissues and organs in our bodies to age.

1 Do you think that oxygen should be described as a 'toxic' substance?
2 Why do you think that some people ensure that their diet contains a certain amount of antioxidants?
3 Do you know of any specific examples of oxygen treatment being used by sports men or women to recover from injury before an important competition?

4 Why do you think that breathing oxygen at high pressure might increase the chance of ill effects?

Figure 4.50 Professional sport players have often used oxygen treatments to speed up their recovery from injury.

Figure 4.51 Some harmful effects have resulted from scuba divers breathing pure oxygen.

Alcohols and biofuels

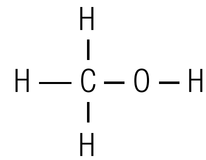
In Australia, oil companies are allowed to include up to 10% ethanol (alcohol) in their petrol. **Alcohols** are a family of compounds that contain carbon, hydrogen and oxygen. The two simplest members of this family are methanol (CH_3OH) and ethanol (C_2H_5OH) (see Figure 4.52). Their formulas are written in this way to show how the atoms are bonded.

Methanol blends have been used in racing cars for many years. Ethanol blends have been used for vehicles for a long time in some other countries.

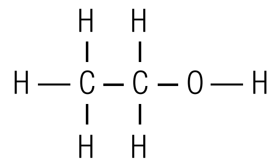
These alcohols are suitable for use in this way because they meet the requirements of a fuel. The equation for the combustion of ethanol is:

ethanol + oxygen → carbon dioxide + water + energy

$$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g) + \text{energy}$$



methanol



ethanol

Figure 4.52 Chemical structures of methanol and ethanol.

Alcohol also burn more 'cleanly' than petrol. So, the greater the percentage of alcohol present, the lower the amount of pollutants produced. Some alcohols also greatly improve engine performance.

The main reason that ethanol is used as a fuel is that it is regarded as a more sustainable fuel because it can be produced by fermenting plant material, even wheat stubble. Its use will help decrease the rate at which we consume the hydrocarbon oils that are obtained from crude oil, a non-renewable resource.

Petrol is called a fossil fuel because the crude oil from which it comes was produced from ancient organisms, mainly plants, in a process that took millions of years. This process occurred with no oxygen. Alcohols such as ethanol are **biofuels** because they come from plant material that has been recently grown and decayed. There is much debate about the long-term use of biofuels because the land required to grow plants can then not be used to grow food crops.

Figure 4.53 Microalgae are farmed to metabolise household wastes and produce methane as a fuel. The carbon dioxide produced in burning the fuel is then pumped back into the tanks to help promote photosynthesis.

Biochemists are looking at ways to produce crops that have higher amounts of sugars. These sugars can then be fermented to produce ethanol. This could lead to higher yields of ethanol and make it more likely that fossil fuels could be replaced by sustainable and affordable biofuels.

LITERACY BUILDER

Biofuels deepen poverty and accelerate climate change: Oxfam report

www.oxfam.org.au, 25 June 2008

The biofuel policies of developed countries like the US and the EU have dragged more than 30 million extra people into poverty according to a report released by international aid agency Oxfam.

The report, 'Another Inconvenient Truth', finds that biofuel policies are not solving climate change or the fuel crisis but are instead contributing to food insecurity, hunger and inflation, which hit poor people hardest.

The report calculates that developed country biofuel policies have dragged people into poverty by causing a 30 per cent increase in global food prices.

The report follows news that food and drink companies including Unilever, Nestle, Cadbury and Heineken asked the European Commission to review its policy that encourages biofuel production, stating that they believed it would help drive agricultural commodity prices to further record highs.

Unlike many other developed countries, Australia has not set mandatory targets for biofuel production or use.

Figure 4.54 Large areas of Amazon rainforest are being turned over to the production of soybeans for biofuel.

Oxfam Australia's biofuels and food crisis expert, Jeff Atkinson, said the report illustrated how catastrophic policies like mandatory targets had been, and urged the Australian Government not to adopt them.

'Biofuel policies are actually helping to accelerate climate change and deepen poverty and hunger. Rich countries' demands for more biofuels in their transport fuels are contributing to spiralling production and food inflation,' Mr Atkinson said.

Mandatory targets for biofuel use place a legal obligation on fuel companies to blend a certain volume or percentage of biofuels with the petrol and diesel they sell.

'The evidence about the damage of mandatory targets is overwhelming, and we strongly urge the Australian Government to ensure that these targets for biofuels are not adopted in Australia. Such targets would only serve to put pressure on agricultural land in developing countries,' Mr Atkinson said.

Mr Atkinson said the cultivation of biofuel products required mass land clearing that took over agricultural land and forced farming to expand into lands like forests and wetlands. This triggered the release of excessive and damaging carbon into the atmosphere, cancelling out the environmental benefits of biofuels.

He said in Indonesia, where peatland tropical rainforest was being cleared to make way for palm oil, which is used in biodiesel, it would take approximately 420 years of biofuel production to pay back the carbon debt accrued from this destruction of the rainforest's carbon stores.

Mr Atkinson said biofuels also would not address wealthy countries' need for fuel security.

'Even if the entire world's supply of grains and sugars were converted into ethanol tomorrow – in the process giving the world less to eat – we would only be able to replace 40 per cent of our petrol and diesel consumption,' Mr Atkinson said.

Questions

1. Biofuels in Australia are promoted as cheaper, cleaner, greener and locally made. Is this statement true? Are biofuels going to solve our fuel crisis?
2. Governments have put mandatory targets on biofuel production. What does this mean? What are the advantages and disadvantages of mandatory targets?
3. This report was published in 2008. Research the changes that have happened in the biofuels debate since then.

Acid pollution

Many people think that acids are only found in bottles in the laboratory, but acids are also found in the environment. Some acids occur naturally in the environment, whereas others are made by humans. Any substance made by people is said to be anthropogenic.

Carbon dioxide

Carbon dioxide is a natural product, but is a pollutant when there is too much of it. The levels of carbon dioxide in the atmosphere are increasing all the time. Some of this carbon dioxide dissolves in the oceans, where it can lower the pH of the sea water, causing it to become acidic.

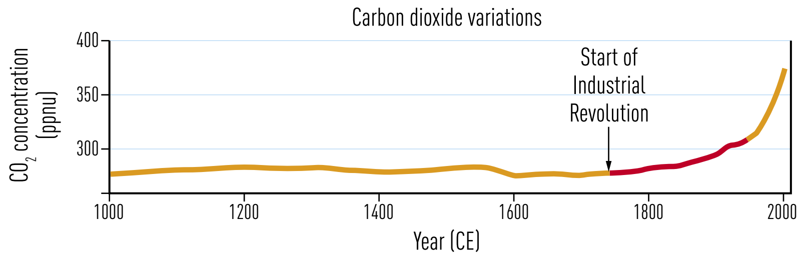


Figure 4.55 Carbon dioxide levels in our atmosphere have increased dramatically since the Industrial Revolution and they continue to rise.

Carbon dioxide is an essential part of the environment. Plants use it for photosynthesis and animals produce it in respiration. It also helps form bones and shells in many animals. Large quantities of carbon are present in the oceans and in the carbonate rocks called limestone and dolomite.

EXPERIMENT 4.3.3: EFFECTS OF ACID POLLUTION ON CARBONATES

Aim

To investigate and compare the reactions of calcium carbonate with a strong acid (hydrochloric acid) and a weak acid (ethanoic acid).

Materials

- 1 M hydrochloric acid (HCl)
- 1 M ethanoic acid (acetic acid) (CH_3COOH)
- Limewater (calcium hydroxide) ($Ca(OH)_2$
- Marble chips (calcium carbonate) ($CaCO_3$)
- Test tubes
- Test tube rack
- Spatula
- 2 × 100 mL conical flasks
- Single-holed rubber stopper with bent glass delivery tube

WARNING

> Wear safety glasses and lab coats, and avoid skin contact with the acids.

Method

1. Draw up a table to record each test and the results for each acid.
2. Using a clean spatula, transfer four or five marble chips to one of the conical flasks. Add approximately 2 cm of limewater or a test tube. Now add enough 1 M hydrochloric acid to cover the marble chips and place the stopper delivery tube in the mouth of the flask so that any gas produced will bubble into the limewater in the test tube.
3. Record your observations of any changes that occur in both the flask and the test tube.
4. Repeat step 2 with 1 M ethanoic acid, using a fresh conical flask and a fresh test tube of limewater. Compare the rate of this reaction with that of the hydrochloric acid.

Results

Record your results in an appropriate table.

Discussion

1. What can be concluded about the strength of ethanoic acid compared with that of hydrochloric acid? Discuss, using your data as evidence.

2 The limewater test is the standard test for carbon dioxide gas. Limewater goes milky because the carbon dioxide reacts with the limewater to produce a precipitate of calcium carbonate. The equation for the reaction is:

$Ca(OH)_2(aq) + CO_2(g) \rightarrow CaCO_3(s) + H_2O(l)$

3 Did your tests confirm that carbon dioxide gas was produced? Was there a difference in the rate of its production? If so, suggest why.

4 Write balanced equations for the reactions of the two acids with calcium carbonate.

Conclusion

Use your data to write a statement that addresses the aim.

Oxides of nitrogen and sulfur

Natural rainwater is slightly acidic due to the carbonic acid dissolved in it. However, acid rain is more acidic because of oxides of non-metals that have dissolved in it.

Small amounts of sulfur in fuels and nitrogen in the air combine with oxygen to form oxides of sulfur and nitrogen. Because there is a variety of oxides formed, each with a different formula, these compounds have been given the general of formulas SO_x and NO_x, where *x* stands for a subscript number, such as 1, 2 or 3.

These oxides can react with water in the atmosphere to form acids, which contribute to the formation of acid rain.

$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$ (sulfurous acid)

$SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$ (sulfuric acid)

$2NO_2(g) + H_2O(l) \rightarrow HNO_2(aq) + HNO_3(l)$
(nitrous acid and nitric acid)

Acid rain is really a mixture of many acids. The water could be rain, snow, cloud or dew, but it is all called acid rain. Even small amounts of acid can raise the acidity enough to disturb the ecological balance.

Natural rainfall has a pH of between 5.8 and 4.8, depending on the amount of carbon dioxide dissolved in it. The average urban rainfall pH is 4.5. The most acidic rain recorded worldwide had a pH of 2.3.

The effects of acid rain include:

- increased corrosion of masonry (stonework and concrete) and metals
- changes to availability of ions in the soil
- damage to new growth on trees
- effects on marine life, such as shell formation.

QUESTIONS 4.3.2: CHEMICALS AND POLLUTANTS

Remember

1 Explain why sulfur is removed from petrol used in vehicles.

2 Identify the difference between natural and anthropogenic carbon dioxide.

3 Identify what a catalytic converter is. Explain why they are used.

4 What is the pH of natural rain and acid rain? Explain why there is such a difference.

Apply

5 Petrol and ethanol originally came from living plant material. However, only ethanol is described as a biofuel. Explain why this is the case.

6 Propose some methods of reducing the incidence of acid rain in the environment.

7 Classify each of the following fuels as hydrocarbon, alcohol or neither.

a C_4H_{10} **b** C_2H_4 **c** H_2 **d** C_3H_7OH

Analyse

8 Propose reasons why carbon fuels are so important to our society.

SAFE AND SUSTAINABLE USE OF CHEMICALS

Not all chemicals are dangerous, and those that are can be handled safely and used in industry. Knowledge and understanding of the properties of chemicals and their potential risks enables chemists to evaluate the risks, and to design appropriate methods of using those chemicals. Continual investigation and research into chemistry can lead to safer alternatives that may produce better quality products at greater quantities or faster rates as well as being better for the environment.

Green chemistry and sustainability

Being 'green' means doing something positive for the environment. Scientists with special knowledge in ecology, biochemistry, zoology and botany study the environment and how it responds to changes caused by natural events, as well as by human actions. They monitor the environment for changes that may have been caused by the actions of society.

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

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

Green chemistry is sometimes called 'sustainable chemistry'. It is about reducing the impact of chemicals on the environment – chemists produce substances in processes that have less impact on the environment than the substances they replace. The following are some examples of why the development of 'green' alternatives are necessary.

- Pesticides and herbicides are poisons used to kill the living things that eat our food crops and the plants that compete with these crops for sunlight and nutrients. In the past, some of these products killed all living things, not just the target species. Most were non-degradable (did not break down) and remained in the environment long after they were no longer needed. These substances are now banned and have been replaced with biodegradable poisons. In many cases, chemical poisons have been replaced with new farming practices, such as crop rotation and the use of pest-resistant crop varieties.
- CFCs were developed as refrigerants and quickly found other uses in aerosol cans and fire extinguishers. It was later discovered that they use caused severe environmental damage – destruction of the ozone layer. CFCs were banned and new substances were developed to replace them.
- Heavy metals include lead, mercury and cadmium. Heavy metals had many uses, especially in dyes, and were used in chemical processes, especially as catalysts. But these metals accumulated in the bodies of living things, including people. The most dramatic example is Minamata disease. In 1956, people in Minamata, Japan, were poisoned by mercury after eating contaminated seafood. The use of heavy metals in situations where they could enter the environment has been largely stopped. They have been replaced by different catalysts and even different production processes.
- Acrylic paints have replaced solvent-based enamel paints and lacquers. The solvent used in the old paints was a hydrocarbon, such as turpentine, and it evaporated as the paint dried. Acrylic paints are water based and set by polymerisation of the paint, not by evaporation of a solvent. The hydrocarbon solvents in enamel paint were toxic to aquatic life in waterways and the fumes from the paint caused 'painter's disease' (a central nervous disorder) in the workers who inhaled them.

Figure 4.56 Many chemical products considered safe for use in the past have been replaced by more environmentally friendly substances.

ACTIVITY 4.3.3: WHAT CAN YOU DO TO CONTROL CHEMICALS IN THE ENVIRONMENT?

What can you, as one person, do to protect the environment and the planet?

By adapting the slogan 'Reduce, reuse, recycle' you can reduce your footprint on the environment. You can do this by:

- taking your own shopping bag and not using plastic
- composting grass clippings and food scraps, and using this compost instead of chemical fertilisers.

By adapting the slogan 'Think global, act local', you can reduce your footprint on the planet. You can do this by:

- buying trigger-action spray cans, not aerosols
- avoiding non-degradable products, such as some biocides
- leaving the car at home for short journeys, and catching public transport or riding a bike instead
- using natural cleaning products and avoiding chlorine-based cleaners.

Figure 4.58 In what ways do 'green' shopping bags reduce harmful chemicals in the environment?

Questions

1 What other materials can be recycled to reduce the risk of chemical pollution?

2 What are the properties of substances that would make them suitable for recycling?

3 What other actions can you take to reduce your impact on the environment? Your actions will make a small difference, but when others join you, the effect is quite dramatic.

Figure 4.57 Riding a bike reduces traffic congestion and is a healthy way of keeping fit, as well as reducing the amount of carbon dioxide produced.

QUESTIONS 4.3.3: SAFE AND SUSTAINABLE USE OF CHEMICALS

Remember

1 What constitutes 'green' chemistry?

2 The 'old masters', the painters of 1600s–1800s, used pigments made of compounds of lead, mercury and cadmium. Explain why these paints are no longer available.

Apply

3 Propose why graphics are used on chemical warning labels.

4 Why do you think 'unleaded' petrol was developed?

5 Propose why green chemistry requires knowledge in ecology, biochemistry, zoology and botany as well as chemistry.

Ethical thinking

6 If you discovered an important new chemical today, could you be responsible for any consequences that occurred 30 years in the future? Could the people who are affected in 30 years time blame you?

CHEMISTRY AND INDUSTRY

4.3 CHECKPOINT

Remember and understand

1 Name two different reactions that release carbon dioxide as a product. [2 marks]

2 Using an example, describe what is meant by the term 'oxidant'. [2 marks]

3 Identify a key difference between a fossil fuel and a biofuel. [2 marks]

4 Describe the effect of acid rain on objects made of limestone (calcium carbonate). [1 mark]

5 Explain the advantages and disadvantages of using alcohol instead of petrol in cars. [2 marks]

6 Identify how many atoms of carbon, hydrogen and oxygen are present in a molecule of ethanol (CH_3CH_2OH). [3 marks]

Apply

7 Polypropylene is a plastic that is easily melted and formed into a range of different products. Describe the likely structure of polypropylene and explain how its structure allows the plastic to be moulded into different shapes. [2 marks]

8 Explain why some people say that our society's energy demands are based on carbon. [2 marks]

9 Describe how acid rain is formed from the burning of fossil fuels. [3 marks]

10 Propose some green chemistry that could be applied at home. [2 marks]

Analyse and evaluate

11 Describe, in terms of molecules, the key differences between the formation and melting of a polymer. [2 marks]

12 Explain why carbon dioxide – a natural product – is regarded as a pollutant. [2 marks]

Ethical behaviour

13 In the 1920s, the compound tetraethyl lead was developed to prevent 'knocking' in car engines (where the spark plugs fire too early, resulting in loss of power and possible engine damage). Adding tetraethyl lead saved the cost of additional refining of petrol, which resulted in lower costs for consumers and motorists. However, some people raised concerns about the use of a lead compound that was being released from the exhaust of cars. If you had been part of the debate in the 1920s, what arguments would you use against the use of tetraethyl lead? [3 marks]

Critical and creative thinking

14 Propose how advances in technology have helped scientists improve their methods for producing chemical products. [3 marks]

15 List the energy sources available to our society. Which of these are suitable as fuel for cars, trucks and buses? Which of these are renewable? Which of these do not contribute to environmental change? [4 marks]

Making connections

16 Prepare a poster or digital presentation on the use of ethanol as a fuel. Outline the advantages and disadvantages of using ethanol in this way. Include relevant diagrams or images that support your arguments. [5 marks]

Figure 4.59 Leaded petrol is no longer available.

TOTAL MARKS
[/40]

4 CHAPTER REVIEW

1 Fill in the gaps, using the words in the Word Bank below:

A range of different types of chemical reactions can be used to make specific _______. The reaction involves a transfer of _______ between the reactants and products. Reactions that have more energy in their products than in their _______, absorb energy and are called _______ reactions. Those that release energy are called _______ reactions.

The _______ of reactions can be altered in a number of ways; _______ temperature increases reaction rate as does introducing a _______.

Knowledge of chemicals and their reactions enables the development of new and _______ products. The needs of _______ and the environment are balanced and generate new career paths like _______chemistry.

WORD BANK

catalyst	green	reactants
endothermic	increasing	society
energy	products	sustainable
exothermic	rates	

Identify that chemical reactions transfer energy and can be classified as either exothermic or endothermic

2 Identify the following reactions as endothermic or exothermic. Provide reasons for your decisions.

a water + energy → hydrogen + oxygen [2 marks]

b methane + oxygen → carbon dioxide + water + energy [2 marks]

3 Explain why all reactions have an activation energy. [2 marks]

4 In terms of chemical bonds, explain how reactions transfer energy. [3 marks]

Construct simple electrochemical cells to describe energy transfer (additional content)

5 Describe the structure of a voltaic electrochemical cell using a lemon. [4 marks]

6 Explain the difference between electrolytic and voltaic electrochemical cells. [3 marks]

Compare combustion and respiration as exothermic reactions of different rates

7 Compare and contrast combustion and respiration. [5 marks]

Describe the effects of changes in temperature, surface area and catalysts on the rate of chemical reactions

8 Explain what is meant by the 'rate of reaction'. [1 mark]

9 Give an example of a:

a slow reaction [1 mark]

b fast reaction. [1 mark]

10 Describe the relationship between the rate of reaction and:

a temperature [1 mark]

b surface area [1 mark]

c concentration [1 mark]

d the presence of a catalyst. [1 mark]

Analyse how the development of new materials can be influenced by social, ethical and environmental considerations

11 Propose why industrial chemists and chemical engineers generally look for ways to increase reaction rates. [2 marks]

12 Identify two advantages and two disadvantages of making carpet from nylon. [4 marks]

13 Identify the advantages and disadvantages of completely replacing fossil fuels with biofuels. [4 marks]

4 CHAPTER REVIEW

Describe examples where advances in science and technology generates new career opportunities

14 Define the term 'green chemistry' and explain why this new branch of chemistry came into being. [2 marks]

15 Explain how the discovery of polymers provided new career opportunities. [3 marks]

Investigate the process involved in the production of synthetic fibres (additional content)

16 Define the terms 'polymer' and 'monomer'. [2 marks]

17 Describe the differences between linear polymers, cross-linked polymers and elastomers. [3 marks]

Balance chemical equations (additional content)

18 Write a balanced chemical equation for the production of hydrogen gas from magnesium and hydrochloric acid (there is one other product). [2 marks]

TOTAL MARKS
[/50]

RESEARCH

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

Rare metals

A range of rare metals is used in microelectronic devices. Many of these metals, such as tantalum and niobium, are sourced from Australia. Find out more about where these metals are found in Australia, the form in which they occur naturally, the chemical processes used to extract the pure metals and what we can do to conserve t these metals.

Nanotechnology

Nanomaterials are now being used as catalysts for a range of chemical reactions, often ones that produce valuable products. Research these products and how the use of nanomaterial catalysts has improved the production method.

Ozone and CFCs

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

REFLECT

Me

1 What do you think was the most important concept in this chapter?

2 What were the most difficult aspects of this topic? Why?

3 How has your understanding of chemical reactions improved?

4 What new science skills have you obtained from this chapter?

My world

5 Why is it important to know how chemical reactions can be used?

6 How has our increased knowledge of chemistry affected how we live?

My future

7 In what ways do you think people will change how they use chemistry in the future?

8 Can chemistry contribute to the sustainable use of our resources?

KEY WORDS

activation energy
adsorb
alcohol
anode
biofuel
catalyst
cathode
collision theory
electrochemical cell
electrode
electrolysis
electrolyte
endothermic
enzyme
exothermic
fossil fuel
green chemistry
lock-and-key model
monomer
oxidant
oxidation
pollutants
polymerisation
polymer
reaction rate
reductant
reduction
reversible
synthesis

4

MAKING CONNECTIONS

Interaction and change

Choose one of the following topics to complete.

Clara Immerwahr

Clara Immerwahr was a Jewish–German chemist. She was the first woman to obtain a PhD at the University of Breslau in Germany. Despite this success, the social and cultural conventions of the time meant Clara was never able to fulfil her potential as a chemist and she spent a lot of her time supporting her husband's work. When she was 44 years old, she pointed her husband's military pistol at her chest and fired a single bullet. Her 13-year-old son held her as she died.

Her husband was Fritz Haber. He was born into a Jewish family on 9 December 1868. Haber's extraordinary life was full of science and tragedy. Fritz Haber's mother died giving birth to him. In his university studies, Haber was guided by Robert Bunsen, who invented the Bunsen burner, and August von Hofmann, also a very famous chemist.

Between 1894 and 1911, Haber worked with Carl Bosch, a chemist and engineer, to develop what became known as the Haber–Bosch process. This process was able to produce ammonia (NH_3) on a vast scale. Ammonia is essential for the production of a number of synthetic fertilisers and, as the population of the world at the beginning of the 20th century was rapidly increasing, the demand for fertilisers to promote the growth of crops was also on the rise. Haber worked to determine the best conditions for the reaction of hydrogen and nitrogen to make the ammonia, whereas Bosch, as an engineer, was able to scale up Haber's laboratory methods into an industrial process. This work enabled the economically viable production of synthetic fertilisers, which resulted in the survival of millions of people.

It was during this time, when he was 33 years of age, that Fritz Haber married Clara. Together, they had one son, Hermann, who would also grow up to be a chemist. In 1918, Fritz was awarded the Nobel Prize in Chemistry for this work, but before this happened his life and work took a tragic turn.

During World War I, Haber supported the German military effort. Not only were large amounts of the ammonia produced by his process being used to produce explosives, but Haber was also instrumental in designing ways to produce chlorine gas as a chemical weapon. Haber himself supervised some of the first uses of chlorine gas on the battlefields during the war. In 1915, one such attack killed 5000 French soldiers at Ypres, Belgium. It was Haber's celebration of this event that was the last straw for Clara, who had always opposed Fritz's use of science for the purposes of war. It was on this night that she took her own life. The next day Haber returned to his work with the military. He went on to help produce the poison gas Zyklon A, which was refined by the Nazis to produce Zyklon B, which was used to kill thousands of Jewish people in the gas chambers during the Holocaust in World War II.

Haber eventually died at 65 years of age, having been driven out of Germany due to his opposition to the actions and philosophies of the Nazi regime, especially in relation to the treatment of Jews. But he was also shunned by many in the scientific community for his work with chemical weapons.

Figure 4.60 Clara Immerwahr.

Figure 4.61 Fritz Haber.

Figure 4.62 Chlorine gas was first used as a weapon in World War I.

Figure 4.63 Huge quantities of ammonia are produced in Australia each year.

Your task

1 Describe how the needs of society at the time influenced the work of Fritz Haber.

2 Describe how the values and conventions of society at the time influenced the work of Clara Immerwahr.

3 Do you think Haber was a good scientist? Justify your response.

The Haber process

Ammonia is produced in the reaction of hydrogen gas and nitrogen gas. The reaction is reversible and can be represented as:

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$

It is possible to speed up the reaction by heating it, increasing the pressure of the gases and adding a catalyst. Unfortunately if the temperature and pressure increase too much, the reverse reaction (i.e. ammonia being converted back into nitrogen and hydrogen) also occurs and it is hard to collect enough ammonia. After years of painstaking trials, Haber was able to determine the exact conditions that would produce a fast enough reaction to produce ammonia without the ammonia converting back into the starting materials. These conditions consisted of temperatures of 300–550°C and a pressure of approximately 200 atm (200 times normal air pressure). An iron catalyst was found to speed up the reaction.

Australia produces large amounts of ammonia each year, with the largest ammonia plant in Australia situated on the Burrup Peninsula in Western Australia. The worldwide production of ammonia is huge, with more than 100 million tonnes currently being produced each year. An amazing fact is that half of all the nitrogen-containing proteins in the average human body have been generated from nitrogen compounds made through the Haber process.

Figure 4.64 Many fertilisers have been manufactured from compounds containing ammonium salts.

Your task

1 Look at the equation for the Haber process.

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$

  a What type of reaction is the forward reaction? Justify your answer.

  b What type of reaction is the reverse reaction? Justify your answer.

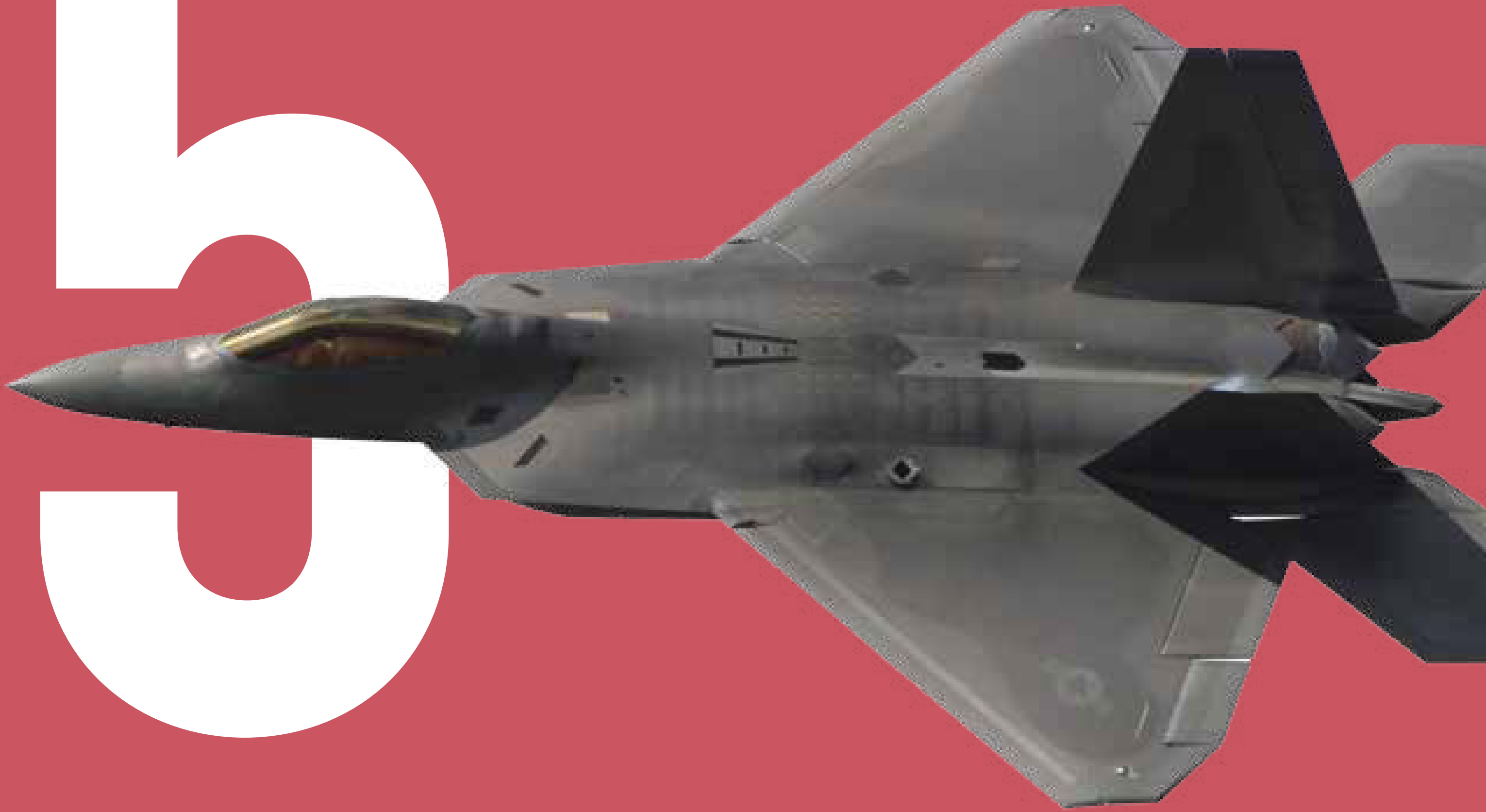
2 Conduct research to locate the Burrup Peninsula. What type of environmental concerns would need to be addressed at this site?

3 Chlorine was used as a chemical weapon in World War I. Describe two uses of chlorine in society today.

4 Use your knowledge of collision theory to explain why, in the Haber process, increasing the pressure of the gases increases the rate of the reaction.

5 Use your knowledge of collision theory to explain why, in the Haber process, the iron catalyst used is in the form of a powder or fine mesh.

5



OBJECTS IN MOTION

Motion, in all its different forms, is essential to our lives. Many sports involve motion of a ball and all involve motion of the human body. We are all familiar with motion in various forms, yet how much do we know about it and how it relates to force, mass and energy? And how good are we at measuring it? In this chapter we will start to unravel how force, mass and motion are linked together within the concept of energy.

CHARACTERISTICS OF MOTION 5.1

Physicists use the terms displacement, direction, time, speed, velocity and acceleration to describe the change in position of an object. These are the characteristics of motion.

Students:

- » explain the relationship between distance, speed and time
- » explain the difference between speed and velocity (additional content)
- » describe the equations of motion (additional content)

FORCE, MASS AND ACCELERATION 5.2

An object cannot move or change its motion unless a force acts on it. Acceleration occurs when a force acts on a mass and its motion changes.

Students:

- » describe the relationship between force, mass and acceleration
- » relate acceleration to a change in the motion of an object due to a net force
- » analyse everyday situations involving motion and describe them in terms of Newton's laws of motion

COLLISIONS AND ENERGY TRANSFER 5.3

When two or more moving objects exert forces on each other, it can be described as a collision. All collisions involve force, mass, acceleration, energy and work.

Students:

- » apply the law of conservation of energy
- » describe how and why the transformation of usable energy is not 100% efficient
- » compare energy transfers and transformations in sports (additional content)

5.1 CHARACTERISTICS OF MOTION

How did you get to school today? How would you describe the motion of the car, bus, train, bike or your own feet that takes you to and from school each day? Several specific scientific terms and mathematical formulas can be used to describe moving objects, and very precise measuring equipment is used to measure the motion of objects. It is important to understand these terms, because motion is part of our everyday lives.

DISTANCE AND DISPLACEMENT

Distance is how far an object travels. **Displacement** describes the overall change in position of an object and its direction. Displacement only compares the end position with the starting position, not all the in-between movements. If an object ends up back where it started, its displacement is always zero. If an object travels hundreds of kilometres but ends up 1 metre north of its starting point, its displacement is 1 metre north. For distance we use the symbol *d*, for displacement we use the symbol *s*, and the standard unit (or SI unit) for both is the metre (m). Remember:

1000 metres (m) = 1 kilometre (km)

Distance is known as a **scalar** quantity because it only has **magnitude** (size) and no direction. Displacement is known as a **vector** quantity because it has both size and direction. The direction part can be a compass direction (north, south, east, west) or a bearing, or it may be as simple as left, right, up, down, forwards or backwards. Table 5.1 lists some examples of distance and displacement measurements.

Table 5.1 Distance and displacement measurements.

Distance (*d*)	Displacement (*s*)
42 m	12 m left
12 cm	44 cm forwards
19 km	5.6 km north

Position–time graphs

Motion graphs are models or visual representations of motion and can take many forms. The simplest is a position–time graph (also called a displacement–time graph). A position–time graph is a picture of the motion of an object. The 'picture' is a line to show the object's position (or displacement) at a given time from its starting point. Position–time graphs are really only useful when the motion is linear, that is, in the same line, such as east–west or up–down. Time is always on the horizontal axis and position is always on the vertical axis. Remember to mark the units (for example, seconds, metres) on the graph.

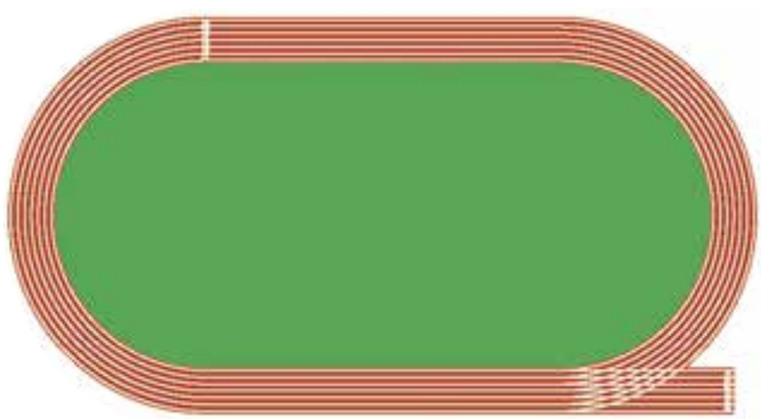


Figure 5.1 Distance and displacement can be very different. When runners complete one lap of this track they have run a distance of 400 m, but if they have returned to where they started, their displacement is zero.

NUMERACY BUILDER

Interpreting motion graphs

Examine the position–time graphs in Figures 5.2 and 5.3 with other members of your class and answer the questions that follow. Include as much detail as possible and be very clear in your answers.

- Describe, in full sentences, the motion of object A.
- Object A covers a distance of 4 metres. How do you know this?
- The final displacement of object A is 4 metres north. How do you know this?
- Between 6 and 8 seconds, object A was stationary. How do you know this?
- Describe, in full sentences, the motion of object B.
- Object B covers a distance of 12 metres. How do you know this?
- The final displacement of object B is 4 metres south. How do you know this?

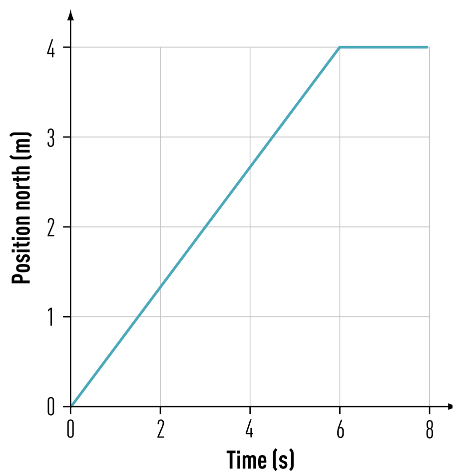


Figure 5.2 A position–time graph for object A.

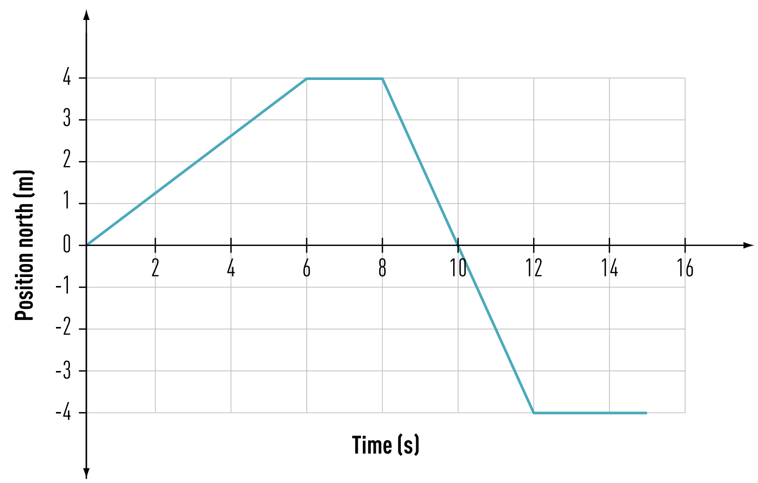


Figure 5.3 A position–time graph for object B. Negative values on the vertical-axis represent positions south of the starting point.

ACTIVITY 5.1.1: BRINGING GRAPHS TO LIFE

In this activity you will work in pairs to act out the position–time graphs in the Figures 5.2 and 5.3.

What you need: a clear space (perhaps outside), tape measure, stopwatch, masking tape, felt-tip pen

1. Lay out a 4-metre piece of masking tape on the ground and mark it at intervals of 1 metre.
2. Rehearse the motion shown in Figure 5.2 by discussing it with your partner and even doing a walk-through rehearsal.
3. Start the stopwatch and try to match your motion to the graph. The person timing you will give you feedback on how you went.
4. Swap roles and repeat the activity.

Figure 5.4 Use the motion graphs to re-enact the motion of the objects.

5 Try it again with Figure 5.3, but this time you will need another piece of masking tape on the ground going 4 metres in the opposite direction.

- How did your group perform in this task?
- What difficulties did you have in demonstrating the motion?
- Draw your own position–time graph and try to act out the motion. How did you go this time?

NUMERACY BUILDER

Distance and displacement diagrams

Instead of graphs, diagrams can be used to represent the distance an object travels. Distance and displacement diagrams are most useful when the motion changes from linear to two dimensions. We can use arrows to show the changes in direction and a scale to show the distances. North commonly points towards the top of the page.

Figure 5.5 shows a diagram of a person walking 5 metres north, then 4 metres west and then 2 metres south. This gives a total distance covered of 11 metres. However, this is not their displacement. Their displacement only compares where they finish to where they started. Look carefully at Figure 5.6 to see how to work out the displacement. The displacement is the final position compared with the starting position. Some of the mathematical tools we can use to calculate this include Pythagoras' theorem and trigonometry. Learning Pythagoras' theorem, trigonometry and bearings in mathematics can help us in science!

1 Calculate the distance between the start and finish points using Pythagoras' theorem.

If x = displacement:

$x^2 = 3^2 + 4^2$

Therefore, x = 5 m (the triangle is a 3–4–5 triad).

2 Work out the angle between the start and finish points using trigonometry.

$$\tan\theta = \frac{4}{3}$$
$$\theta = \tan^{-1}\left(\frac{4}{3}\right)$$
$$= 53°$$

Therefore, the displacement is 5 m on a bearing of N53°W or 307°.

Your turn

1 Determine the distance travelled by the person when they reach each of the two corners.

2 Determine the displacement at each of the two corners. You may like to draw diagrams to assist you.

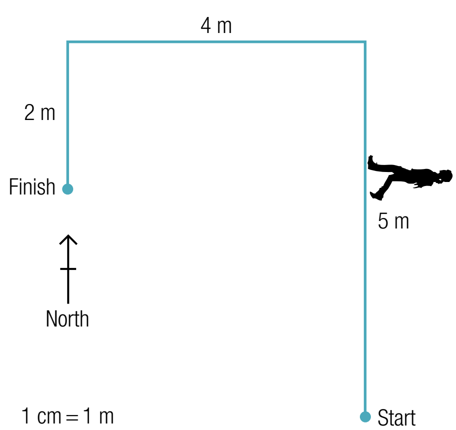


Figure 5.5 Find the sum of each section of the distance diagram to calculate the total distance travelled.

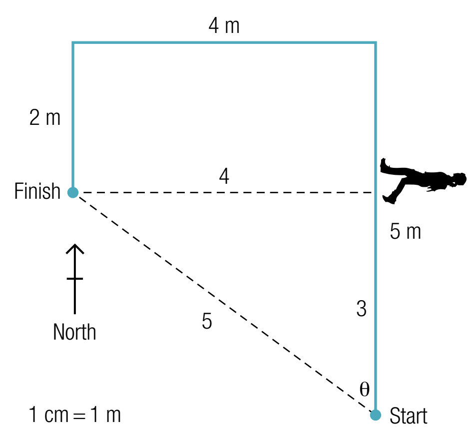


Figure 5.6 A person walked at total of 11 metres. What was their displacement?

QUESTIONS 5.1.1: DISTANCE AND DISPLACEMENT

Remember

1 Describe an example of motion that has zero displacement.

2 Explain the difference between 'displacement' and 'distance'.

Apply

3 Compare 'vector' and 'scalar' quantities.

4 An object moves 14 metres north and then 14 metres south. Calculate the distance it has covered and determine its displacement.

5 On the school oval, a person runs 50 metres north, then 20 metres south and then 30 metres west. Calculate the total distance covered. Use a diagram to determine the person's displacement.

6 A car starts from rest (stationary) and moves north at a constant rate for 400 metres, then stops for 10 seconds before moving north another 150 metres. Construct a position–time graph to accurately represent this motion.

Analyse

7 Examine the position–time graph shown in Figure 5.7.

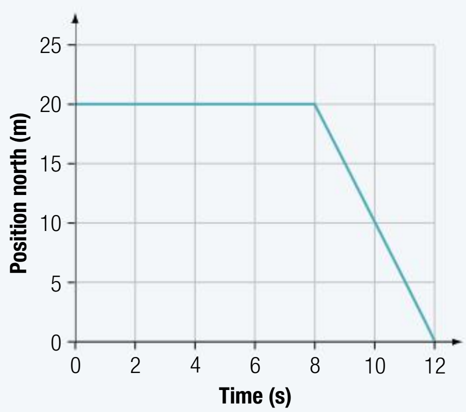


Figure 5.7 A position–time graph.

a Describe the motion shown.

b Determine the distance covered.

8 Explain any similarities or differences in the displacement shown in Figure 5.7 and the distance you determined in the previous question.

SPEED AND VELOCITY

Speed is a measure of how fast any moving object is travelling. It is measured in SI units of metres per second (m/s or ms^{-1}), although kilometres per hour (km/h or kmh^{-1}) is often used instead, especially for cars and planes.

Speed is defined as the distance travelled per unit of time. Hence, a constant speed of 5 m/s means the object travels 5 metres in every second of its motion. Speed is a scalar quantity because it only has size and no direction.

Average speed

Most objects don't move at a constant speed so it is necessary to calculate an object's average speed ($speed_{av}$). To calculate average speed, divide the total distance travelled by the total time taken. The units for speed depend on the units of distance and time.

This formula can also be expressed in a triangle (see Figure 5.9). The triangle is a good memory tool to help work out three formulas from the one diagram.

Average speed can also be determined by the gradient (slope) of a position–time graph. In maths, you have probably already learned that the gradient is calculated using 'rise over run'. Take another look at Figure 5.2 on page 197. The speed of the object between 0 and 6 seconds is calculated as 0.67 m/s. This is because the rise is 4 and the run is 6, giving a gradient of $\frac{2}{3}$ or 0.67, correct to two decimal places.

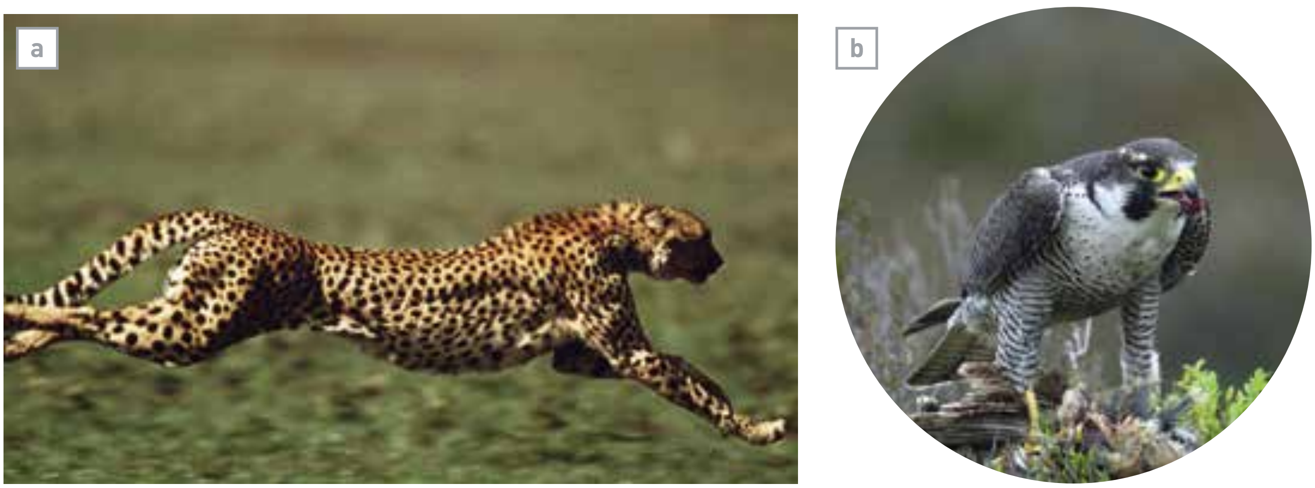


Figure 5.8 (a) The cheetah is the fastest land-based animal. It can travel at speeds up to 112 km/h. (b) The peregrine falcon can reach speeds of well over 300 km/h during a hunting dive, making it the fastest animal on the planet.

NUMERACY BUILDER

Average speed

$$\text{Average speed} = \frac{\text{distance}}{\text{time}}$$

The average speed triangle (Figure 5.10) is used to show the formula for average speed. Cover the quantity you want to calculate with your finger and the other two quantities will form the formula.

This gives: $speed_{av} = \frac{d}{t}$

but also $d = speed_{av} \times t$

and $t = \frac{d}{speed_{av}}$

Speed is the rate of change of distance over time.

$$\text{Acceleration} = \frac{\text{change in distance}}{\text{change in time}}$$

Your turn

1. Calculate the average speed of a car that travels a distance of 100 m in 5 seconds.
2. Determine the distance a runner would travel in 1 minute if they run at 0.5 m/s.
3. How long would it take a cyclist travelling at 2.5 m/s to cycle 1000 m?

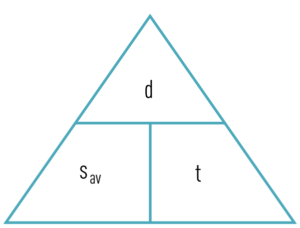


Figure 5.9 The average speed formula triangle.

STUDENT DESIGN TASK

Measuring and graphing a person's motion

In this activity, you will measure and graph the motion of one of your classmates.

Questioning and predicting

Before you start, decide how your classmate is going to move. Will they walk, jog or run? Will they travel at a constant speed, speed up or slow down? Predict what you will find. Sketch a distance–time graph that you expect to get from your results.

Planning and conducting

To measure the motion of one of your classmates, you will need to design a method. Consider the following:

- How will you measure their motion? Hint: You need to know their displacement at different times.
- What will you measure?
- How many times do you need to measure it?
- What equipment will you need?
- Where will you do it?
- What sort of graph will you use to present your results?

Remember, when you write a method it needs to be complete so anyone can use it to repeat the exact experiment. All the relevant details need to be included. Discuss your method with your teacher, other groups and/or the class, and identify any risks or hazards. Write your method and have it approved by your teacher, then conduct your experiment. Note: This experiment could be done as a class with students placed at each interval so that many times are gathered at each distance. Averages could then be calculated and used on a graph.

Processing, analysing and problem solving

- Did your prediction match your results? If not, why?
- From the distance–time graph of your results, calculate the gradient and therefore the average speed of the runner. Also calculate the average speed using the total time, total distance and the formula on the previous page.
- Did your two calculations of average speed match?
- What was changing over time while the measurements were being taken?
- Did the runner manage to maintain a constant speed? Explain how you know.
- Look at your results and describe the motion of the runner in words.
- How is the average speed of an object related to the distance travelled and the time taken?
- Were there any errors in your measurements? How do you know?
- Calculate the average speed of the student in kilometres per hour (see the following Numeracy Builder).

Figure 5.10 What units should you use to measure the speed of a runner?

Communication

- Present your investigation in a format negotiated with your teacher.

NUMERACY BUILDER

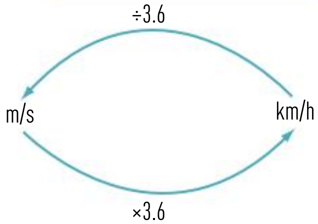


Figure 5.11 To convert from one unit to the other, follow the arrows.

Unit conversion

The basic unit of speed is metres per second (m/s); however, kilometres per hour (km/h) is also commonly used. Most vehicle speedometers use km/h.

To convert m/s to km/h, multiply by 3.6.
To convert km/h to m/s, divide by 3.6.

The 3.6 arises because there are 60 seconds in a minute and 60 minutes in an hour, giving 60 × 60 = 3600 seconds in an hour. Also, there are 1000 metres in a kilometre, so 3600 ÷ 1000 = 3.6.

Your turn

1. Convert 15 m/s to km/h.
2. Convert 100 km/h to m/s.

NUMERACY BUILDER

Graphing speed

It is useful to represent an object's speed graphically. This is called a speed–time graph. In these graphs, speed is plotted on the vertical axis and time on the horizontal axis.

Figure 5.13 shows an object with constant speed of 3 m/s for 4 seconds. The object would cover a distance of 12 metres in this time, which is calculated from the area under the graph (between the graph line and the horizontal axis up to 4 seconds): 4 × 3 = 12 metres.

It can also be calculated using the distance formula on page 200.

d = s(av) × t
= 3 × 4
= 12

Figure 5.14 shows an object with changing speed. The object increases speed from 0 to 3 m/s in 2 seconds, maintains this speed for another 4 seconds, then slows down in the final 2 seconds before coming to a rest (stopping). The distance formula cannot be used to calculate the distance covered because the speed of the object changed. The total distance is calculated from the area under the graph. The area can be broken up into two triangles and a rectangle, giving 3 + 12 + 3 = 18 metres, or it can be treated as a trapezium:
$\frac{1}{2}$ x (8 + 4) x 3 = 18 metres

Your turn

Use the graph in Figure 5.15 to answer the following questions.

1. Determine the fastest speed that the vehicle reaches during its journey.
2. Calculate the displacement of the vehicle in the first 50 seconds of its journey.
3. Identify the part of the journey where the vehicle changes its speed the most.

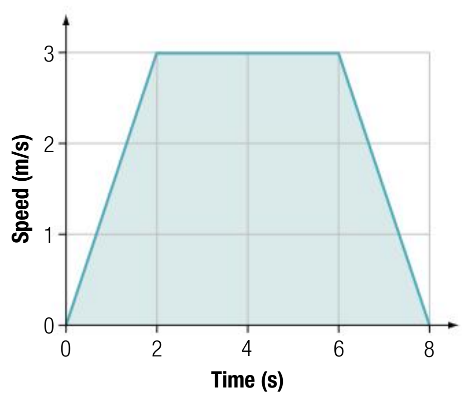


Figure 5.13 A speed–time graph showing changing speed.

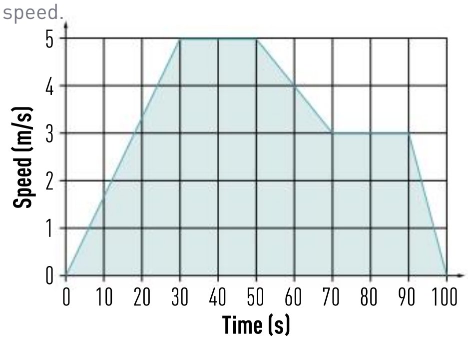


Figure 5.14 A speed–time graph showing the changes in speed of a vehicle.

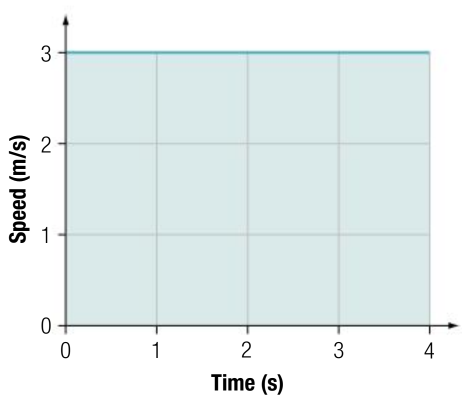


Figure 5.12 A speed–time graph showing constant speed.

Instantaneous speed

Over the course of a bus or car trip, your speed changes from moment to moment. The speedometer gives the instantaneous speed in km/h. This is the speed at each moment of the trip.

A **ticker timer** is commonly used to measure the speed of objects in the science laboratory. A motion sensor can also be used to measure speed, as well as position, displacement and acceleration.

Figure 5.15 A speedometer measures the instantaneous speed of a vehicle.

EXPERIMENT 5.1.1: THE TICKER TIMER

Aim

To learn how a ticker timer operates and to use it to produce a speed–time graph.

Materials

- Ticker timer
- Scissors
- Power supply
- Graph paper
- 2 electrical leads
- Glue
- Ticker tape
- Carbon discs
- Ruler

Method

1. Connect the ticker timer to the AC terminals of the power supply using the two electrical leads.
2. Thread a 30 cm length of ticker tape through the slots in the ticker timer. Turn on the power and pull the tape through the timer. Examine the tape to see if the dots are clear.
3. If the dots are too faint, adjust the equipment by increasing the voltage, replacing the carbon disc or loosening/tightening the screw holding the 'arm' of the ticker timer.
4. Repeat with a 1 m length of ticker tape. As you pull the ticker tape through, adjust your pulling speed so there is a very slow section, a medium section and a very fast section, in any order.

Results

1. Start your analysis by finding the first clear dot. Number this dot '0'. Count along another five dots and rule a line through the middle of the fifth dot. This gives a five 'gap' section of tape. The gap between successive dots is 0.02 seconds, so five gaps equals 5 × 0.02 or 0.1 seconds.
2. Divide the rest of your tape into five-gap sections by ruling lines through the middle of every fifth dot.
3. Number the sections of your tape and cut along the lines.
4. Glue each section of tape onto your graph paper, side by side, to form a column graph.
5. Add axes to your graph (speed on the vertical axis and time on the horizontal axis) and work out a scale for each axis (Hint: average speed = distance ÷ time).

Discussion

1. Why does the length of each tape column indicate the speed?
2. How could you work out the average speed of each section?
3. Why is it only the 'average' speed?
4. Design another experiment you could conduct using a ticker timer. Ask your teacher for permission to carry out your experiment.

Conclusion

Write a statement that describes how a ticker timer is used to measure speed.

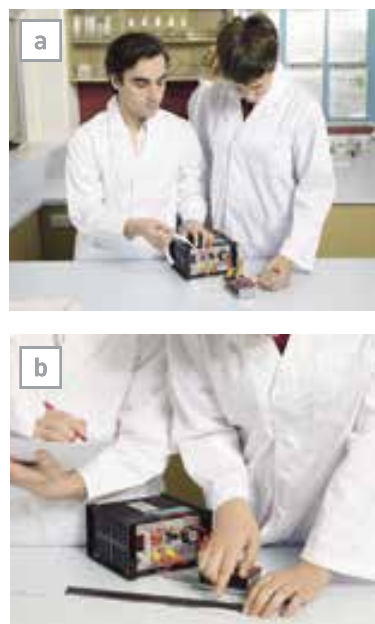


Figure 5.16 (a) Pull the threaded ticker tape through the ticker timer. (b) Measure the length of each five-dot section.

EXPERIMENT 5.1.2: USING A MOTION SENSOR

Aim

To become familiar with the operation of a motion sensor and use it to produce motion graphs.

Materials

- Motion sensor
- Dynamics trolley
- Laptop computer

Method

1 Connect the laptop to the motion sensor and open the appropriate software on the laptop.

2 Position the motion sensor several metres in front of the dynamics trolley and push the trolley towards the sensor. (The trolley may need a cardboard reflector attached to the front of it to reflect the signal from the motion sensor back to the sensor.)

Results

Analyse the data on the laptop to produce a position–time graph. Also produce a speed–time graph if possible.

Discussion

1 Can you work out what each graph is showing?

2 How well did the graphs represent the actual motion of the trolley?

3 Design another experiment you could conduct using the motion sensor.

4 Evaluate this experiment compared with Experiment 5.1.1 in which you used the ticker timer. Which measuring instrument did you prefer and why?

Conclusion

Write a statement that describes how a motion sensor can be used to measure and depict speed.

Velocity

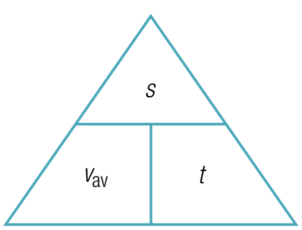


Figure 5.18 The average velocity formula triangle.

Pilots and sailors need to know both the speed of the wind and its direction. **Velocity** is speed in a particular direction and is therefore a vector quantity (a measurement of both size and direction). It has the same unit as speed (m/s). The average velocity (v_{av}) of an object is calculated in a similar way to average speed, but displacement (s) is used instead of distance (d) (Figure 5.17).

$$v_{av} = s/t$$

The direction of the average velocity is the same direction as the displacement. Like speed, average velocity can be determined from the gradient of a position–time graph, but the nature of the gradient indicates the direction.

Look again at Figure 5.3 on page 197. From 0 to 6 seconds, the average velocity is:

$$\frac{4}{6} = 0.67 \text{ m/s north}$$

The direction is north because the gradient is positive, and positive is north on the graph.

From 8 to 10 seconds, the average velocity is:

$$\frac{4}{2} = 2 \text{ m/s south}$$

The direction is south because the gradient is negative, and negative is south on the graph.

Look again at Figures 5.5 and 5.6. In these figures, the distance is 11 metres and the displacement is 5 metres in the direction N53°W. 53° west. If the motion occurred over 11 seconds, the average speed would be:

$$v_{av} = \frac{11}{11} = 1 \text{ m/s}$$

The average velocity would be:

$$v_{av} = \frac{5}{11} = 0 \text{ m/s}$$

Average velocity would be in the same direction as the displacement: N53°W or on a bearing of 307°.

Figure 5.18 The wind's speed and direction affect the velocity of a yacht.

QUESTIONS 1.1.2: SPEED AND VELOCITY

Remember

1 Identify units other than m/s that can be used to measure speed.

2 Is 4 m/s a speed or a velocity? Explain your answer.

3 Use the average velocity triangle to write three different formulas that describe the relationship between average velocity, displacement and time.

4 What does the gradient of a position–time graph indicate?

5 What does the area under a speed–time graph indicate?

Apply

6 An object travels 40 km in 5 hours. Could the object in question have had an instantaneous speed greater than the average speed? Explain your answer.

8 Construct a displacement–time graph and a speed–time graph for a car travelling at 25 m/s for 10 seconds.

9 Sketch a speed–time graph for a car initially travelling at 20 m/s that slows to a stop by 5 m/s every second.

10 Convert 80 km/h to metres per second (m/s).

ACCELERATION

Pressing the accelerator pedal in a car makes the car move forward and increase in speed. This is the same as saying the car accelerates. **Acceleration** is the rate of change of speed.

$$\text{Acceleration} = \frac{\text{change in speed}}{\text{change in time}}$$

$$a = \frac{\Delta\text{speed}}{\Delta t}$$

Just as the accelerator pedal causes a car to speed up, the brake pedal causes a car to slow down. We call this **deceleration** (or negative acceleration).

Acceleration is measured in units of metres per second per second (m/s/s) or metres per second squared (m/s^2 or ms^{-2}) because speed is usually in metres per second and time is usually in seconds. However, other units are possible depending on the units of speed and time.

To understand acceleration, we will only consider objects travelling in one direction in a straight line and under constant acceleration. Consider a falling object, such as a rock, as shown in Figure 5.19.

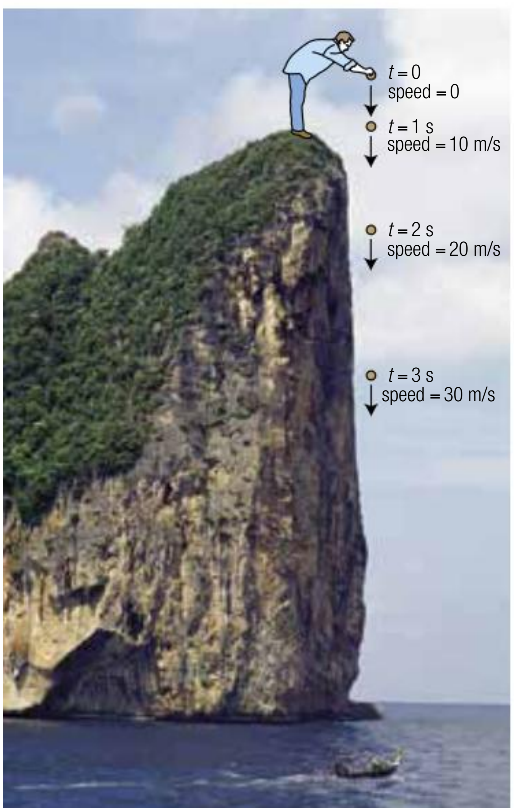


Figure 5.19 Each second, the speed of the falling rock increases by almost 10 m/s, ignoring air resistance. This means the acceleration is 10 m/s^2.

When the rock is held out to one side and dropped vertically (not thrown), the rock starts at rest and increases in speed as it falls. If it were dropped from high enough, the rock may accelerate to quite a high speed.

After 1 second, it should reach a speed of almost 10 m/s due to gravity (actually, it is 9.8 m/s, which is very close to 10). We say it has accelerated at a rate of 10 metres per second in 1 second or at 10 metres per second per second (written as 10 m/s/s or 10 m/s^2 or 10 m s^{-2}).

After another second at the same rate, the rock would reach a speed of almost 20 m/s.

After 3 seconds, it would reach a speed of almost 30 m/s, although this analysis ignores the effects of air resistance, which would prevent the rock from reaching a speed of 30 m/s after 3 seconds.

The acceleration value of 10 m/s^2 is called **acceleration due to gravity** and is given the symbol g. The motion of a skydiver follows the pattern of the rock. As a skydiver falls, they speed up until they open their parachute and slow down to land.

How can we calculate acceleration from a speed–time graph? Acceleration is indicated by the gradient of a speed–time graph. The steeper the gradient, the greater the acceleration, as shown in Figures 5.20 and 5.21.

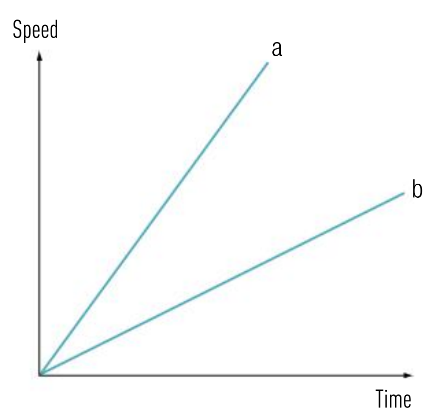


Figure 5.20 Speed–time graphs showing (a) a steep gradient, indicating high acceleration, and (b) a gentle gradient, indicating lower acceleration.

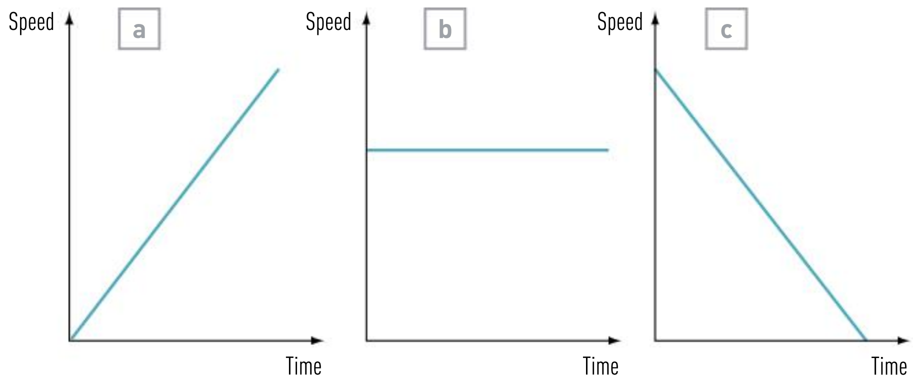


Figure 5.21 Speed–time graphs showing (a) constant positive acceleration (speeding up), (b) zero acceleration (constant speed) and (c) negative acceleration (slowing down or decelerating).

NUMERACY BUILDER

Acceleration

$$\text{Acceleration} = \frac{\text{change in speed}}{\text{change in time}}$$

$$a = \frac{(\text{final speed} - \text{initial speed})}{\text{time taken}}$$

$$a = \frac{\Delta\text{speed}}{\Delta t}$$

where Δ is the Greek letter 'delta' and means 'change in'.

Your turn

1 Calculate the acceleration of an object that begins at rest and accelerates to 10 m/s in 25 s.

2 A vehicle accelerates at 10 m /s^2 for 12 s and reaches a final speed of 800 m/s. Determine the initial speed of the vehicle.

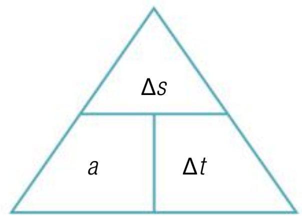


Figure 5.22 The acceleration formula triangle.

ACTIVITY 5.1.2: MEASURING ACCELERATION

In this simple activity, you will determine acceleration due to gravity by simply dropping a ball and measuring the time it takes to fall a certain distance. For more accuracy, or as a comparison, a motion sensor connected to a computer could be used to measure the acceleration directly. The ball will be released from a measured height *h* metres above the ground and it will take a time *t* seconds to reach the ground.

What you need: ball, stopwatch, tape measure, motion sensor

WARNING

> Never drop objects from high places without looking below to make sure the area is clear. Never drop objects off buildings or bridges.

1 Use the results to determine the acceleration due to gravity in units of m/s^2. The formula that describes this situation is: $h = \frac{1}{2} \times a \times t^2$

2 Rearrange the formula to make *a* the subject and substitute your values for *h* and *t*. The resulting value for *a* is the acceleration due to gravity (although it usually has the symbol *g*), which is approximately 9.8 m/s^2 near the Earth's surface, although we often round it off to 10 m/s^2 for calculations.

- How close to 9.8 m/s^2 were your results?
- Can you account for any differences?

You may like to make several different measurements and plot them as a height–time^2 graph. If you do a regression fit to the data, the gradient is $\frac{h}{t^2}$, which is $\frac{1}{2}g$. Multiply the gradient by 2 to obtain an average value for *g*.

ACTIVITY 5.1.3: MAKE AN ACCELEROMETER

An accelerometer is an electronic device used to measure the acceleration of an object, such as a car or a crash test dummy. It does not have to be complicated though, and you can make one yourself.

What you need: small glass jar and lid, paperclip, short length of cotton, sticky tape

1 Tie one end of the cotton to the paperclip.
2 Stick the other end of the cotton to the underside of the lid so the paperclip hangs vertically inside the jar without touching the bottom.
3 Fill the jar with water and screw the lid on.
4 Test your accelerometer by pushing it slowly along a table, then make it speed up, go at constant speed and finally slow down.
5 Take your accelerometer with you in a car, bus or train and observe the position of the cotton and paperclip when the vehicle is:
   a accelerating
   b decelerating
   c travelling at constant speed in a straight line
   d travelling at constant speed around a corner.

Figure 5.23 Any mass on a string can be an accelerometer, even a stationary hanging mass on a string used to find which way is vertical. This device is known as a 'plumb bob' and is used sometimes in the building industry (although a spirit level is more convenient).

- What position does the cotton and paperclip have for each of the above types of motion?
- How can you tell if the vehicle is undergoing a small or a large acceleration?
- How do our own bodies tell us we are accelerating, decelerating or travelling around a corner?

STUDENT DESIGN TASK

Balloon car race

Challenge

Your task is to build a balloon-powered model car and race it against the cars of other students. This means your car will need to accelerate faster and reach a higher speed than your competition. Any small model car can be used or you could build one from Lego© or other materials. The model car needs to have freely spinning wheels and an aerodynamic design to travel far and fast. Real drag-racing cars are very powerful and sleek in design.

Figure 5.24 Top fuel dragsters (racing drag cars) use their enormous acceleration to win races.

Questioning and predicting

Work out how you will attach the balloon to your car so it can be easily inflated each time.

Planning and conducting

Race your car along a model drag strip at school and against cars made by other students.

Processing, analysing and evaluating

How did your car perform? What improvements could you make to your car to increase its performance? You could use a motion detector to analyse the motion of your car. How fast did your car go?

Communicating

Present your investigation in a formal practical report.

QUESTIONS 5.1.3: ACCELERATION

Remember

1 Use the acceleration triangle to identify three different formulas that explain the relationship between change in speed, change in time and acceleration.

2 Define the term 'deceleration'.

3 Describe the acceleration of an object if its speed is constant.

Apply

4 Describe the motion of an object with the speed–time graph shown in Figure 5.25.

5 Compare accelerating and decelerating objects.

6 How can a passenger in a moving car detect whether the car is accelerating or decelerating without looking out of a window or at the speedometer?

7 For a car accelerating at 5 m/s^2, sketch the:

a acceleration–time graph

b speed–time graph

c displacement–time graph.

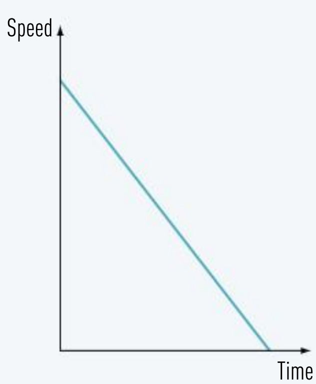


Figure 5.25 What does this speed–time graph tell you about the motion of the object?

5.1 CHECKPOINT

CHARACTERISTICS OF MOTION

Remember and understand

1 Match each term with its meaning. [8 marks]

vector	speed of an object at a moment in time
average velocity	measures how an object's speed changes
average speed	slope of a graph
acceleration	graph where speed is plotted against time
distance	quantity that has magnitude and direction
instantaneous speed	calculated by dividing distance by time
gradient	measures how far an object has travelled
speed–time graph	calculated by dividing displacement by time

2 Describe an object's speed if it travels with zero acceleration. [1 mark]

3 Describe an object's speed if it travels with constant acceleration. [1 mark]

4 Describe an object's speed if it travels with constant deceleration. [1 mark]

Apply

5 Describe the relationship between distance, speed and time. [2 marks]

6 Construct a displacement–time graph for a person walking at 0.5 m/s for 5 seconds. [2 marks]

7 Identify the characteristic of an object's motion that must change for the object to accelerate. Justify your answer. [2 marks]

8 A car is driven along a straight road. Starting from rest, it takes 10 seconds of steady acceleration for the car to reach a speed of 20 m/s. The car then cruises for 60 seconds at 20 m/s, before slowing down to a halt over a period of 30 seconds.

- a What is the maximum speed of the car in km/h? [1 mark]
- b Sketch speed–time and acceleration–time graphs for the car, using SI units. [2 marks]
- c Use the graphs to calculate the distance moved in metres and then in kilometres. [2 marks]

Analyse and evaluate

9 A school bus that has to travel 24 km leaves its starting place at 7.35 a.m. and only manages an average speed of 36 km/h on its trip to school. There is a clear section on the highway when the bus has a speed of 74 km/h. The bus then does various runs during the day and arrives back at the school in time to depart at 3.45 p.m. It arrives back at its exact starting place at 4.25 p.m.

- a Determine the displacement of the bus between 7.35 a.m. and 4.25 p.m. [1 mark]
- b At what time will the bus arrive at school? [1 mark]
- c The bus's average speed on the way to school is 36 km/h, but on one stretch the bus moves at 74 km/h. Use this data to explain the difference between 'average speed' and 'instantaneous speed'. [2 marks]

10 A section of a position–time graph has a gradient of +7 and another section has a gradient of −4. If the units on the graph are metres and seconds, and positive means south, what do these numbers mean about the motion being studied? [3 marks]

Critical and creative thinking

11 Some objects or devices require high accelerations that are many times greater than 9.8 m/s^2, the acceleration due to gravity. Identify an object or device in this category and explain how it achieves such a high acceleration. (Hint: Does it have an engine or some other propulsion mechanism? What fuel does it use?) [6 marks]

TOTAL MARKS [/35]

FORCE, MASS AND ACCELERATION 5.2

Sometimes high-speed motion, such as cruising in an aeroplane, is barely noticeable. You may not even feel that you are moving until you look out of the aeroplane's window and see the gradual movement of the land far below you. How can you be going so fast and hardly notice it? In relation to motion, a force is something that can change an object's motion. A force is not necessarily needed to keep an object moving, but most objects slow down because of the force of friction.

NEWTON'S FIRST LAW

English scientist Isaac Newton (1642–1727) formulated three laws to explain the nature of motion. Newton was a professor of mathematics and physics, and wrote one of the greatest scientific publications of all time, the *Principia*. In his book, Newton outlined his laws of motion and his law of universal gravitation. Newton's formulation of these laws led to nearly all the important advances in physics in the areas of magnetic, electrical and atomic forces for the next 200 years.

To appreciate Newton's laws of motion, it is important to understand the concept of **force**. A force is a push or a pull acting upon an object as a result of its interaction with another object. Force has the symbol *F* and is measured in newtons (N).

Figure 5.26 Newton is famous for the story of the apple falling from a tree as he sat in his family orchard. Although the story is fictional, Newton himself is responsible for its creation.

ACTIVITY 5.2.1: INVESTIGATING INERTIA

What you need: small objects such as coins or pens, sheet of A4 paper

1 Place a small object, such as a coin or a pen, on top of a sheet of A4 paper on the lab bench. Pull the paper slowly with the object on top. What happens?
2 Try pulling the paper really fast from under the object. What happens?

Discuss your findings in a group and see whether you can justify what happened in each case. You will soon find out how this activity demonstrates Newton's first law.

The law of inertia

Newton's first law, also known as the law of **inertia**, has two applications. First, look around you and find something that is stationary ... maybe even yourself. Why is the object stationary? It has the force of gravity (its weight force) acting on it to pull it down. But why doesn't it move? This is because there is another force, equal in magnitude (strength) to the weight force but acting in the opposite direction, pushing up on the object from the surface. Because these two forces are equal in magnitude and opposite in direction, and because they both act on the same object, we say that the object has zero **net force** (or zero resultant force) acting on it. The two forces are balanced.

Newton's first law states: An object remains at rest or in constant motion in a straight line unless acted on by a net unbalanced force.

Figure 5.27 Zero net force means all forces are balanced. The person resting on the couch remains stationary because his weight is balanced by an upwards force from the couch.

Newton's first law and moving objects

Think of any motion you have experienced today, maybe in the car or on the bus, train, or even on your bike. In constant motion we sometimes hardly notice we are moving, but if there is a sudden stop or start, or a turn of a sharp corner, your body may move unexpectedly. This is inertia. Inertia keeps stationary objects stationary too. The effect of inertia is to keep an object in the same type of motion it was in. The larger the mass of the object, the more inertia it has. Think back to Activity 5.2.1 with the coin or pen on a piece of paper. In terms of inertia, why did the object stay in place on the bench when the paper was rapidly pulled out from under it?

If you are a passenger in a car and you are not wearing a seatbelt, and the car comes to a very sudden stop, your body will continue moving forward because inertia keeps it in the same motion it was in (moving forward). The same thing happens on a bike and may cause you to continue your motion over the handlebars. The same thing also happens in a bus or train, especially if you are standing up and not holding onto something. It is also this effect that causes us to feel lighter or heavier in an elevator or on a roller coaster.

Figure 5.28 Inertia is responsible for vehicles tilting as they turn. Without friction from tyres gripping the road, turning would be nearly impossible.

Figure 5.29 Seatbelts are an inertia device. They are often called 'inertia reel seatbelts'. The aim of a car seatbelt is to transfer the force on the car to the passenger wearing the seatbelt so that the person moves with the car. You start moving when the car starts moving and, when wearing your seatbelt, you stop moving when the car stops moving.

ACTIVITY 5.2.2: BOMBING RUN

What you need: small empty rubbish bin, tennis ball, safe space to run or move about

1. In a clear space, set up an empty rubbish bin.
2. Hold the tennis ball in your hand with your arm outstretched to the side. As you walk or run past the bin, try to release your 'bomb' so that it lands in the bin. You must only drop the ball, not throw it into the bin.

- Do you score a 'hit' every time?
- How does Newton's first law explain your observations?

Force and vector diagrams

A **force diagram** is a way to clearly represent all the forces acting on an object. The forces are drawn as lines with arrowheads. The direction of the arrowhead shows the direction of the force. The length of each line shows the size of each force. A force diagram can be very useful when you are solving a problem involving forces.

A **vector diagram** shows the net force acting on an object. It is similar to a force diagram, but all the forces are 'added' together to show the overall net force, or resultant force.

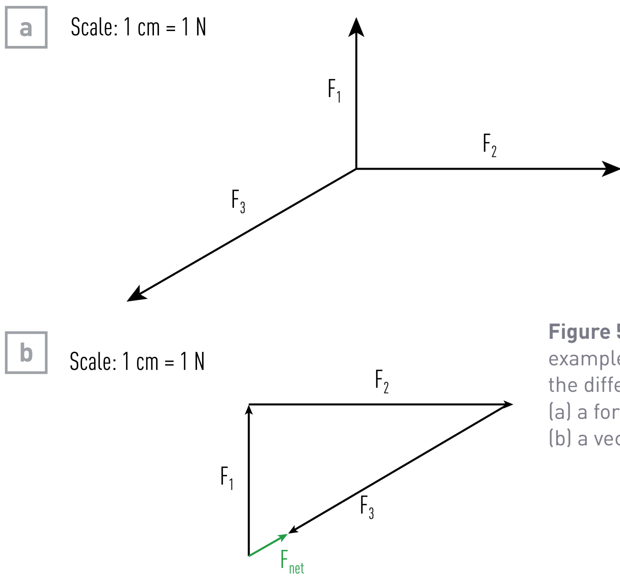


Figure 5.30 These examples demonstrate the differences between (a) a force diagram and (b) a vector diagram.

EXPERIMENT 5.2.1: RESULTANT FORCES

Aim

To investigate the addition of vectors using three spring balances.

Materials

- 3 spring balances (0–10 or 0–20 N are best)
- 2 rubber bands
- Graph paper
- Masking tape
- Felt-tip pen

Method

1. Test to see that each spring balance reads zero with no force exerted on its hook. (This is known as checking the 'calibration'.) If not, adjust them until each reads zero.
2. Tape a piece of graph paper to the bench and draw a large dot in the centre of the paper.
3. Tie one rubber band to the centre of the other to create three 'loops' with a knot in the centre.
4. Hook each spring balance onto the loops and position the knot directly above the dot on the graph paper.
5. Pull on the spring balances in different directions so that the knot stays directly over the dot.
6. Record the force reading on each spring balance and draw the direction of the force onto the graph paper. This can be done by drawing a line directly below the rubber bands.
7. Repeat the experiment twice more using different-sized forces and different directions.

Results

Drawing a force diagram

Remove the graph paper and create a force diagram by choosing an appropriate scale (usually 1 cm = 1 N) and drawing the three forces acting from the dot in the correct directions.

Drawing a vector diagram

To convert the force diagram into a vector diagram, leave one of the force arrows in position where it is, then 'slide' the other two force arrows so that all three join head to tail with each other. When all three forces are added, determine the net force by drawing a line from the start to the end and head-to-head and tail-to-tail. This shows the net force of the three individual vectors, which should be very small or even non-existent if your experiment was free from errors.

Discussion

1 Write several statements analysing your results.

2 If the net force given by your vector diagram(s) was non-zero, what observation would you have made during your experiment to indicate that it should be zero? Explain your answer.

3 Identify the source of any errors, if any, in this experiment and their effect on the results.

Conclusion

Write a statement that describes how vectors alter motion when combined.

ACTIVITY 5.2.3: HOW DO YOU LIKE YOUR EGGS?

What you need: Two eggs in their shells – one fresh and one hard-boiled, but with no indication of which is which

1 Spin both a hard-boiled egg and a fresh egg on a flat surface.

2 Stop the eggs gently with one finger placed momentarily on top of the spinning egg, then release the egg by lifting your finger off it. Do the eggs remain motionless or keep spinning?
   - How does the egg's motion after you release your finger help you to predict whether the egg is hard-boiled or fresh? Open the shells (over a rubbish bin or sink) to see if you are correct.
   - Think about the inside of the egg and the motion of the shell and the egg itself while they are spinning. Think also of Newton's first law. Describe what you did in terms of inertia.

Friction

When using Newton's first law to explain motion in everyday situations, the force of friction can cause confusion. If you push a box along the floor and then release it, the box slides only for a short while as it slows down not long after you release it. This might seem to contradict Newton's first law and can cause confusion. Friction is acting on the box in the direction opposite to motion the whole time. Once you stop pushing the box, the force of friction becomes an unbalanced force. This unbalanced force (friction) causes the box to slow down and stop.

QUESTIONS 5.2.1: NEWTON'S FIRST LAW

Remember

1 Define the term 'net force'.

2 Describe what happens to a stationary object with zero net force acting on it.

3 Describe what happens to a moving object with zero net force acting on it.

4 Define inertia.

5 Describe the effects of friction on the motion of everyday objects.

Apply

6 Explain examples of how inertia affects your motion inside a car, bus or train.

7 Explain why people lurch backwards in a bus or a train when it moves suddenly.

NEWTON'S SECOND LAW

Newton's first law deals with the consequences of zero net force, but if an object does have net force acting on it then the object will change its speed, direction or both. A moving object will speed up (accelerate) if a net force acts on it in the same direction as it is moving. In the case of riding a bike, the bike will speed up if you pedal harder to increase the driving force (commonly known as thrust) as shown in Figure 5.31.

When the net force acts in the opposite direction to motion, the moving object will slow down or decelerate and eventually stop. A moving bike will slow down when you squeeze the brake lever, as shown in Figure 5.32.

Acceleration depends on the net force, but does mass have a role too? It would be easier to push and accelerate a small car because it has less mass than a truck. Heavier objects are harder to accelerate with the same force. Hence, acceleration increases if the net force increases and/or if the mass decreases.

Newton's second law states: The acceleration of an object is directly related to the magnitude and direction of the force acting on the object, and inversely related to the mass of the object: $F = ma$.

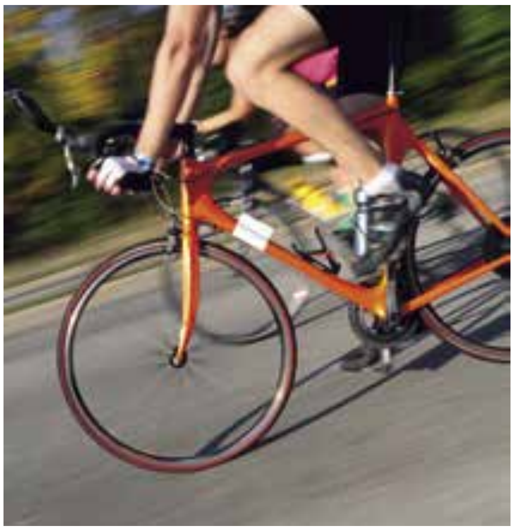


Figure 5.31 Pedalling provides the thrust (net force) when riding a bike.

Figure 5.32 Braking provides friction in the opposite direction of motion (net force).

Figure 5.33 Cars can accelerate faster than trucks mainly because of their smaller mass.

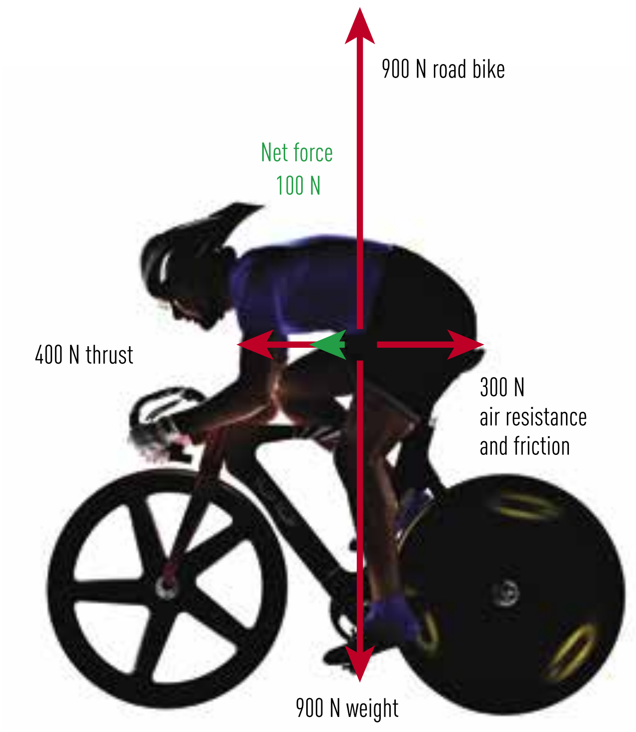


Figure 5.34 Various forces act on a cyclist.

Mass versus weight

Newton's second law also connects an object's mass to its **weight**. If an object is falling, it speeds up (accelerates). It is the term 'weight' that we often use to indicate how much mass something has in kilograms, but in Physics, weight is a force, not a mass. Figure 5.36 in the Numeracy Builder shows how weight and mass are linked with the acceleration due to gravity, *g*. Weight is the force of gravity as acting on an object, whereas mass is the amount of matter in an object. Every object on or above the Earth has weight. The only time objects do not have weight is when there is no gravity, in deep space, but objects always have mass.

All the individual forces acting on an object need to be taken into account to work out the net force. In Experiment 5.2.1 you learned how to draw a vector diagram to add forces together.

Consider the cyclist and bike shown in Figure 5.35. In this case, the weight force of 900 N is balanced (or cancelled out) by the 900 N upward force of the road on the cyclist and bike. The forward-acting thrust force is 400 N and the total drag force from air resistance and friction is 300 N backwards. As a result, the net force is 100 N forward. This would produce acceleration.

NUMERACY BUILDER

Mass, weight and net force

Weight

Weight is the force of gravity acting on an object, measured in newtons. It is equal to the product of the mass of the object (in kilograms) and the constant *g*.

Weight = mass × acceleration due to gravity

$$W = m \times g$$

where $g = 9.8\ \text{m/s}^2$ at sea level on the Earth's surface (10 m/s^2 can be used to simplify calculations).

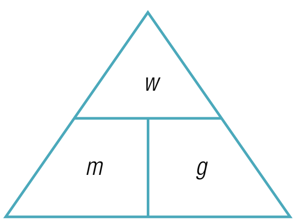


Figure 5.35 The weight formula triangle.

Net force

Net force = mass × acceleration

$$F_{net} = m \times a$$

A net force is a force that is not cancelled out or balanced by any other force. It will cause a change in the motion of an object. A change in an object's motion is called an acceleration. The connection between the net force and the acceleration is shown in the following equation, which expresses Newton's second law mathematically.

When the mass is in kilograms (kg) and the acceleration is in metres per second squared (m/s^2), the net force will be in newtons (N). Acceleration and net force are both vectors, and always act in the same direction.

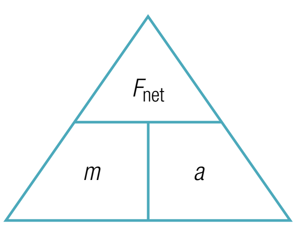


Figure 5.36 The net force formula triangle.

The mass of the cyclist and bike in Figure 5.34 can be determined using the weight formula triangle:

$$m = \frac{W}{g} = \frac{900}{10} = 90\ \text{kg}$$

The acceleration of the cyclist and bike can be worked out using the net force triangle:

$$a = \frac{F_{net}}{m} = \frac{100}{90} = 1.11\ \text{m/s}^2 \text{ forward}$$

If the thrust were reduced to 300 N, there would be zero net force and therefore zero acceleration, and the cyclist would continue at constant velocity. If the cyclist stopped pedalling, the thrust force would become zero and the net force would be 300 N backwards, causing the cyclist to decelerate and eventually stop. Can you work out what this deceleration value would be?

EXPERIMENT 5.2.2: ACCELERATING MASSES

Aim
To determine the relationship between mass and acceleration.

Materials
- Dynamics trolley
- String
- Mass hanger and brass 50 g masses
- Several 1 kg masses
- Desk-mountable pulley wheel with clamp
- Electronic balance
- Motion sensor or stopwatch
- Tape measure or ticker timer
- Power supply
- Ticker tape

Method
1. Clamp the pulley wheel to the edge of the desk. Try to set it up with the largest height above the floor as possible.
2. Attach one end of the string to the dynamics trolley and the other end to the mass hanger, carrying a total of approximately 200 g of mass.
3. Hang the masses over the pulley so they can pull the trolley along as they fall towards the floor.
4. Record the motion of the trolley as the masses fall, by using a motion sensor, timing with a stopwatch or recording the motion on ticker tape.
5. Successively add 1 kg masses to the trolley and repeat your measurements several times.

Results
1. Determine the acceleration of the trolley for your method.
2. If you used a motion sensor, use software to determine the acceleration directly or from the gradient of a velocity–time graph.
3. If you used a stopwatch, calculate the acceleration using the formula introduced on page 207: $h = \frac{1}{2} \times a \times t^2$
4. If you used a ticker timer, use the 'every fifth dot method' as per Experiment 5.1.1 to divide the tape into sections. Determine the speed of each section by dividing the distance covered by 0.1 because the gap between successive dots is 0.02 seconds. Plot a speed–time graph and determine the acceleration from the gradient of the graph.

Extension
5. Plot an acceleration–total mass graph. This should give a reciprocal graph or a hyperbola.
6. Plot a graph with acceleration on the vertical axis and 1/m on the horizontal axis. This should give a straight-line graph.

Discussion
Identify the variables involved in this experiment. Analyse and evaluate your results.

Conclusion
Describe the relationship (or formula) between mass and acceleration.

Extension challenge
Design another experiment using the same equipment where you choose a different independent variable, and investigate the relationship between mass and acceleration.

Acceleration without a change in speed

Acceleration can also occur when an object changes its direction. Recall that acceleration is a change in speed over time. When we consider vector quantities, then acceleration is a change in velocity over time. Velocity (v) has both magnitude and direction, so even if the speed remains the same, if an object changes direction, it is accelerating. This is because its velocity is changing direction.

Consider the example shown in Figure 5.37. If you were to swing a ball around on the end of a string, Newton's first law tells you that it should continue in a straight line unless acted on by a net (unbalanced) force. Clearly, the ball will continue in a circular path so the string must be supplying a net force towards the centre of the circular path. If the string breaks, then Newton's first law will be obeyed and the ball will head off in a straight line.

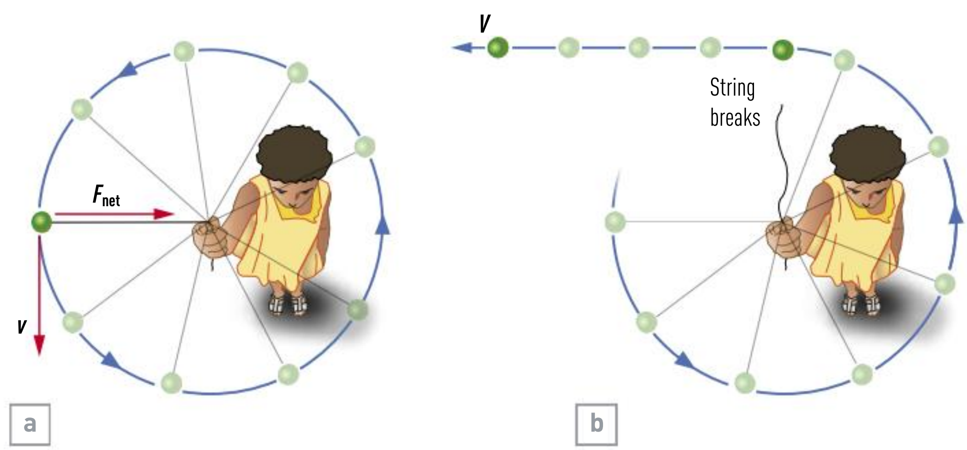


Figure 5.37 (a) The green ball is accelerating due to the changing direction of its velocity (v). (b) When the force applied by the string is removed, the ball travels away in a straight line. Newton's first law says its velocity will now remain constant unless another force acts on it.

QUESTIONS 5.2.2: NEWTON'S SECOND LAW

Remember

1 Contrast the terms 'weight' and 'mass'.

2 Describe what happens to a moving object if it is acted on by a net force in the same direction as its motion.

3 Describe what happens to a moving object if it is acted on by a net force in the opposite direction to its motion.

4 Explain how acceleration can occur if the magnitude of the velocity of an object does not change.

Apply

5 Compare the acceleration of a bus full of passengers with that of an empty bus if the same net force acts in both situations.

6 Explain why a bike slows down on a level road when the rider stops pedalling.

7 A net force causes a mass of 10 kg to accelerate at 2 m/s^2. Calculate the magnitude of the net force.

NEWTON'S THIRD LAW

If you blow up a balloon and let it go, it flies around the room. As the air is forced backwards out of the opening, the balloon is propelled forwards by another force. These two forces are equal in magnitude and opposite in direction. They form an action–reaction pair and obey Newton's third law. The action force is the rubber of the balloon contracting and pushing the air backwards. The reaction force is the force of the air pushing forward on the inside of the balloon.

> Newton's third law states: For every action force, there is an equal and opposite reaction force.

The motion of a person on roller blades pushing off from another person (see Figure 5.39) works in a similar manner. What happens if the two people have different masses? Newton's second law tells us that smaller masses have higher accelerations for the same force. So, a lighter person will have a higher acceleration and will reach a higher speed while the force is acting.

You may think that if the two forces in the action–reaction pair are always equal and opposite they must cancel each other out and that no net force exists, and hence no motion is possible. But the forces cannot cancel. The two action–reaction forces act on different objects. Only forces acting on the same object can cancel or balance.

Rockets, missiles and jet engines work on the action–reaction principle. So does the firing of bullets and shells from rifles and guns. The reaction force in this instance is known as recoil.

Figure 5.38 The action–reaction principle means a blown-up balloon will fly around when it is released.

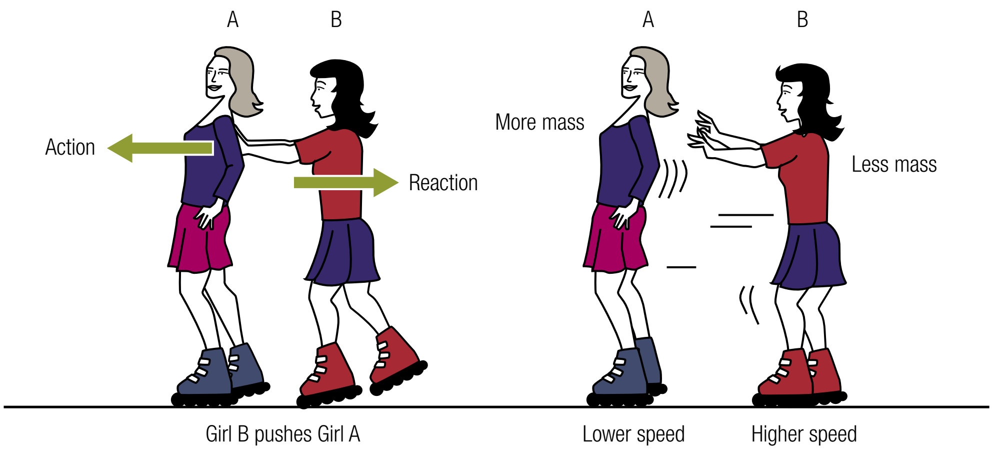


Figure 5.39 Different masses have different accelerations and reach different speeds, even though the forces shown by the arrows are equal in size.

ACTIVITY 5.2.4: AN ACTION–REACTION FORCES PAIR

1 Hook a spring balance onto a large fixed object, such as a desk. Apply a small pulling force on the desk and measure the force in newtons. This is the force your hand is exerting on the desk. According to Newton's third law, what is the size of the force the desk is exerting on your hand?

2 Give another spring balance to a classmate and make sure they both read 0 N before they are connected to anything. Hook the two balances together between your hands as shown in Figure 5.40. Measure the forces and name them in the same way the forces were named in part 1 of this activity.

- Are these two forces an action–reaction pair and are they therefore consistent with Newton's third law?

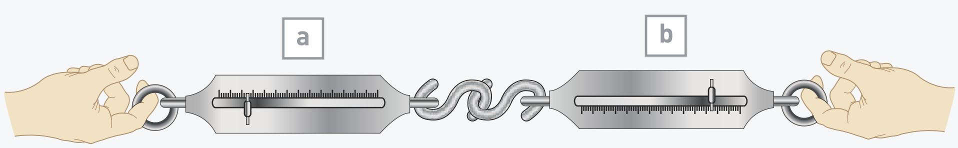


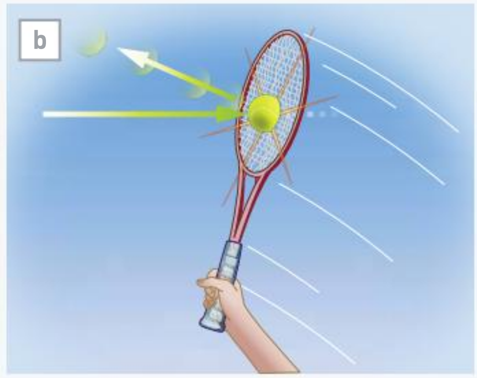
Figure 5.40 Spring balance A exerts a force on spring balance B. This force is the same size as the force spring balance B exerts of spring balance A, but is in the opposite direction.

ACTIVITY 5.2.5: EXPLAINING EVERYDAY SITUATIONS

Newton's laws of motion can be applied to everyday situations involving motion.

1 Working in groups, look at Figure 5.41 and explain what is happening in each image, using at least one of Newton's laws. You must use all three laws at least once.

2 In your group, come up with at least one other situation that demonstrates each of Newton's laws of motion.



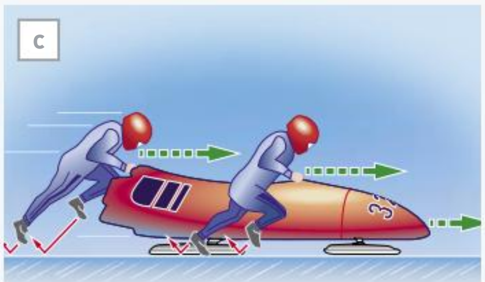


Figure 5.42 How do Newton's laws of motion explain what is happening when (a) flying over the handle bars of a bike, (b) hitting a tennis ball and (c) accelerating a bobsled?

QUESTIONS 5.2.3: NEWTON'S THIRD LAW

Remember

1 What is Newton's third law of motion?

2 What is the name given to a pair of forces that obey Newton's third law?

Apply

3 Describe a situation in your everyday life where a pair of forces obey Newton's third law.

4 A person pushes forwards on an object, which remains at rest, with a force of 30 N. Describe the reaction force that acts on the person.

5 A boy of weight 500 N sits on a chair. Describe the reaction force that acts on the boy.

6 In space, an astronaut pushes on another astronaut with a force of 80 N. Identify the magnitude of the reaction force in this case. Explain why the second astronaut could have a higher acceleration than the first astronaut.

7 Identify the action–reaction pair when a sprinter uses a set of starting blocks for the start of a sprint race.

8 Identify the action–reaction pair when a softball player hits a home run.

9 Explain why the two forces in an action–reaction force pair have to act on two different objects. Predict the result if the two forces acted on the same object in opposite directions. Explain your answer.

FORCE, MASS AND ACCELERATION

5.2 CHECKPOINT

Remember and understand

1 Match each term with its meaning. [6 marks]

mass	when the net force on an object is not equal to zero
net force	amount of matter in an object
balanced	force on an object due to gravity
unbalanced forces	overall effect when all forces are combined together
weight	causes an object to remain in its state of motion
inertia	when two forces are equal in magnitude and opposite in direction

2 Identify whether the following statements are true or false. Rewrite any false statements to make them true.

- **a** A force will only change an object's speed. [1 mark]
- **b** A force is always needed to keep an object in motion. [1 mark]
- **c** The quantity of weight is measured in kilograms. [1 mark]
- **d** A force has magnitude and direction, making it a vector. [1 mark]
- **e** Acceleration increases if the net force increases and the mass is kept constant. [1 mark]
- **f** Mass is a measure of how much space an object occupies. [1 mark]

Apply

3 For each of the diagrams in Figure 5.42, calculate the magnitude and direction of the net force acting on the object. (Hint: Use the terms left, right, up and down.) [8 marks]

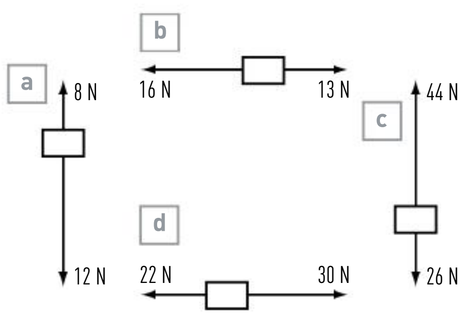


Figure 5.42

Analyse and evaluate

4 Renee catches a softball.

- **a** Identify the action force. [1 mark]
- **b** Describe what the action force does. [1 mark]
- **c** Identify the reaction force. [1 mark]
- **d** Describe what the reaction force does. [1 mark]

5 Calculate the mass of an object if it accelerates at 3.5 m/s^2 under the influence of a net force of 70 N. [1 mark]

6 Calculate the acceleration of a 500 g object under the influence of a net force of 500 N. [2 marks]

7 Use the concept of inertia to explain the relationship between the mass and acceleration of two objects of different mass acted on by the same force. [2 marks]

8 Motion is the result of forces acting in different directions. Describe the forces you believe to be acting when an object is stationary, moving, accelerating and changing direction. Which forces are always acting? [5 marks]

Critical and creative thinking

9 Design a poster on motion that explains each of Newton's three laws. Give a detailed example that has not already been mentioned in the text that illustrates each law. [6 marks]

10 Extend your ideas about Newton's laws, weight and motion to freely falling objects.

- **a** Explain why falling objects eventually reach a constant velocity by comparing the forces acting on an object. [2 marks]
- **b** Identify the term used to describe this velocity. [1 mark]
- **c** Explain why all objects fall at the same rate in a vacuum by comparing to objects falling in air. [2 marks]

TOTAL MARKS
[/45]

5.3 COLLISIONS AND ENERGY TRANSFER

Modern cars are fitted with many safety devices. Arguably the most important are seatbelts and the airbags that deploy in the case of a crash. But what triggers the airbags or makes the seatbelts work? Sensors inside the car act like mini accelerometers – when they detect rapid deceleration, the airbag system is deployed. The seatbelt mechanism reacts to a sudden force on the seatbelt and stops you from continuing in motion as the car changes its velocity. These innovations are the result of the scientific understanding of movement and collisions. All collisions involve force, mass, acceleration, energy and work.

ENERGY AND MOTION

Energy is difficult to define, but basically it is 'the ability to do something'. As you learned in *Oxford Insight Science 9*, energy comes in many forms, can be **transformed** (converted) from one form to another, and can be **transferred** from one object or material to another. A study of these forms of energy will help you to understand more about things that move and what happens in collisions.

ACTIVITY 5.3.1: BALLS IN MOTION

What you need: tennis ball, a safe area in which to throw a ball

1 Throw a tennis ball vertically into the air and and then catch it as it falls. The motion of the ball seems pretty straightforward, but this simple activity shows all the elements of motion.

2 Working in pairs, observe each other repeating the activity again and again. Together, think about and discuss the motion quantities, such as distance, displacement, speed, velocity, acceleration, mass, weight, action force, reaction force and Newton's laws, and explain which part of the motion of the ball demonstrates each of these.
   - Record your observations in a table and discuss them with the class.
   - Brainstorm the types of energy the ball might have during its flight.

Figure 5.43 Energy is converted into kinetic energy if the object gains speed, such as pushing a scooter with your foot.

Kinetic energy

For cars to crash, they must be in motion, and when they are moving they have energy. The energy of motion is called **kinetic energy (KE)**. The larger the mass of an object, the greater its KE. Also, the faster an object is travelling, the greater its KE. KE is proportional to the square of the speed (or velocity) of the object.

$$\text{Kinetic energy} = \frac{1}{2} \times \text{mass} \times \text{velocity}^2$$

$$\text{KE} = \frac{1}{2} \times m \times v^2$$

with mass in kilograms (kg), velocity in metres per second (m/s) and KE in joules (J).

When the driver of a car presses the brakes, all the KE of the car is transformed by the brakes into heat (another form of energy). This heat is then lost to the surrounding air. In a car crash, the KE is dissipated much more quickly. Some of it is converted into heat and sound. Some KE also goes into deforming the car.

How speed affects kinetic energy

KE depends on an object's mass and its speed, but not in the same way.

Example

A car of mass 1400 kg is travelling at 40 km/h. What is its KE?

Step 1: Convert the speed to m/s.

$$\text{Speed} = \frac{40}{3.6}$$
$$= 11.1 \text{ m/s}$$

Step 2: Use the KE formula to calculate KE.

$$\text{KE} = \frac{1}{2} \times m \times v^2$$
$$= \frac{1}{2} \times 1400 \times 11.1^2$$
$$= 86\,247 \text{ J or } 86 \text{ kJ}$$

(1000 J = 1 kilojoule or kJ)

Your turn

The same car is now travelling twice as fast, at 80 km/h. What is its KE now?

NUMERACY BUILDER

Gravitational potential energy

If we lift an object to a height, it gains **gravitational potential energy (GPE)**. The larger the mass and the height, the more gravitational potential energy the object gains.

$$\text{Gravitational potential energy} = \text{mass} \times \text{gravity} \times \text{height}$$

$$\text{GPE} = m \times g \times h$$

with mass in kilograms (kg), height in metres (m) and GPE in joules (J). Gravity is 9.8 m/s^2 (or 10 m/s^2 for simplification).

Elastic potential energy

Figure 5.44 Energy is converted into elastic potential energy if the object is squashed or stretched, such as stretching the rubber band of a slingshot.

Elastic potential energy (EPE) is the potential energy stored as a result of distorting an elastic object, such as a ball. Bouncing a ball is a collision between the ball and the ground. It involves GPE, KE and EPE, plus usually a small amount of each of sound and heat energy. As the ball hits the ground, it compresses and stores elastic energy. This energy returns when the ball expands again and is propelled upwards into the air. A 'flat' ball cannot return this energy, so it does not bounce.

$$\text{Elastic potential energy} = \frac{1}{2} \times \text{spring constant} \times \text{extension or compression squared}$$

$$\text{EPE} = \frac{1}{2} \times kx^2$$

where k is the spring constant, a measure of how 'stiff' the object is measured in units of newtons per metre (N/m), x is the extension or compression, is in metres (m), and EPE is in joules (J).

The law of conservation of energy

Whenever energy is transformed from one form into other forms, the total energy of the system is always constant because extra energy cannot be created, nor can energy be destroyed. This is called the **law of conservation of energy**.

If you lift an object with a mass of 0.1 kilogram through a distance of 1 metre, you give it close to 1 joule of GPE. When you drop the object and it falls 1 metre, its GPE is converted into KE and it speeds up. After falling 1 metre, it has lost the 1 joule of GPE it had and gained 1 joule of KE. The total amount of energy is constant.

Figure 5.45 Energy is converted into gravitational potential energy if the object is lifted, such as lifting books onto a shelf.

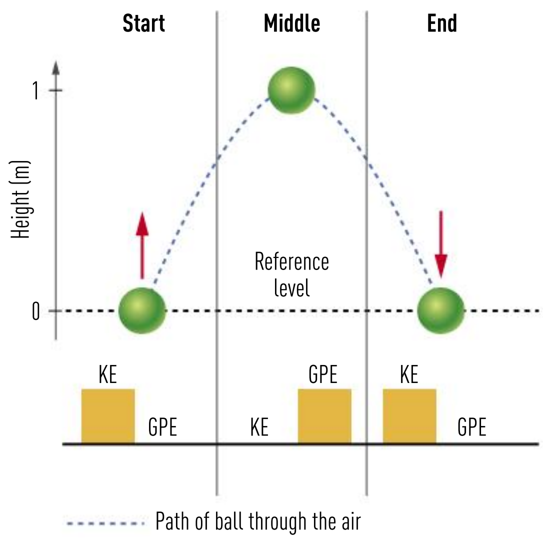


Figure 5.46 The flight of a ball thrown into the air and the energy conversions that occur. The total energy remains the same, which demonstrates the law of conservation of energy. The height of the bar graphs show how much of the ball's total energy is KE or GPE at the beginning, middle and end of the ball's flight.

Recall Activity 5.3.1 where you threw a ball into the air. Figure 5.46 illustrates the flight of the ball and the types of energy it has at different points along its flight. Energy is transformed from one form (KE) to another (GPE) and back again. When the ball is at its highest point (the middle of its flight), all the KE has been converted into GPE and for one moment the ball stops moving in the vertical direction. Notice that at the three positions shown, the total energy of the ball is the same; it has just changed from one form to another.

In reality, there may be a slight amount of heat energy produced as an object travels through the air; this is due to air resistance. Energy that is transformed into heat energy and transferred to the surroundings is extremely difficult to reuse, and is often considered as 'lost'. This energy is actually transferred to the movement of the particles in air, which we could theoretically measure as a slight rise in temperature.

Consider the following example. If 1 joule of GPE were transformed into 0.9 joule of KE and 0.1 joule of heat, then the system would be said to be 90% **efficient**.

$$\text{Energy efficiency} = \frac{\text{amount of usable final energy}}{\text{amount of initial energy}} \times 100$$

In this example:

$$\text{Energy efficiency} = \frac{0.9}{1} \times 100$$
$$= 90\%$$

The law of conservation of energy still applies because the total of energy has not changed: 1 joule of initial GPE equals 0.9 joule of KE plus 0.1 joule of heat energy.

ACTIVITY 5.3.2: ONE NEWTON AND ONE JOULE

What you need: an object with mass as close as possible to 100 g, ruler.

Note: An object with a mass of 100 g has a mass of 0.1 kg; this means it will weigh 0.1 × 9.8 = 0.98 N, or very close to 1 N.

1 Hold the object in your hand. This is equivalent to 1 N of force.

- Is 1 N a very large force?

2 Lift the object through a distance of 1 metre at a steady rate. You have just given the object GPE.

$$\text{GPE} = m \times g \times h$$
$$= 0.1 \times 9.8 \times 1$$
$$= 0.98 \text{ J (or very close to 1 J)}$$

- Is 1 J a lot of energy?
- What could you do with this amount of energy?

Food gives people energy. This is usually measured in units of kilojoules (kJ), where 1000 J = 1 kJ. The energy you used to raise the object through 1 metre came from your food.

- When you walk up some stairs and you are 2 metres higher than you were before, you have gained GPE. Calculate how much GPE you have gained.
- If you fell from a height of 2 metres, how much KE would you have just before you hit the ground?
- Use your results above to calculate the speed you would be travelling at just before you hit the ground.

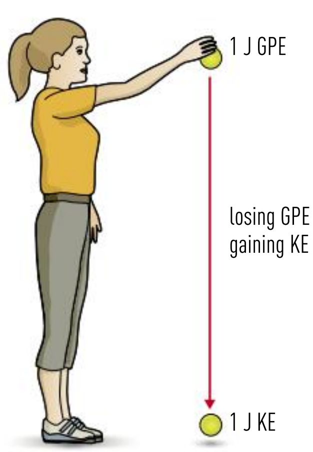


Figure 5.47 This conversion is shown as 100% efficient, which is not possible in reality.

ACTIVITY 5.3.3: CONSERVATION IN ACTION

Analysis of a simple pendulum follows a similar pattern to dropping a mass.

What you need: simple pendulum (made from a mass on the end of a length of string), retort stand

Figure 5.48 Attach the mass to a string and tie the strong firmly to the retort stand.

1 Hang a simple pendulum from a retort stand.
2 Lift up the mass and release it. As it swings, its GPE is converted into KE and back into GPE then back into KE, and so on. The process continues until the pendulum finally comes to rest.
3 Measure how much GPE the pendulum mass had at the start before it was released. Do this by measuring its mass and starting height above the bench, and using the GPE formula.
4 Allow the pendulum to complete 10 full swings (the release point is swing 0) and catch it at the end of its 10th swing.
5 Measure the finishing height of the final swing.

- Determine how much energy was 'lost' to air friction in each swing (divide by 10 swings).
- Work out the energy efficiency of the pendulum. Lay out your calculations clearly and accurately.

QUESTIONS 5.3.1: ENERGY AND MOTION

Remember

1 The following statements are incorrect. Rewrite them to make them correct.
  a The energy efficiency of all systems is always 100%.
  b The law of conservation of energy does not always apply.
2 Name at least three different types of energy involved in dropping a ball from a height and watching it bounce.

Apply

3 Describe how the KE of an object is affected if its mass decreases and the other variables remain constant.
4 Describe how the GPE of an object is affected if its height increases and the other variables remain constant.
5 Describe how the EPE of an object is affected if its stiffness increases and the other variables remain constant.
6 Explain the law of conservation of energy using an example of your own with an estimate of the amount of joules of energy at the start and the finish.

WORK AND ENERGY IN COLLISIONS

Crumple zones of cars are designed to absorb energy by crumpling during a crash. In scientific terms, the crumpling occurs when **work** is done. Work is done whenever things are moved or rearranged by a force. The amount of work done depends on the size of the force and the distance over which the force acts. The larger the force acting, the greater the work done. The longer the distance over which the force acts, the greater the work done.

Work and energy are scalar quantities, so no direction is needed. If you apply a force to an object and it does not move, then no work is done. When a force is applied to an object and it moves, the object will gain energy. The change in the amount of kinetic energy is equal to the amount of work done.

NUMERACY BUILDER

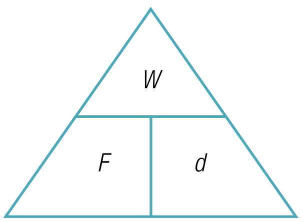


Figure 5.49 The work formula triangle.

Work

If the force is measured in newtons (N) and the distance is measured in metres (m), the work done will be in joules (J).

Work = force applied × distance moved

$W = F \times d$

Example

A heavy object takes a force of 200 N to move it 3 m. How much work is done?

$$W = F \times d$$
$$= 200 \times 3$$
$$= 600 \text{ J}$$

Your turn

800 J of work is done to an object using 250 N of force. How far did the object travel?

Figure 5.50 Cars are tested in controlled collisions to assess their safety.

Figure 5.51 Modern cars are designed to crumple and absorb energy in a collision. This reduces the forces on passengers thereby causing fewer injuries.

Vehicle collisions

Consider a car crash where a car collides with a wall, as shown in Figure 5.51. With your understanding of Newton's laws, work and energy, you can determine what happened.

The vehicle and everything in it has KE because they are moving. When the car strikes the wall, the car stops very quickly. When the car stops, the law of conservation of energy tells us that the KE must have been converted into other forms of energy. The change in KE is equal to the work done. Newton's second law tells us that a net force has acted over a distance to stop the car. The wall has exerted a force over the distance the car travelled before it stopped moving forward and while it was in contact with the wall. This force has damaged the car.

In the car collision shown in Figure 5.50, much of the KE has been transformed into EPE as the car was compressed at the front. Some of the EPE stored in this way would then be converted back into KE as the car bounces off the wall. Figure 5.51 shows where the car came to rest after the collision. Since the car did not travel very far backwards, the transformation of energy back into KE was not very efficient. Much of the energy must have been transformed into other forms such as heat and sound. Some would have also transformed into work to break the chemical bonds between atoms in the parts of the car that are now broken or deformed.

The car is not the only object that had to stop moving. The passenger had to stop over some distance. Newton's second law tells us that a force had to act to bring the person to rest. If this force is large enough, then it will do work on the passenger and damage them too. The seatbelt and airbag have applied the force to the passenger and brought them to rest. If it were not for these safety devices, the passenger would stop over a much shorter distance and the force on them would be much higher. Safety devices make the forces on a passenger smaller during a collision, and therefore protect passengers from more serious injuries.

Seatbelts, crumple zones and airbags

Most people think that seatbelts just keep you in the car and stop you when the car stops. Although they do this, and apply net (unbalanced) forces to you as the car changes speed and direction, they also reduce the force on you in an accident by slowing you down over a larger distance when they stretch. As the seatbelt stretches, you slow down over a larger distance, and therefore your acceleration is less.

Remember that Newton's second law says that when a net force acts on a mass it changes direction or velocity – it accelerates. Since $F = ma$, if the acceleration (or deceleration) is less, then force is less. Less force means less work is done and there are fewer injuries in a crash.

An airbag is like an automatic cushion that undergoes rapid inflation and deflation during a high-speed car crash (Figure 5.52). It is designed to complement other restraining systems in a car (such as seatbelts) and not replace them. An airbag also acts like a seatbelt to increase the distance it takes you to stop (often called the stopping distance). If you stopped by hitting the steering wheel or dashboard, then your stopping distance would be very short. The work done to stop you would be the same, but the forces would be higher because the stopping distance is smaller.

The front and rear crumple zones of a modern car are designed to crumple evenly during a car crash to absorb the energy of a collision, keeping the passenger area more intact and undamaged. Crumple zones also allow the car to stop over a larger distance and decrease the size of the force on the passengers. If a car were very strong and rigid, then it would stop in a very short distance. The forces on the car and passengers would be much larger and cause more injuries.

Safety devices in cars act to disperse the KE that the car and passengers have from when they were moving. This energy is converted into heat, sound and damage (work done) to the car and the passengers. These safety devices minimise damage to the passengers by directing the energy into damaging the car instead.

Figure 5.52 Airbags in a car act to increase the stopping distance of a person during a crash.

Figure 5.53 Scientists conduct controlled crash tests on all makes and models of vehicles to give them a safety rating.

EXPERIMENT 5.3.1: CRASH TESTING

Aim

To investigate the effectiveness of crumple zones during collisions.

Materials

- Dynamics trolley
- Plasticine
- Talcum powder
- Solid vertical surface, such as a wall
- Additional materials for making a crumple zone (such as paper, masking tape, foam)
- Video camera (optional)

Method

1 Build a plasticine person to act as 'Buster', the crash test dummy.
2 Lightly coat the deck of the dynamics trolley with talcum powder so Buster will not stick. Sit Buster in the middle of the trolley.
3 Push the trolley and crash it into a solid surface. Observe the effect of the collision on Buster for several different collisions: low speed, medium speed and high speed. Find the lowest speed collision that would cause damage to Buster if he were a real person. Repeat this collision to try to gain consistency of impact speed. You could record your tests and watch them in slow motion to help decide the extent of the damage.
4 Build a 'crumple zone' at the front of the trolley. Ideally, it should absorb the energy of the collision and not be too springy. Repeat the test collision with the crumple zone in place. Improve the crumple zone, if necessary, to increase Buster's chances of survival.

Results

1 Record the observations of the speed collision tests in an appropriate format.
2 Record the observations of the same collision tests with the crumple zone in place.

Discussion

Relate the findings to real-life collisions, the laws of motion, energy and work.

Conclusion

Write a statement, using your results as evidence, to describe how effective crumple zones are during collisions.

Extension

Design another experiment that involves dropping a raw egg onto a partially inflated plastic bag. Propose some design features for an airbag and test your hypotheses through experimentation. As a class, find the optimum design by each group concentrating on a different design feature.

QUESTIONS 5.3.2: WORK AND ENERGY IN COLLISIONS

Remember

1 Describe what must happen for work to be done.
2 Construct three formulas from the formula triangle for work.
3 Identify the purpose of crumple zones at the front and rear of modern cars.
4 In terms of Newton's laws of motion, explain how the safety devices in cars protect passengers from injury in the event of an accident.

Apply

5 Calculate how much work is done if a force of 400 N is applied to a heavy object and it does not move.
6 Calculate how much work is done if a force of 200 N moves an object 6 m.
7 Choose an example of an object that is stopped by a force. Describe the example and the energy transformations that can occur.
8 Draw a flowchart to represent the energy transformations that occur during a car crash.

Analyse

9 Assess the risk of having an unsecured package sitting on a car's back seat.
10 Which is more dangerous: falling from 10 m above the ground onto a mattress that is 0.2 m thick or stopping over 1 m inside a car that crashes at 100 km/h? Justify your answer with quantitative evidence (using calculations).

ENERGY TRANSFORMATIONS IN SPORT

Whenever objects interact, energy is transformed and transferred. These transformations are easily seen in sporting activities.

Hitting or kicking a ball

All sports involving kicking or hitting balls rely on the transformation of energy from one form to another. When a ball is struck, the bat, racquet, club, foot or hand has KE. When the ball is struck, it is compressed and energy is stored in the ball as EPE. This can be seen in Figure 5.55. The tennis ball is compressed during its impact with the strings of the racquet. Some of the KE of the racquet is transformed into EPE within the ball.

The conversion of KE to EPE in a collision is never 100% efficient. Some energy is converted into sound and you can hear the collision. In televised cricket matches, sensitive microphones detect the small sounds a ball makes when it comes in contact with the edge of the bat. This helps television viewers see if the umpire has made the right decision. This technology is called the snickometer or 'snicko'. It is possible because energy in a collision is transformed from kinetic energy into sound.

In addition to sound, energy in a collision is converted into the motion of the particles in the colliding objects. We can detect this energy transformation as a rise in temperature. Again in cricket, this is used to assess the umpire's decisions via technology called Hot Spot.

Hot Spot uses infrared cameras to see the rise in temperature due to a collision. The warmer an object is, the brighter it appears to an infrared camera. If the bat hits the ball, a bright spot of higher temperature remains on the bat.

The most obvious consequence of hitting or kicking a ball is that the ball changes its speed and/or direction. Most often, you hit the ball and it goes flying away from you at high speed. This illustrates what happens to the EPE stored in the ball during the collision.

Once a ball is compressed by its maximum amount during a collision, it begins to spring back to its normal shape. The compressed ball exerts a force on the object that compressed it. The EPE is converted into KE. The ball moves away from the bat, racquet, club, foot or hand at a new speed and/or direction.

When a ball gains KE through a collision with a moving object, there has been a transfer of KE. This transfer has occurred through a transformation of energy from KE to EPE and back to KE.

Energy transformations common to ball sports can also be illustrated using the example of golf. The flowchart in Figure 5.57 shows the transformations that occur at various times during the collision between a golf club and a golf ball.

Figure 5.54 A tennis ball is compressed and deformed as it is struck by a racquet.

Figure 5.55 The sound of the bat on the ball can be heard by people watching the cricket on TV.

Figure 5.56 Temperature rises during a collision, which can be detected by infrared cameras

The types of transformations responsible for losses of energy in these collisions are heat and sound. Previously you have seen where these transformations can be readily detected in cricket. The sound of the collision involving the golf ball is easy to detect with your ears. Once a ball is struck, the EPE is released. If you could measure the internal temperature of the ball, then you would see that it was warmer after the collision.

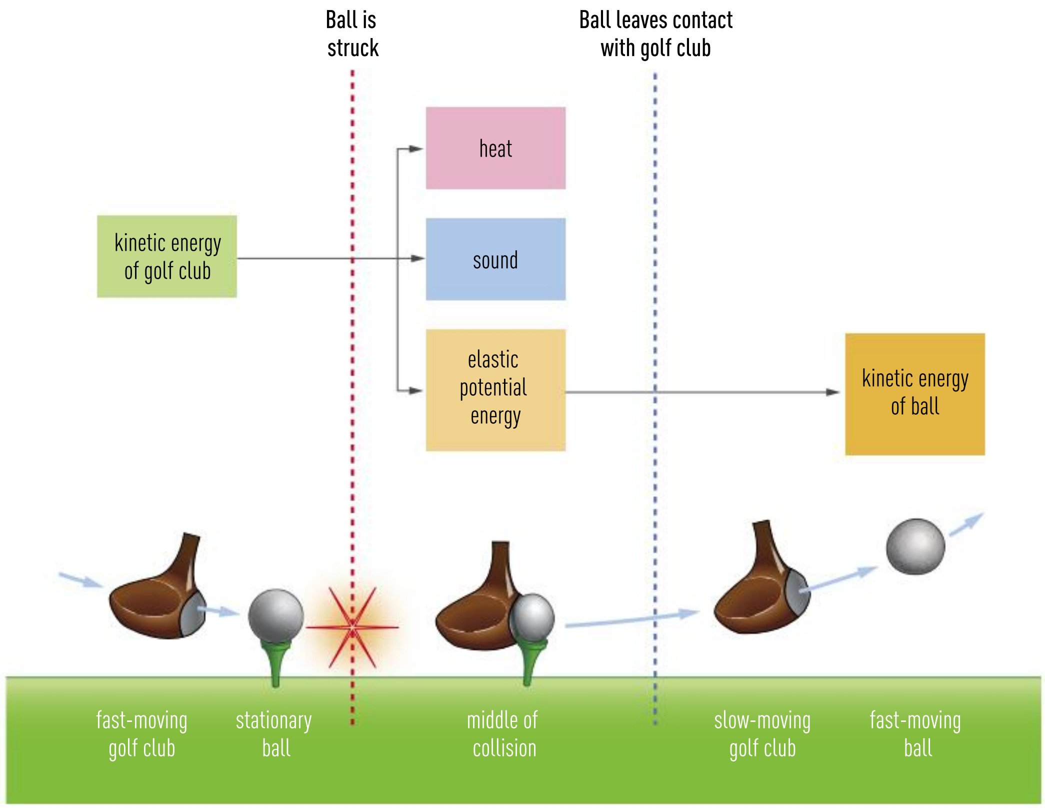


Figure 5.57 The energy transformations that occur when a golf ball is struck by a golf club.

ACTIVITY 5.3.4: ENERGY CONVERSIONS IN COLLISIONS

What you need: infrared thermometer, squash ball, racquet, appropriate space with a wall

1. Measure the temperature of a squash ball with an infrared thermometer.
2. Hit the ball against a wall with a squash racquet a certain number of times.
3. Measure the temperature of the ball again.
4. Repeat steps 1–3 at least five times.

- Plot your results on a temperature–hits graph.
- Use the gradient of the graph to determine the temperature rise each time the ball is hit.
- What does the rise in temperature of the ball indicate?

Extension

Each time the ball is hit by the racquet or the wall, KE is converted into heat. Since a squash ball is very inefficient, the temperature rise is more noticeable than for other balls. Design an experiment to compare the efficiency of different balls or the temperature rise in different balls as they are hit. Make sure it is a fair test.

Human collisions in sport

Some collisions in sport have an impact on the player themselves. When a player is tackled, the KE the players have is sometimes transformed into physical damage as work is done. Body parts are compressed, blood vessels are ruptured and bones are broken. Energy is lost when permanent damage is done.

Some of the energy in these collisions is transformed back into KE as the players bounce off each other. The situation is similar to hitting a golf ball with a club: energy is stored as EPE, some is lost by transformation into other forms, and some is converted back into KE again.

Even playing a non-contact sport involves collisions, forces and many resulting injuries. Every time your feet touch the ground it is a collision. Some of these collisions result in damage to muscles, tendons and joints. Sports like netball and basketball result in a huge number of knee injuries. Again, this is all about transformation of energy.

Figure 5.58 During a tackle in rugby league, KE can be transformed into work, which can sometimes cause damage to the player.

Figure 5.59 Injuries also occur due to collisions between the player and the ground.

QUESTIONS 5.3.3: ENERGY TRANSFORMATIONS IN SPORT

Remember

1 Identify the type of energy a ball has when it is moving.

2 Describe the effects of hitting a ball with a bat, racquet, club, foot or hand.

3 Outline the transformation of energy when you hit a golf ball with a club.

Apply

4 Construct a flow diagram to illustrate the energy transformations that occur when you kick a football.

5 When a tennis ball is hit with a racquet, the energy transformation from the KE of the racquet to the KE of the ball is not 100% efficient. Account for the loss in energy and describe how you could measure it.

Analyse

6 Select two sports and assess which has a higher potential of injury to the player. Justify your assessment using your knowledge of physics.

5.3 CHECKPOINT

COLLISIONS AND ENERGY TRANSFER

Remember and understand

1 Copy and complete:

a The energy of motion is called _______________ energy. [1 mark]

b The _______________ an object travels, the more kinetic energy it has. [1 mark]

c Work happens whenever things are moved by a _______________. [1 mark]

d Work and energy are _______________ quantities, so no _______________ is needed. [2 marks]

e If we lift an object to a height, it gains _______________ _______________ energy. [1 mark]

f In collisions, energy is _______________ into other forms of energy. [1 mark]

2 Complete the following table. [4 marks]

Quantity	Symbol	Unit	Unit symbol	Formula
				W = *Fd*
		newton		
	KE			
Gravitational potential energy				

5 A golfer wants a golf ball to travel as far as possible when hit. She asked for a ball that was the most efficient at transforming energy from one type to another. Explain her reasoning. [4 marks]

Analyse and evaluate

6 Propose what may happen if there are no crumple zones to crumple and absorb the energy of a car crash. [4 marks]

7 The more efficient a ball is at converting energy from one form to another, the higher it rebounds when it is bounced and the slower it heats up as it is bounced continually. You have been asked to design the safety features of a car. Would you want the car to behave like an efficient or an inefficient ball in a collision? Justify your answer. [4 marks]

Apply

3 Construct a flowchart to illustrate the transformations and transfers of energy that would occur when you bounce (dribble) a basketball. [3 marks]

4 Calculate the different amount of work done to stop a 25 kg child and a 95 kg adult in a crash where the child experiences a force of 7000 N, the adult experiences a force of 26 000 N and they both have a stopping distance of 0.5 m. [2 marks]

Critical and creative thinking

8 Examine the test car shown in Figure 5.61. Identify the safety features of the car and any safety features that are missing. [2 marks]

9 The kinetic energy formula demonstrates that speed contributes to the seriousness of a car crash in a major way. Extend your ideas about collisions to include other factors that contribute to car crashes. Produce a fact sheet for learner drivers to inform them of your findings. [5 marks]

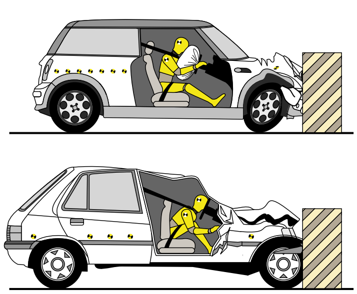


Figure 5.60 A test car crash.

TOTAL MARKS [/35]

5 CHAPTER REVIEW

Objects in motion

1 Fill in the gaps using the words in the Word Bank below:

When an object is moving at a constant ____________, it covers a certain distance in a certain amount of time. Newton's _________ law says that the object will continue at a constant speed unless acted on by a net force.

If this object originally started at rest and a net __________ is responsible for accelerating it, Newton's __________ law tells us that the ____________________ of a certain mass is determined by the size of the net force that acts on it. The bigger the mass, the ___________ the force required if you want to accelerate at the same rate. A net force can bring about a change in _________________ as well as a change in speed.

Movement is a large part of our everyday lives. When we travel in a vehicle, for example, energy is ___________________ from one form to another to make the vehicle move. These transformations are never 100% _______________ and a large amount is __________ as heat. To study the energy involved, scientists use the law of ____________________ of energy, which says that energy cannot be lost or __________. It can only be converted from one form to another.

WORD BANK

acceleration	first	lost
conservation	force	second
direction	gained	speed
efficient	larger	transformed

Explain the relationship between distance, speed and time

2 Identify the standard unit for speed. [1 mark]

3 An object covers a larger distance in the same amount of time as it did before. Explain whether the object's speed has increased or decreased. [1 mark]

4 Identify the property that velocity has and speed does not. [1 mark]

5 You are the driver of a car travelling at a speed of 100 km/h. Explain why it is important to control the velocity of the car and the speed. [2 marks]

Describe the equations of motion (additional content)

6 Calculate the distance travelled in 10 minutes by a car travelling at 60 km/h. [2 marks]

7 Describe the relationship between the change in velocity and the acceleration of an object. [1 mark]

8 Calculate the acceleration of a train that began at rest and reached 25 m/s in 300 seconds. [1 mark]

Describe the relationship between force, mass and acceleration

9 Identify which of Newton's laws describes the relationship between force, mass and acceleration. [1 mark]

10 If a trolley has a mass added to it while it is being accelerated, explain whether a bigger or smaller force is needed to maintain the same acceleration. [1 mark]

11 Describe the effect of decreasing the net force acting on an object. [2 marks]

Relate acceleration to a change in the motion of an object due to a net force

12 A driver lifts his foot off the accelerator until the car travels at a constant speed. Identify the net force acting on the car and the car's acceleration. [2 marks]

13 An object is acted on by a net force that is twice as large as the initial net force. Describe the change in the motion of the object and its acceleration. [2 marks]

Analyse everyday situations involving motion and describe them in terms of Newton's laws of motion

14 Identify which of Newton's laws explains why a passenger in a car continues moving forward if the car stops suddenly and they are not wearing their seatbelt. [1 mark]

15 Use Newton's first law to explain why you feel as though you are being pulled to the right when the car you are travelling in turns left. [2 marks]

16 A cyclist has a mass of 95 kg including his bike. He applies a force of 25 N to accelerate himself from rest to a top speed in 50 seconds. Calculate the top speed the cyclist achieves. [2 marks]

17 If a watermelon were dropped on your head from a great height, the watermelon would break and your head would be injured. Use Newton's laws to explain all the details given for this situation. [2 marks]

18 A 5 kg box is accelerated along a floor at 2 m/s^2 by applying a force of 50 N. Calculate the force of friction acting on the box. [2 marks]

Apply the law of conservation of energy

19 If a moving car has 10 kJ of kinetic energy and it collides with a building, the car bounces back with 2000 J of kinetic energy. 1250 J of energy was lost as sound and heat. Calculate how much energy has gone into the work done to damage the building and the car. [1 mark]

20 When a ball is dropped, it only rebounds to 65% of its original height. Use the law of conservation of energy to explain how you know where the other 45% must have gone. [2 marks]

Describe how and why the transformation of usable energy is not 100% efficient

21 Identify the common form of energy responsible for bouncing balls being less than 100% efficient. [1 mark]

22 A ball has an efficiency of 40% when it bounces. Describe the transfers and transformations that must occur to result in this 40% efficiency. [2 marks]

Compare energy transfers and transformations in sports (additional content)

23 Compare a transfer of energy to a transformation of energy. [1 mark]

24 A squash ball is much less efficient at bouncing than a tennis ball. Compare the transformations that occur when these balls bounce to explain their difference in efficiency when bouncing. [2 marks]

TOTAL MARKS
[/35]

5 CHAPTER REVIEW

RESEARCH

Choose one of the following topics for a research project. A few guiding questions have been provided, but you should add more questions that you wish to investigate. Present your report in a format of your own choosing.

Car safety features

Modern cars may be equipped with electronic stability control (ESC), anti-lock braking systems (ABS), electronic brake distribution (EBD), RVC tachometers, traction control systems (TCS) and park assist. Find out about each of these and other car safety features under development. How do they contribute to the safety of passengers?

g-forces

Aircraft pilots flying military jets commonly experience *g*-forces. What is a *g*-force? When do pilots experience *g*-forces? What is the human tolerance of *g*-forces and what effect do they have on the body? What other examples are there of theme park rides or situations where people experience *g*-forces?

Movement of aircraft

Aircraft are the second fastest mode of transport, after rockets. Find out about the different types of aircraft and how they move. Explain the interactions between lift, weight, thrust and drag in aircraft movement. What speeds can aircraft achieve?

Drag forces

The modern design of vehicles involves the study of drag forces and how to reduce them. This involves knowledge of streamlining and aerodynamics. What are these areas of science and how are new designs tested?

REFLECT

Me

1 How is the information you have learned in this chapter relevant to your life?

2 What is the most interesting thing you learned about movement?

3 Did you take movement for granted before you read this chapter? Do you still?

My world

4 How has increased scientific knowledge and understanding of movement improved the world?

5 What skills or knowledge can you take from your study of movement and apply to another school subject or another part of your world?

My future

6 What careers might you pursue if you are interested in force, mass and movement?

KEY WORDS

acceleration
acceleration due to gravity (*g*)
deceleration
displacement
distance
efficient
elastic potential energy (EPE)
energy
force
force diagram
gravitational potential energy (GPE)
inertia
kinetic energy (KE)
law of conservation of energy
magnitude
net force
scalar
speed
ticker timer
transfer
transform
vector
vector diagram
velocity
weight
work

5

MAKING CONNECTIONS

Building an energy converter – a come-back can

Challenge

To build a can that, when rolled across the floor, comes to a stop and then rolls back to where it started, illustrating the law of conservation of energy.

Materials

Cylindrical can or tin with removable lid (like a small Pringles tin)

Rubber band

Mass to be attached to the centre of the rubber band

Scissors

Tape

Questioning and predicting

Tape one end of the rubber band to the centre of the underside of the lid. Tape the other end of the rubber band to the centre of the end inside the can. Attach your mass to the rubber band so it causes the rubber band to wind up when the can is rolled across the floor.

Planning and conducting

Write out your method in steps, and then follow the steps to see if your method works.

Processing, analysing and evaluating

Consider the results of your experiment. If necessary, modify your method and try it again.

This demonstration should illustrate the conversion of kinetic energy to elastic potential energy and back. The potential energy is stored internally in the twisted rubber band.

Communicating

Write a formal report of this activity, including as many of the motion concepts you have learned in this chapter as possible, such as speed, acceleration, deceleration, Newton's laws, momentum and energy conservation.

Figure 5.61 Some possible materials needed for this investigation.

Figure 5.62 Attach the rubber band and mass inside the can.

Figure 5.63 Roll the can away and see if it comes back!

6

THE UNIVERSE

Where do we come from? Are we alone in the universe? Do black holes actually exist? Will the universe last forever? Your science class could probably fill the whiteboard with questions about the universe. Scientists don't know all the answers. We are constantly discovering new planets and other objects in the universe, and new information about our closest planets. It's a big universe and it's constantly changing. Only recently, new ideas about planets resulted in Pluto being reclassified as a dwarf planet. Understanding our universe better may provide clues as to the future of our own planet and, ultimately, us.

DESCRIBING THE UNIVERSE 6.1

Galaxies are made of stars, and stars are at the centre of every solar system like ours. The main objects astronomers study are stars. These stars go through many stages within their lives and eventually die. Many of the greatest minds in astronomy have dedicated their lives to measuring the distances to the stars. It is only now that we really appreciate where our place in the universe really is.

Students:

» outline the main features of the universe, like galaxies, nebulae, stars and solar systems

» use appropriate scales and units to describe sizes and distances within the universe

» relate the colours of stars to their age, size and distance from the Earth (additional)

» describe recent contributions by Australian scientists in the investigation of the universe (additional)

INVESTIGATING THE UNIVERSE 6.2

Astronomy is the oldest science. Humans have studied the night sky for as long as there is evidence of our existence on the Earth. Once Galileo started the race for bigger and better telescopes, technology played an increasing part in exploring the universe. Who knows where this will all take us next? Maybe one day we will live on the moon or somewhere out in space.

Students:

» describe some technologies that have advanced scientific understanding about the universe

HISTORY OF THE UNIVERSE 6.3

Over the last century, astronomers have gathered evidence about the history of the universe. This evidence has shaped the components of the Big Bang theory through the use of the scientific method. The evidence shows us that the universe is expanding and therefore was once a hot dense place. With better technology, we are now observing the evolution of galaxies through time. We can see how gravity has shaped galaxies and pulled them together into clusters.

Students:

» identify that all objects in the universe exert the force of gravity

» use scientific evidence to outline how the Big Bang theory can be used to explain the origin of the universe and its age

» outline how reviews by the scientific community have refined ideas about the origin of the universe

6.1 DESCRIBING THE UNIVERSE

The universe is huge, and is organised into groupings and structures by gravity. It is lit up and powered by the stars. Many of the stars are so far away from the Earth that their light takes thousands of years to reach us. This means we are actually looking back in time, because the light from a star tells us how that star looked thousands of years ago and not how it looks today. If a star is 3000 light years away, it takes 3000 years for the light to reach us and, when we look at it, we are seeing it as it appeared 3000 years ago!

STARS, GALAXIES AND THE UNIVERSE

Stars surround us at all times, although their glow is overpowered during the day by the brightness of our **Sun**. The stars are just like our Sun, and we owe much of our existence to them. Once the universe formed, it was the stars that controlled our destiny. They produced the chemical elements we are made of and provided all the energy that life on the Earth needs to survive.

A **star** is a giant ball of hot glowing plasma. Plasma is a state of matter that is formed when electrons are stripped from atoms in a gas due to extremely high temperatures. This plasma is made of positive ions (charged atoms) and free electrons.

Figure 6.1 Our night sky is lit up by stars.

Figure 6.2 The Sun is the Earth's closest star.

Most stars are made almost entirely of hydrogen and helium. These elements are constantly reacting at the core (centre) of the star through a process called nuclear fusion (when the nuclei of atoms join to make larger atoms). A small amount of mass is converted into energy in each fusion reaction. The energy is emitted as visible light (and other forms of **electromagnetic radiation**) and is what we see when we look at the stars at night.

Some stars appear bright in the sky, whereas others appear dim. The observed brightness of stars depends mainly on how far away they are from us. Usually, the closer the star, the brighter it appears. A star that looks bright in the sky might actually be a dim star that is very close, while a dim star might really be very bright, but is just a very long way away.

The **apparent magnitude** of a star is a measure of its apparent brightness, or how bright it appears from the Earth. Bright stars have a low magnitude and dim stars have a high magnitude. Our Sun, for example, is not a very bright star compared to other stars, but because it is so close to the Earth, it appears to be blindingly bright. Sirius is the next brightest star in our sky.

Planets and moons also have an apparent magnitude, although they are not creating the light. It is simply the reflection of the light from stars, usually our own Sun.

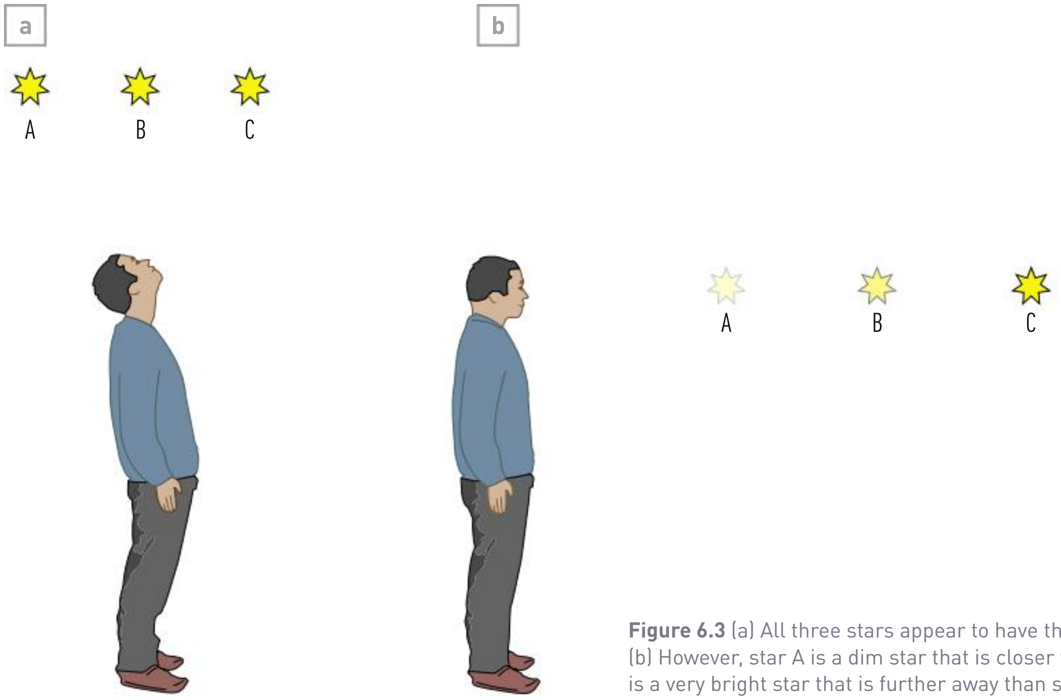


Figure 6.3 (a) All three stars appear to have the same brightness. (b) However, star A is a dim star that is closer than star B, and star C is a very bright star that is further away than star B.

Absolute magnitude measures stars' brightness as if the stars were the same distance from the Earth, in other words, their actual brightness.

Stars vary in size, mass, temperature and brightness. The most fundamental property of a star is its mass. The mass of a star determines how fast it uses its nuclear fuel in fusion reactions. A massive star lives fast, is very bright and dies young. Since these massive stars burn their fuel quickly, they are also very hot. The colour of a star is determined by its surface temperature, so massive stars are blue–white. The smallest stars are the coolest stars and these are red. The mass of our Sun is nearly 2 million × 10^{24} kg, which is 333 000 times the mass of the Earth, which is about 6 × 10^{24} kg. The temperature on the surface of our Sun is approximately 5500°C, and it appears yellow–white.

Figure 6.4 Don't be mistaken; the moon and Venus appear very bright, but they are really just reflecting the light of the Sun.

ACTIVITY 6.1.1: INVESTIGATING THE MAGNITUDE OF STARS

You can investigate the brightness of stars using some light globes as a model.

What you need: 2 light globes suitable for 'dimming', 2 power packs, alligator clip leads, camera (optional)

1. Connect each globe to a power pack. Set each power pack to the same, mid-range voltage. Both globes should be glowing with the same brightness.
2. Position the globes so they are equal distance from the viewer. Describe the brightness of each globe. You may like to photograph them.
3. Reposition the globes so they are at significantly different distances from the viewer (at least a 2-metre difference). Describe and/or photograph the brightness of each globe.
4. Repeat steps 2 and 3 but alter the voltages on the power packs so that each globe is receiving a different amount of energy.

- Describe the difference between apparent magnitude and absolute magnitude.
- Explain how distance from the viewer affects the apparent brightness of a star.
- Explain how the energy of a star affects its apparent brightness.

Figure 6.5 What factors affect the apparent brightness of a globe?

Figure 6.6 The Great Orion Nebula, like all nebulae, is an active cloud of dust and gas where stars are formed.

The lives of stars

To discover the details of the life cycles of stars, astronomers gathered data on millions of stars at different stages of the stars' lives. This data was plotted on what we now call the **Hertzsprung–Russell (HR) diagram** (Figure 6.7). This enabled astronomers to develop theories for the life cycles of stars with different masses. The HR diagram shows a plot of the star temperature on the horizontal axis and the brightness (absolute magnitude) on the vertical axis. When plotted this way, most stars, including our Sun, fall into a narrow diagonal band called the main sequence. Giant stars are brighter and appear above the main sequence. The remnants of stars like **white dwarfs** appear below the main sequence.

A star usually remains on the main sequence in a steady state for approximately 90% of its lifetime, fusing hydrogen into helium. For the other 10% of the time the star changes in size and absolute magnitude. It becomes a giant star before finally ending up as a white dwarf, a **neutron star** or a **black hole**.

A star is born

Part of the Orion constellation is sometimes seen as 'The Saucepan'. In the handle of the saucepan is a misty patch, visible to the naked eye, called M42 or Great Orion Nebula (see Figure 6.6). This **nebula** is a region of gas and dust, and is considered to be a stellar 'nursery' as stars are constantly being born in this region.

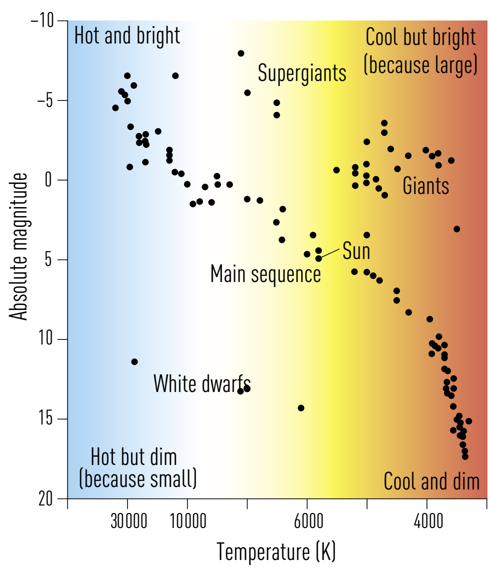


Figure 6.7 A Hertzsprung–Russell diagram.

Adult stars

When stars are born, their hydrogen fuel is changed into helium through nuclear fusion in the core. A star like the Sun may do this in a relatively stable way for 10 billion years, existing as a main sequence star as shown in the HR diagram (see Figure 6.7).

Old age

Over the life of a star, the hydrogen runs out and the fusion reaction occurs in a shell around the core. Helium produced through nuclear fusion at the core eventually fuses into heavier elements like carbon and oxygen. The outer layers of the star expand and cool, forming a **red giant** star. Our Sun will do this in about 5 billion years from now. Because of its size, the Sun will swallow up the inner planets of the solar system – Mercury, Venus, Earth and Mars.

Stellar death

For a star that started out roughly the size of the Sun, the outer regions of the red giant are gently blown into space. The shell of gas left behind is called a **planetary nebula**, although it has nothing to do with planets. Just over 200 years ago, William Herschel observed the first of these objects and thought its rounded shape looked like a planet. Only the remnants of the star's core remains at the centre as a white dwarf. These white dwarfs are made mostly of carbon and oxygen and are very dense. You could think of it like a diamond the size of the Earth but with the mass of the Sun.

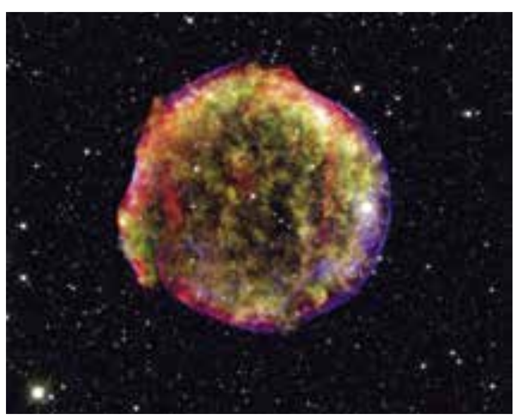


Figure 6.8 The Tycho supernova. This star explosion was seen by Tycho Brahe in 1572. The explosion left behind a hot cloud of expanding debris (green and yellow). The outer blue ring shows the shock wave of the explosion.

Heavier stars have a different fate. The nuclear fusion process continues through various elements until iron is formed. The star then collapses and the resulting explosion is a **supernova** – one of the most energetic events in the universe (see Figure 6.8). The remaining core is extremely dense, and collisions between electrons and protons form neutrons, creating a neutron star. Neutron stars are only tens of kilometres in diameter and are amazingly dense. Less than a teaspoonful of neutron star material has around the same mass as 100 000 cars! If a neutron star collapses further, its gravitational pull and its density become so huge that not even light can escape. This is called a black hole.

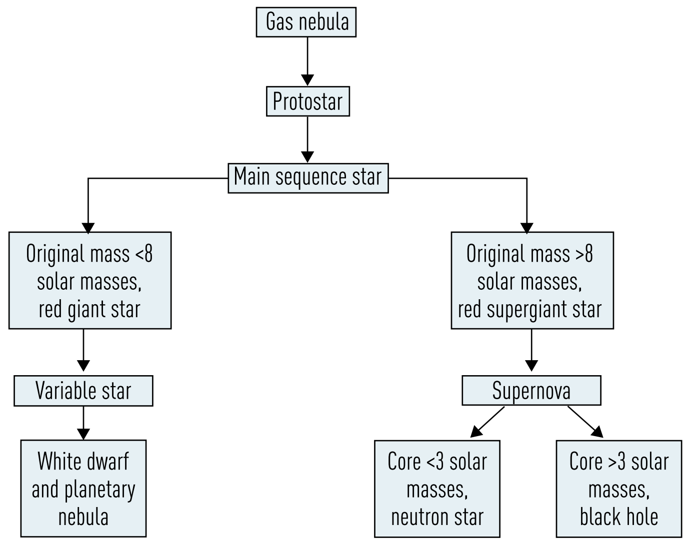


Figure 6.9 The life cycle of a star.

ACTIVITY 6.1.2: STAR PROFILES

There are many different types of stars, some of which you have just learned about. Working in a small group, find an image of each of the objects listed below. Print each one out on a full page in colour and paste them onto a large sheet of paper, or organise them in an electronic document. Use the information about the life cycle of a star in Figure 6.9 and place them into chronological order, with labels. Construct a diagram that traces the lives of low-mass stars (that form white dwarfs) and high-mass stars (that form either neutron stars or back holes).

red giant	nebula	main sequence star
white dwarf	black hole	supergiant
protostar	neutron star (pulsar)	supernova

- Discuss the implications of the life cycle of stars for life on planets orbiting around them.
- When the first stars in the universe formed, they contained only hydrogen and helium. Describe the role of stars in allowing us to exist today.

QUESTIONS 6.1.1: STARS, GALAXIES AND THE UNIVERSE

Remember

1 Define the term 'star'.

2 What is the name of the process that generates energy within a star?

3 What property of a star determines its:

a colour b apparent brightness?

Apply

4 Draw a flow chart to show the life cycle of a star the size of our Sun.

Analyse

5 Propose why we cannot see individual stars at night that are in other galaxies.

6 A star appears bluish-white in colour. Identify some other properties this star is likely to have.

Research

7 Investigate the spectral class of stars, including the average temperatures of stars of different colours. Present your findings in table.

STRUCTURE OF THE UNIVERSE

Basically the universe includes everything that exists. Anything you know of is part of the universe. Even the three-dimensional space you move around in and the time that passes from moment to moment are part of the universe.

Scientists study the universe at all scales – from the most fundamental particles within atoms to the largest clusters of stars within their galaxies, and the principles that govern their behaviour. To understand the universe, we must look at what is in it and how these things are related. Figure 6.10 shows the structures in the universe and how they fit together.

In the previous section we looked at the most familiar objects in the universe – stars. Many people forget that the Sun is our closest star, and the other stars in the night sky are just like the Sun. Another familiar object is a planet. There are billions of planets just in our **galaxy**. Perhaps more than one of them has life.

Stars and planets are only two of the common astronomical objects that astronomers study. Table 6.1 summarises the key structures and features within the universe.

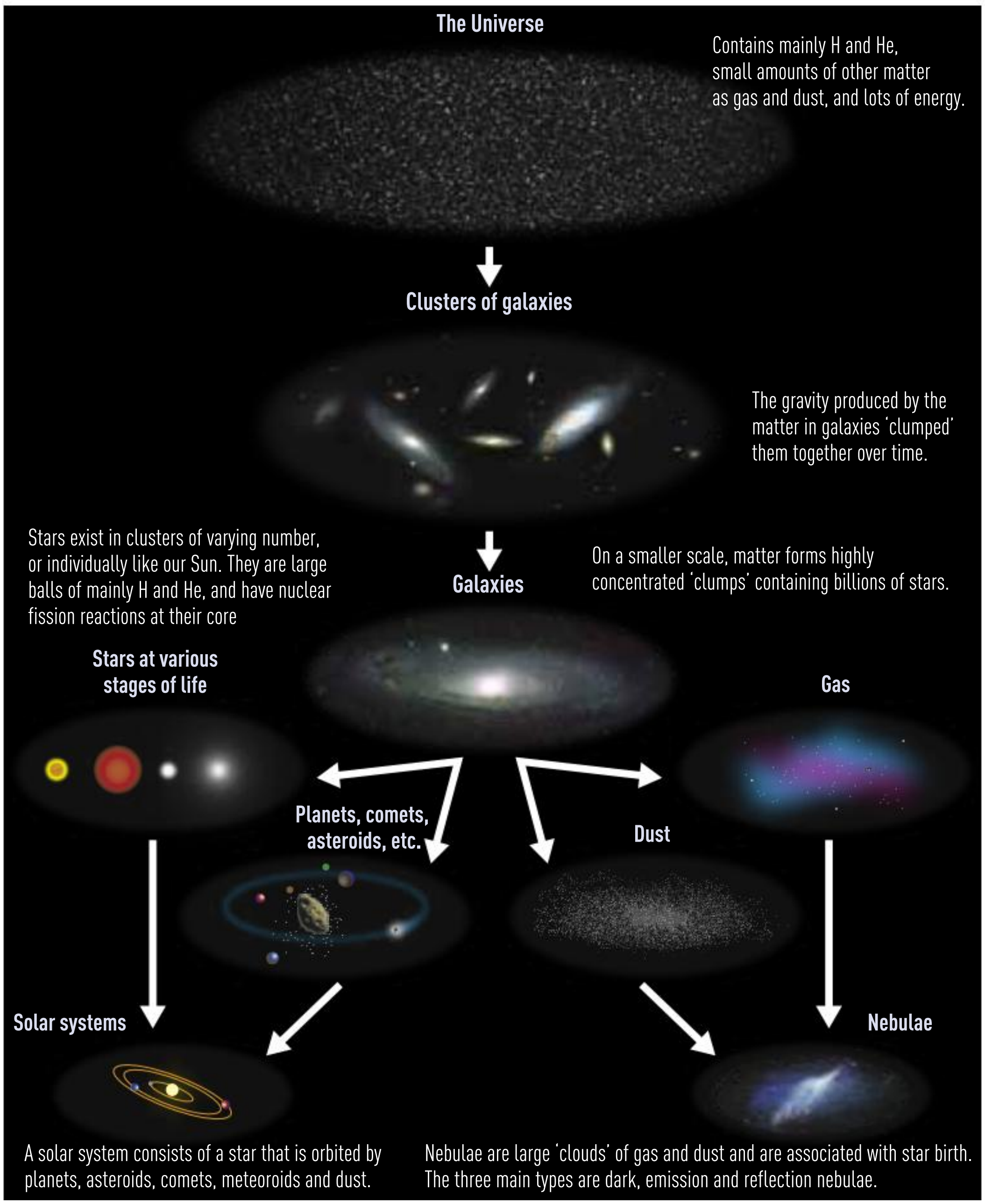


Figure 6.10 The hierarchical structure of the universe.

Table 6.1 Major features contained within the universe.

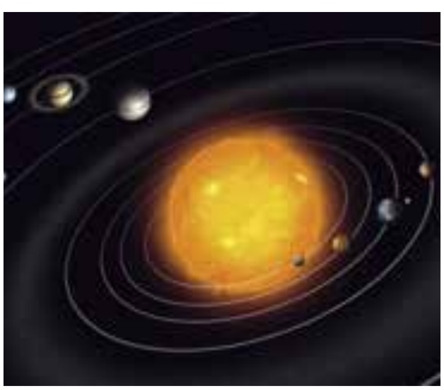
Galaxies
Galaxies are huge collections of gas, dust and billions of stars, held together by the force of gravity. Many of the stars they contain are at the heart of solar systems.
Galaxies come in many shapes and sizes. The most familiar examples are galaxies like our Milky Way, which are disk-shaped with spiral arms of young stars. Galaxies are basically the building blocks of the largest structures in the universe. They form large groups called clusters and these clusters form superclusters, all under the influence of gravity.

Nebulae
The word nebula means 'a cloud or mist' in Latin. A nebula is a cloud of gas and dust in space. The gas is mainly hydrogen and the dust is generally as fine as smoke from a fire. Nebulae are the birthplaces of stars. Gravity pulls the gas together forming stars and whole solar systems. The Orion Nebula, and other similar nebulae, have hundreds of solar systems forming within them right now.

Stars
Stars are giant balls of hot glowing plasma held together by gravity. Most stars are made almost entirely of hydrogen and helium. These elements are constantly reacting at the core of the star through a process called nuclear fusion. Stars fuse hydrogen into helium for most of their lives and this produces the energy that makes them shine.

Planets
Astronomers recently changed what they call a planet because they kept finding new ones. A planet is an object that orbits a star, has enough mass to have formed into an approximately spherical shape due to gravity, and there are no other bodies of a similar size in a similar orbit around the Sun. This means there are eight planets around the Sun and other objects, like Pluto, are called dwarf planets.

Solar system
A solar system consists of a central star with planets orbiting it. It also includes the other objects found around the star, such as comets, asteroids, moons, dwarf planets and dust.



Others
There are many other objects in the universe that have been given names and classified into categories. Many of them are just stars at different stages of their lives. Examples are planetary nebulae, black holes, neutron stars and white dwarfs.

ACTIVITY 6.1.3: CLASSIFYING GALAXIES

Galaxies are key structures in the universe. They are classified according to their shapes. The formation of galaxies can be studied using images from the Hubble Space Telescope archive, but there is so much out there that everyone's assistance is required. In addition, as in all good scientific investigations, repetition is the key to reducing errors and ensuring reliability of results.

Visit the Galaxyzoo website and find out about this galaxy project. To learn more about galaxies, read the section 'How Do Galaxies Form?'. Click 'Begin Classifying' and have a try. Look at the examples as a guide. Summarise what you learn from this activity.

Figure 6.11 There are two galaxies visible from the Earth with the naked eye or with binoculars in a very dark sky: the Small Magellanic Cloud (SMC) and the Large Magellanic Cloud (LMC). Most galaxies are too faint to be seen with the naked eye and a telescope is needed to reveal the most amazing images.

Figure 6.12 The Milky Way galaxy is a spiral galaxy containing at least 200 billion stars. It is 100 000 light years across and 1000 light years thick. Our Sun is just one of the stars in this galaxy and is located in one of the spiral arms.

ACTIVITY 6.1.4: DEFINING A PLANET

In 2006, the International Astronomers Union changed their definition of a planet. This led to Pluto being removed from the list of planets in the solar system. Your mission is to work out what is a planet and what is not. Form a group with your classmates and follow the steps below.

1. Search the Internet for some reliable definitions of the objects in the solar system.
2. Record these definitions appropriately and a definition for the solar system itself.
3. Research the characteristics of the objects in the solar system.
4. Discuss what characteristics you could use to classify these objects into different groups.
5. Construct a dichotomous key to classify these objects. If you are not sure how to do this, look for some examples on the Internet.
6. Report back to the class with your group's classification key. Discuss everyone's ideas and come up with an agreed classification key.
7. Find some examples of objects in the solar system and work out what category they fall into.

Do not worry if your results are not perfect. Even professional astronomers have found it difficult to define a planet.

NUMERACY BUILDER

Scientific notation

The numbers used by astronomers to quantify time and distance in the universe are enormous. Just writing some of these numbers down would take pages and pages of your book. Luckily there is an easier way.

In maths, you may have come across scientific notation. This way of summarising big numbers involves using powers of ten. Table 6.2 shows some numbers reduced to powers of ten.

Table 6.2 Scientific notation.

Number	Power of ten
10	10^1
100	10^2
1000	10^3
1 000 000	10^6
1 000 000 000	10^9

To change any number into scientific notation, convert the original number into a decimal between 1 and 10. Then count the number of times the decimal point would have to be moved to reach the end of the original number. This is your power of ten.

Example

The Sun is about 150 000 000 km from the Earth (on average). Convert this to scientific notation.

First, add the decimal point after the first digit → 1.5

Next, the decimal would have to move 8 places to the right to reach the end of the original number, so:

the distance to the Sun is 1.5×10^8 km

Your turn

The universe is 14 800 000 000 years old. Convert this to scientific notation.

QUESTIONS 6.1.2: STRUCTURE OF THE UNIVERSE

Remember

1 Identify the main chemical elements present in the universe.

2 Describe a nebula.

3 What are the main structures within a galaxy?

Apply

4 Order the main features in the universe in ascending order of size.

5 Draw a diagram to relate the objects and structures in the universe to each other. Include details about which of them is inside another or which appeared before something else.

6 Propose what has caused matter to clump together over time in the universe.

ACTIVITY 6.1.5: SIZES AND DISTANCES IN THE UNIVERSE

The scale of the universe is enormous, bigger than most people can truly appreciate.

1 Predict the order the following objects should be placed in to rank them from closest to the Earth to farthest away:
   - a galaxy other than the Milky Way
   - a star
   - clusters of galaxies
   - a planet other than the Earth
   - a nebula
2 Use the Internet to research the distance to the objects above to test your prediction. Record the correct answer as a diagram that illustrates the distance from the Earth.
3 Predict the relative size of the objects in the list above, ranking them from largest to smallest.
4 Continue your research to discover the relative size of these objects.
5 Draw a diagram showing the relative size and include numerical estimates or approximations. Research and define all the units and measures you have found, such as light years and parsecs, to ensure you understand them.
6 Write down your location right now so that anyone in the universe could find you. This needs to include your location on many size scales, such as your location on the Earth, the Sun's location in the Milky Way galaxy (the Orion arm), and the galaxy's location in the local group of galaxies.

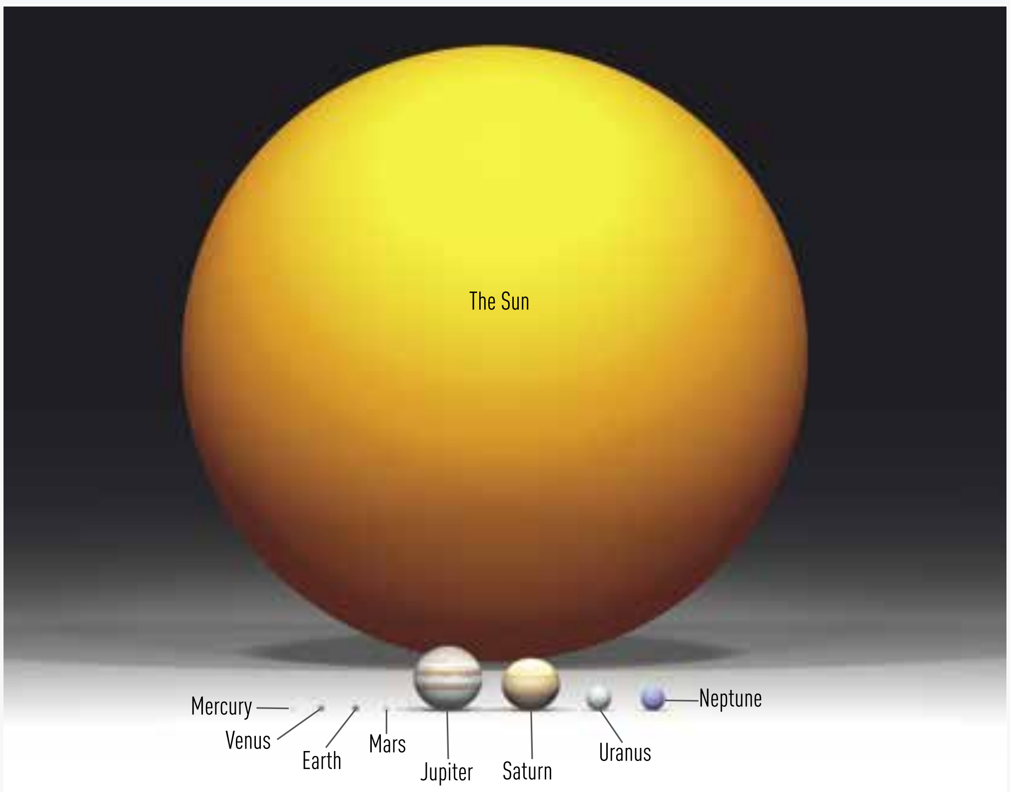


Figure 6.13 Earth is only a tiny part of the universe. Our concept of scale must be greatly expanded when thinking about the universe.

THE SCALE OF THE UNIVERSE

The universe we can observe consists of all the stars, galaxies and other objects that we can see from the Earth. It is enormous! We can only see these objects because visible light or other types of electromagnetic radiation from these objects has had time to reach the Earth and we are able to detect this signal.

The time it takes for this light or signal to reach the Earth depends on how close the object is to the Earth. The further away an object is, the more time its light or signals have taken to reach the Earth, and therefore we are looking back in time to when the light left the object we are observing. Looking through a **telescope** is like looking back in time to the past!

Since the invention of the telescope in the 16th century, we have been able to see many objects in the night sky for the first time. These include double stars (binary stars), galaxies and nebulae. Since these objects were observed, astronomers have been trying to find out how far away they are.

Figure 6.14 From a distance, two stars that are close together may appear as one. A pair of stars is called a binary star system.

SCIENCE SKILLS

Scales of distance or time?

The closest star to the Earth, apart from the Sun, is Proxima Centauri. It is 4.2 **light years** away. But how far away is this? It can be confusing because a 'light year' is not a measure of time. It is the distance that light travels in 1 year. Because light travels very, very fast (at 300 000 km/s), 1 light year is an enormous distance!

Example

In 1 year, light travels at:

300 000 km × 60 seconds × 60 minutes × 24 hours × 365 days

This means that light travels 9 460 800 000 000 km in 1 year.

In science, we write this number as 9.46×10^{12} km.

Proxima Centauri is 4.2 light years away from the Earth.

$4.2 \times 9.46 \times 10^{12} = 3.97 \times 10^{13}$

So Proxima Centauri is about 4×10^{13} km from the Earth.

This is our Sun's closest neighbour!

Our Sun is approximately 8 light minutes away from the Earth. This means its light takes 8 minutes to reach us travelling at the speed of light.

Questions

1. Why are the units light years used to measure distances between stars?
2. Compare the distances between stars with the distances between planets in our own solar system.
3. You may have seen road signs such as 'coffee 3 minutes ahead'. Is this a measure of time or distance? Discuss your answer with others.
4. Search the Internet for examples of the main structures in the universe and obtain images or descriptions. Record their size and distance from us. Convert these sizes and distances into the same units and then rank their size and distance from smallest to largest.

EXPERIMENT 6.1.1: CALCULATING THE DISTANCE TO THE SUN

Aim
To determine a value for the distance from the Earth to the Sun, using a pinhole screen, and to compare this with the known value.

Materials
- 1 m ruler
- Retort stand
- Clamp
- Coat hanger or retort ring
- Sticky tape
- Needle or pin
- 2 sheets of A4 paper
- Calculator
- Sun visible in the sky

Theory
This experiment uses ratios to determine the distance from the Earth to the Sun. If we know the distance from the pinhole to the image of the Sun, the diameter of the Sun's image and the actual diameter of the Sun, we can calculate the distance.

We will use the following symbols:

L_i = distance from pinhole to Sun's image

L_S = distance from the pinhole to the Sun

d_i = diameter of Sun's image

d_S = diameter of the Sun

You can write an equation using these four quantities. One example would be the ratio of d_i to L_i is equal to the ratio of d_S to L_S. Try writing this equation or ask your teacher for help. It can be written in either fraction or ratio form.

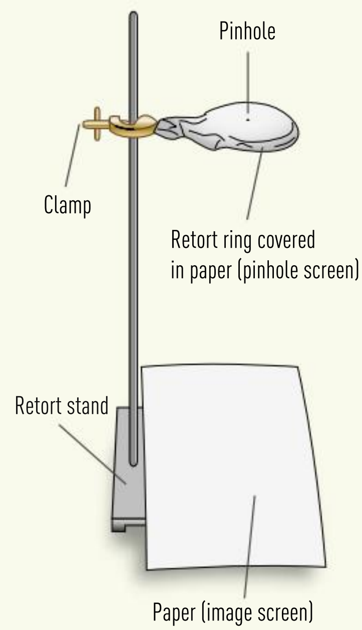


Figure 6.15 Experimental setup.

Method
1 Attach a piece of flat A4 paper to the coat hanger or retort ring using sticky tape to make a screen. Make a tiny pinhole with the needle in the centre of this screen. This will be called the pinhole screen.

3 Attach the other piece of A4 paper to the retort stand so it is lying over the base. This will be the image screen.

4 Clamp the coat hanger or retort ring with the pinhole to the clamp horizontally so both screens are parallel, and place the screen as far up the retort stand as possible, as shown in the experimental setup in Figure 6.15.

5 Go outside and point the pinhole screen at the Sun so a small circle of sunlight falls on the image screen.

Results

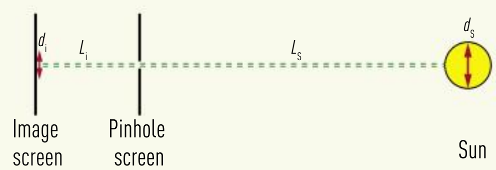


Figure 6.16 Experimental measurements.

- Measure and record the diameter (in millimetres) of the small circle of sunlight falling on the image screen. This is d_i in the equation.

  d_i = ______________

- Measure and record the distance between the two screens in millimetres. This is L_i in the equation.

  L_i = ______________

- The accepted value of the diameter of the Sun, d_S, is 1 392 000 km.
- Use the equation to perform a calculation based on the measurements to determine a value for L_S. Hint: Remember to use the same units in each part of your calculation.
- Determine how accurate your result is. The correct value for the distance to the Sun is approximately 149 600 000 km. Determine the difference between your calculated distance (L_S) and this correct value. Divide the difference by the correct value and multiply by 100. This converts it to a percentage and is called the percentage error. Round it off to the nearest whole number.

Discussion

1 How close was your calculated result to the known distance to the Sun?

2 What factors contributed to the percentage error? (Hint: Which measurements were not exact?)

3 Is this level of error acceptable? How could you improve the accuracy of your results?

Conclusion

Write a conclusion for this experiment that relates the findings to the aim.

Stellar parallax

There are many motions that stars appear to make across our skies. Every night, the stars and planets appear to move across the night sky. During the day, we can observe the 'movement' of our Sun through the sky as it rises and sets. Over a year, you may notice that the Sun rises and sets in different places. You may also see different constellations at night. These apparent motions are due to the movement of the Earth, as it either rotates on its axis or orbits around the Sun.

Many people of ancient civilisations were fascinated by the movement of the stars across the night sky, and used this movement to predict planting and harvesting times, and to navigate across oceans.

Astronomers can use the apparent motion of stars to measure their distance from the Earth.

The first person to measure the distance to a star, other than the Sun, was German astronomer Friedrich Bessel in 1837. When a star is observed from two different positions (such as in January and then 6 months later in July), its position relative to other stars may appear to be different (Figure 6.17).

This effect, known as **stellar parallax**, is used by astronomers to calculate the distance to nearby stars (stars closer than 100 light years). Beyond this distance, spacecraft are needed to calculate the distance accurately.

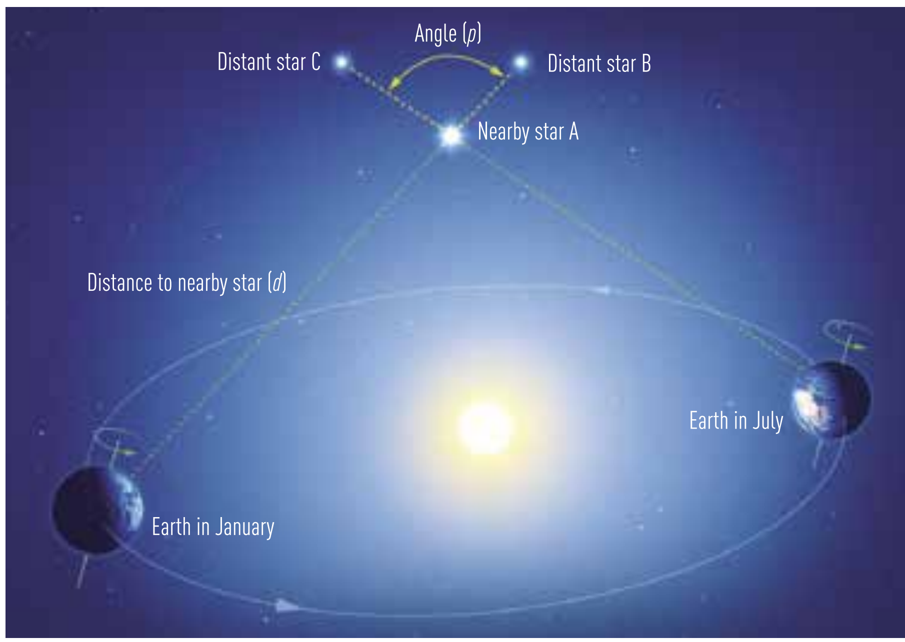


Figure 6.17 Measuring the distance to stars using stellar parallax. In January, star A, a close star, is in line with a more distant star, star B, but in July it is in line with star C. By measuring the parallax angle and knowing the radius of the Earth's orbit, the distance to star A can be calculated.

Aside from these apparent motions, all stars move within the galaxy relative to each other. This is called proper motion. Since they are so far away, their proper motion goes undetected unless you use a telescope and record their position with reference to other stars over long periods of time.

NUMERACY BUILDER

Calculating the distance of a star using stellar parallax

Even the nearest stars are many light years away. Therefore, astronomers use a larger unit of distance called the parsec. One parsec is equal to 3.26 light years. The parsec comes from the use of stellar parallax to measure the distance to nearby stars.

Angles are divided into minutes and seconds, just like hours. Therefore, one arc second is an angle of $\frac{1}{3600}$ of a degree. When the parallax angle (p), shown in Figure 6.17, is measured for a star and it is 1 arc second, the distance to the star is 1 parsec.

The equation for calculating distance d (in parsecs) to a nearby star using parallax is $d = \frac{1}{p}$ where the parallax angle (p) is in arc seconds (see Figure 6.17).

Example

An astronomer measures a parallax angle of 0.8 arc seconds for a star. Use the equation to calculate the distance to that star in parsecs.

Convert this answer to light years.

Hint: 1 parsec = 3.26 light years.

1.25 × 3.26 = 4.08 light years

Your turn

Calculate the parallax angle in arc seconds measured for a star at a distance of 4 parsecs.

ACTIVITY 6.1.6: UNDERSTANDING PARALLAX

What you need: whiteboard, whiteboard marker

1. Position a student in front of the class approximately 2–4 metres in front of the whiteboard (if possible).
2. Write a series of numbers, about 5 cm apart, across the whiteboard just above the height of the student's head.
3. Ask each member of the class to decide which number is in line with the student's head.

- Why do most members of the class see a different alignment of the student and the numbers on the whiteboard?
- Relate this activity to the night sky. What do the numbers represent? What does the student represent? What do the members of the class represent?
- How would the results of this activity be different if the student stood only approximately 30 cm in front of the whiteboard?

QUESTIONS 6.1.3: THE SCALE OF THE UNIVERSE

Remember

1. Define the term 'stellar parallax' and describe what causes it.

Apply

2. If a star 20 light years away exploded right now, when would we see it explode?
3. Calculate the distance from the Earth, in kilometres, of:
   a. the Large Magellanic Cloud at 180 000 light years
   b. Beta Centauri at 525 light years
   c. the Andromeda galaxy at 2.5 million light years.

Analyse

4. Propose why astronomers use many different units to measure distance.
5. Why can the distance to stars beyond 100 light years only be measured using spacecraft?

DESCRIBING THE UNIVERSE

6.1
CHECKPOINT

Remember and understand

1 Match each of the following terms with their correct definition. [4 marks]

the Sun	everything that exists
galaxy	a cloud of gas and dust associated with star birth
nebula	huge collection of stars, gas and dust held together by gravity
universe	a ball of plasma held together by gravity with nuclear fusion is occurring at its centre

2 Recall the approximate distance between the Sun and the Earth. [1 mark]

3 Define the term 'light year' and identify it as a unit of distance or time. [2 marks]

4 Explain why light years are used to describe measurements within the universe. [2 marks]

5 Explain how looking at the night sky is like 'looking back in time'. [2 marks]

6 List the information an astronomer can tell about a star simply by knowing its colour. Hint: Refer to Figure 6.7 on page 242. [2 marks]

Apply

7 Draw a labelled diagram to explain how astronomers use stellar parallax to measure the distance between the Earth and nearby stars. [4 marks]

8 Compare the features of stars and planets using a table or a graphic organiser. [3 marks]

9 List the following in descending order of size: neutron star, our Sun, white dwarf, red giant. [4 marks]

10 Compare and contrast a white dwarf with a red giant. [3 marks]

11 Decide whether the following statements are true or false. Rewrite the false statements to make them true:

- **a** All stars are yellow and very hot. [1 mark]
- **b** All stars are the same shape and size. [1 mark]
- **c** The brightness of a star when viewed from the Earth is its absolute magnitude. [1 mark]
- **d** Bigger stars are usually hotter, brighter and burn for longer than smaller stars. [1 mark]
- **e** The colour of a star is determined by its surface temperature. [1 mark]

12 If the speed of light is 300 000 km/s, calculate the distance light travels in:

- **a** 1 second [1 mark]
- **b** 1 minute [1 mark]
- **c** 1 hour [1 marks]
- **d** 1 day. [1 marks]

Analyse and evaluate

13 Explain why it is difficult to judge the distance of a star by measuring only its brightness. [2 marks]

14 A star is discovered 20 light years from the Sun and a planet is found 30 light years from the Sun. Determine whether these two objects are part of the same solar system. Explain your answer. [3 marks]

15 If our Sun is 4.6 billion years old, estimate how far it is through its life. [3 marks]

16 If the Orion nebula is 1500 light years away and 26 light years in diameter, calculate how many Orion nebulae would fit between the Earth and the Orion nebula. [2 marks]

17 Look at Figure 6.18 and identify the star that has 'moved'. Account for the 'movement' of the star. [2 marks]

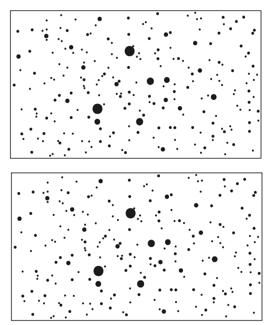


Figure 6.18 Identify the star that has 'moved'.

Critical and creative thinking

18 Draw a Venn diagram to illustrate the features of the universe and to show which features appear within other features. [4 marks]

19 Using your diagram (or electronic document) of the different types of stars from Activity 6.1.2, link up the different stars in order according to the flow chart in Figure 6.9 on page 243. Link up the pictures with arrows as in the flowchart. [3 marks]

TOTAL MARKS
[/55]

6.2 INVESTIGATING THE UNIVERSE

Astronomy is the oldest science. People have been studying the heavens in detail for thousands of years. This study began with the naked eye. Instruments like the telescope have transformed our understanding beyond our wildest dreams. Much of the exploration of the solar system has been done by our marvellous machines, spacecraft and rovers. Although we have set foot on the moon, the difficulties and expense make it hard for us to venture much further right now. What is next in our quest to discover the universe around us?

THE AGE OF DISCOVERY

When the Ancient Greeks looked at the stars in the sky, they saw them in groups that made images. These images were of ancient gods, heroes, animals or even everyday items, mostly from Ancient Greek mythology. These groups of stars form what we call **constellations**.

Some of the constellations are easy to recognise and you may already know them. One of the easiest constellations to find at night in the southern hemisphere is the Southern Cross, or Crux. The Southern Cross is so famous and significant that it appears on many national flags of countries in the southern hemisphere, including Australia's.

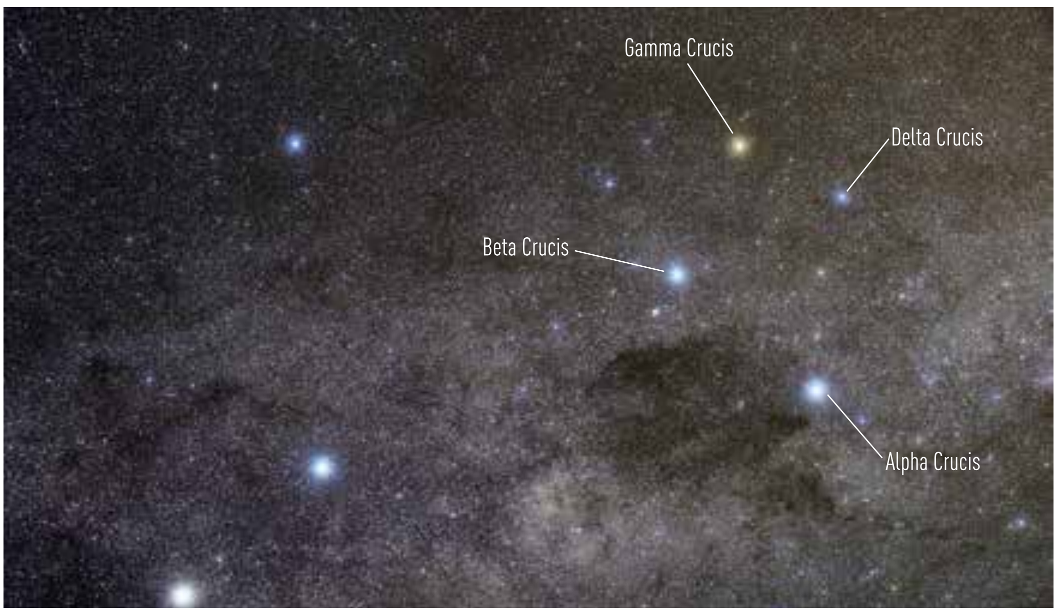


Figure 6.19 The constellation Crux or Southern Cross in the night sky.

Figure 6.20 The Southern Cross appears on a number of national flags, including the flags of (a) Australia and (b) Brazil.

Two stars, Alpha and Beta Centauri, are known as the Pointers to the Southern Cross, pointing or lining up in the direction of the Southern Cross. Alpha Centauri is only 4.4 light years away from the Earth, making it one of the closest stars to the Sun. Beta Centauri is much further away, at 525 light years. The Southern Cross and the Pointers can be used to find south. When the sky is dark, well away from city lights, you might be also able to see the Coalsack – a dark nebula just under the Southern Cross on the side nearest to the Pointers.

The well-known constellation Orion the hunter is shown in Figure 6.21. Part of this constellation is also sometimes called the Saucepan. The three stars close together in a line that form the base of the saucepan also form Orion's belt. The stars that form the handle of the saucepan also form Orion's scabbard (a sheath for his sword). Orion also contains the well-known stars Rigel and Betelgeuse.

Rigel is the brightest star in Orion. It is a blue supergiant star and has a bluish-white appearance, which indicates it is very hot. Betelgeuse is a cooler star and appears reddish-orange in colour. It is one of the largest red supergiant stars and, if placed in our solar system in the position of the Sun, it would reach out past Mercury, Venus, Earth and Mars!

Until the 16th century, people thought the Earth was the centre of the universe, and all the stars and planets rotated around the Earth. Each night, the stars and constellations appear to move across the sky as the Earth spins around on its axis. The constellations also appear to move across the sky with the seasons. As the Earth orbits around the Sun over a year, we view the night sky from different perspectives, and the position of the constellations in our sky changes due to stellar parallax. While many ancient civilisations could not explain the phenomenon, they used these changing positions of the stars and constellations to determine the seasons.

In ancient times, they also noticed some bright stars that wandered among the other stars that were fixed in position. They called these 'planets', which means 'wandering stars'. These too were thought to orbit the Earth. The human eye was not good enough to discover any of the details about these objects. It was a long time before our technology advanced enough to allow our understanding to develop.

Figure 6.21 Orion, the hunter.

Figure 6.22 Rigel and Betelgeuse are the two brightest stars in the Orion constellation.

ACTIVITY 6.2.1: ASTROLOGY

Discuss the topic of astrology as a class or in small groups. Consider these questions:

- Define 'astrology' and 'astronomy'. How are they different?
- How are the zodiac signs linked to astronomy?
- Is astrology a science or a pseudo-science? Why?

In the past, astrology and astronomy were indistinguishable. People observed the paths and patterns of celestial bodies with the aim of making clear parallels to human affairs, personality and other earthly matters. Detailed observations made by early astrologists paved the way for the emergence of astronomy as a scientific discipline.

To distinguish between ideas that are considered facts and those that are opinions or beliefs, we need to find evidence.

Research the topic of astrology in your group. Try to understand the ideas behind astrology and how you can distinguish it from astronomy.

Present your research as a PowerPoint presentation, animation or other visual media.

Figure 6.23 Scorpio is one of the signs of the zodiac.

SCIENCE SKILLS

Using a star chart

Planispheres or star charts are maps for locating various stars in the night sky. A two-page star chart can be easily downloaded each month from skymaps.com. The first page is the star chart and a calendar, and the second page contains various notes and explanations about the objects you can see.

Download and print a copy of this month's star chart. (Make sure you click on the southern hemisphere version.)

Read the instructions on how to use the star chart, which are printed around the outside of the circular chart, along with other useful information about the chart.

Find the south celestial pole (SCP), which is marked a few centimetres above south on the chart. This is just a place in the sky; there is no star nearby. Over the course of a night, the stars appear to rotate about this point. Interestingly, in the northern hemisphere, the North Star is located at the north celestial pole (NCP) and so it is used in navigation to find north.

Look at the bottom right-hand corner of the chart, which gives a key to the symbols on the chart. The star magnitudes give the brightness of the stars as viewed from the Earth.

1 Which star is the brightest?

2 Which is brighter, Alpha or Beta Centauri?

3 Use your star chart to observe the night sky. How many stars and constellations can you identify? Can you create any constellations of your own? Report back to your class.

4 Can you find any of the bright planets?

5 Take note of the position of the brightest stars when you begin observing. Use a landmark such as a building or a tree to help you. When you are finished observing, look at the location of these stars again. Can you tell whether they have moved? If they have not, wait at least an hour or two and have a look again. Explain this movement.

QUESTIONS 6.2.1: THE AGE OF DISCOVERY

Remember

1 Describe the main difference between astronomy and astrology.

2 Is Orion a constellation or a galaxy? Identify the features that can help to locate Orion in the night sky.

Apply

3 Use the data on a star chart to see whether all the brightest stars in the sky are at the same distance from the Earth. If not, why are they the same brightness?

Evaluate

4 Compare and contrast a galaxy and a constellation.

TECHNOLOGY USED TO INVESTIGATE THE UNIVERSE

Even though people have watched and recorded their observations of the stars for centuries, it was not until the development of specific technology that scientists were able to describe and explain the features and activities of the universe. As technology improves, so too does our understanding of the universe.

Telescopes

Our understanding of the universe took a great step forward after Galileo Galilei turned his telescope to the night sky. Until then, observations had been limited by what the human eye could see. Now human eyes could gather more light to see fainter things and resolve finer details with the aid of a telescope.

In 1610, Galileo discovered that Jupiter had four bright moons orbiting it and that Venus went through phases like the moon. At that time, these observations were the best evidence that the Earth was not at the centre of the solar system as was previously thought. It took some time for this idea to gain widespread acceptance due to opposition by the Roman Catholic Church.

Galileo is often regarded as one of the fathers of science. His pioneering use of the scientific method paved the way for modern science. He began a quest to build larger telescopes, and this quest still continues today. Astronomers and engineers have built increasingly sophisticated instruments, such as the twin Keck telescopes in Hawaii (see Figure 6.24), to peer further away into the universe at fainter objects and further back in time. Yet the quest for a bigger and better telescope is far from over.

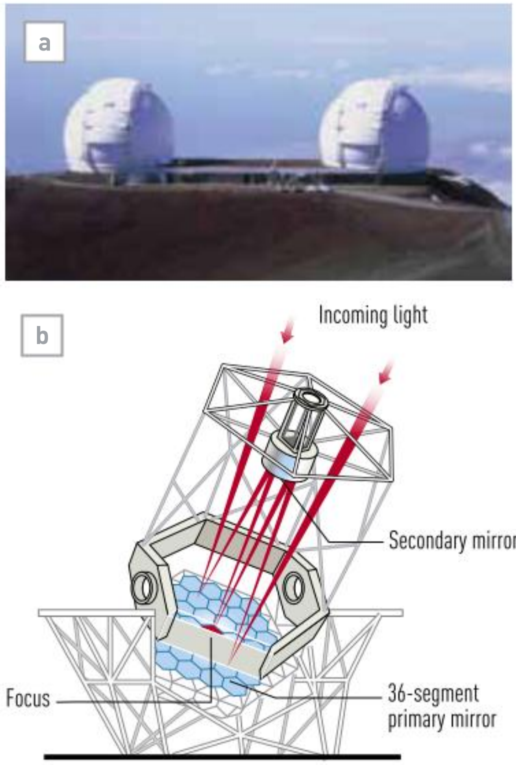


Figure 6.24 (a) The twin telescopes of the Keck Observatory. (b) Each telescope uses 36 hexagonal mirrors, each with a diameter of 1.8 m, which are controlled by computers to focus on astronomical objects. The telescopes can work together or independently.

Figure 6.25 Galileo shows others the wonders he has discovered in the night sky through his telescope in Venice.

ACTIVITY 6.2.2: BUILD A TELESCOPE

What you need: 2 biconvex lenses (for best results, one lens should have a focal length of at least twice the other)

1 Hold the two lenses in front of you as if each lens was at each end of a small telescope like those Galileo used (see Figure 6.25). The lens with the smaller focal length (the eyepiece) should be the one closer to your eye. You may need to devise stands for your lenses to hold them still.
2 Point your two lenses towards a distant object so the light will travel through both lenses to get to your eye.
3 Vary the distance between the lenses as you look through the eyepiece. At a certain distance between the lenses, the distant object will become clear (focused) and appear magnified.

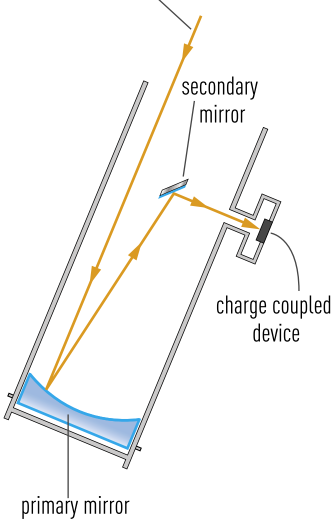


Figure 6.26 How a small telescope and a CCD are combined to take astronomical images.

Charge-coupled devices

Not long after telescopes had been developed, the race was on to find better ways to measure and record what was observed. The first replacement for the naked eye was the use of photography. Crude electronic detectors followed and eventually the **charge-coupled device (CCD)** was invented. The CCD is the chip in a digital camera or mobile phone for taking images. One of their early applications was for astronomy, and the technology was then developed for our everyday use. The importance of CCDs was highlighted when the Nobel Prize in Physics was awarded for their development in 2009.

Astronomers use CCDs to detect electromagnetic radiation and convert it into digital information for processing. Huge mirrors, such as those in the Keck telescope, collect millions more times the light than the naked eye, and then focus it onto these CCD chips (see Figure 6.26). Each chip collects millions of pixels of information over a period of time. The electronic information is then sent to a computer and the image is seen as millions of dots (pixels) with different brightness.

Figure 6.27 *Curiosity* uses advanced technology to gather as much information as possible about the surface of Mars.

Robot explorers

Our exploration of the universe continues to develop beyond observation with telescopes. Over the last 100 years, we have developed rockets, computers and communication technology that have allowed us to take our first steps in physically exploring the universe. Humans have walked on the moon and sent spacecraft to every planet in the solar system. The cost of human exploration of the solar system is enormous, so much of our investigation is being done by remote control.

Many robotic explorers have taken us to the surface of the other rocky planets in our solar system. The Mars Science Laboratory mission with its rover *Curiosity* is the latest in a fleet of rovers to explore Mars. This rover includes advanced technology such as laser spectrometers, microscopic imagers, a robotic arm to collect samples, and artificial intelligence for autonomous navigation. This mission will investigate whether Mars ever had an environment that could support life such as bacteria. This will take us a step closer to answering the question of whether are we alone in the solar system.

LITERACY BUILDER

Australian astronomers (additional content)

Professor Penny Sackett and Professor Brian Schmidt are prominent astronomers based in Australia. Below is a list of facts about these two scientists. Carry out some research to match each fact to the correct person. Answer any questions and add any other interesting or up-to-date facts about each person. Find some images to go with your information.

- Conducted major research into extrasolar planets. (What are these?)
- Headed the SkyMapper project. (What is this?)
- Was a member of the High-Z SN search team. (What did this team do?)
- Served on the Board of Directors of the Giant Magellan project. (What is this?)
- Born in 1967 in the USA.
- Has worked as a Science reporter for *Science News*.
- Born in 1956 in the USA.
- Made a major scientific breakthrough in 1998. (What was it?)
- Worked as Director of the ANU Research School of Astronomy and Astrophysics. (When?)
- Worked mainly with exploding stars called supernovae.
- Appointed as the Chief Scientist of Australia. (When?)
- Was jointly awarded the US$1 million Shaw Prize for astronomy. (When and why?)
- Was jointly awarded the Nobel Prize in Physics in 2011 for the discovery of the acceleration of the expansion of the universe.

Figure 6.28 Professor Brian Schmidt and Professor Penny Sackett.

QUESTIONS 6.2.2: TECHNOLOGY USED TO INVESTIGATE THE UNIVERSE

Remember

1 Describe the basic structure of a simple telescope.

2 Outline the function of a telescope in astronomy.

3 Name some of the major discoveries made using a telescope.

4 Describe technology other than the telescope we have used to explore the solar system.

Apply

5 Propose why the 36 segments of the primary mirror in the Keck telescopes are controlled by computer rather than by hand.

Analyse

6 Explain, using examples, how advances in technology have led to advances in scientific knowledge and understanding of the universe.

FUTURE EXPLORATION

As technology improves, advances are made in our knowledge and understating of the universe. Space probes that were launched years ago are still sending information back to the Earth. New probes and rovers are planned for construction and launch with new destinations and new missions in the coming years.

New technological developments expand the possibilities of exploration, discovery and even travel through space and the universe.

ACTIVITY 6.2.3: LIVING IN SPACE?

Investigating the universe involves a range of methods. Many observations are made from the Earth, but these are limited owing to investigators' distance from the objects they are observing. Some observations are made from unmanned spacecraft, such as probes that are designed to either land on planets or collect information as they travel.

The most significant manned observation platform so far is the International Space Station (ISS). The ISS is home to a team of carefully selected and trained experts who process, analyse and evaluate the data collected by the instruments on board as it is collected.

But living in space comes with its own issues. Consider the recycling of air and water on the ISS, as shown in Figure 6.29.

- Convert the information in Figure 6.29 into a table that identifies the requirements of the ISS crew and how these needs are met.
- Evaluate the efficiency and amount of waste produced, and comment on the self-sustaining nature of the ISS.

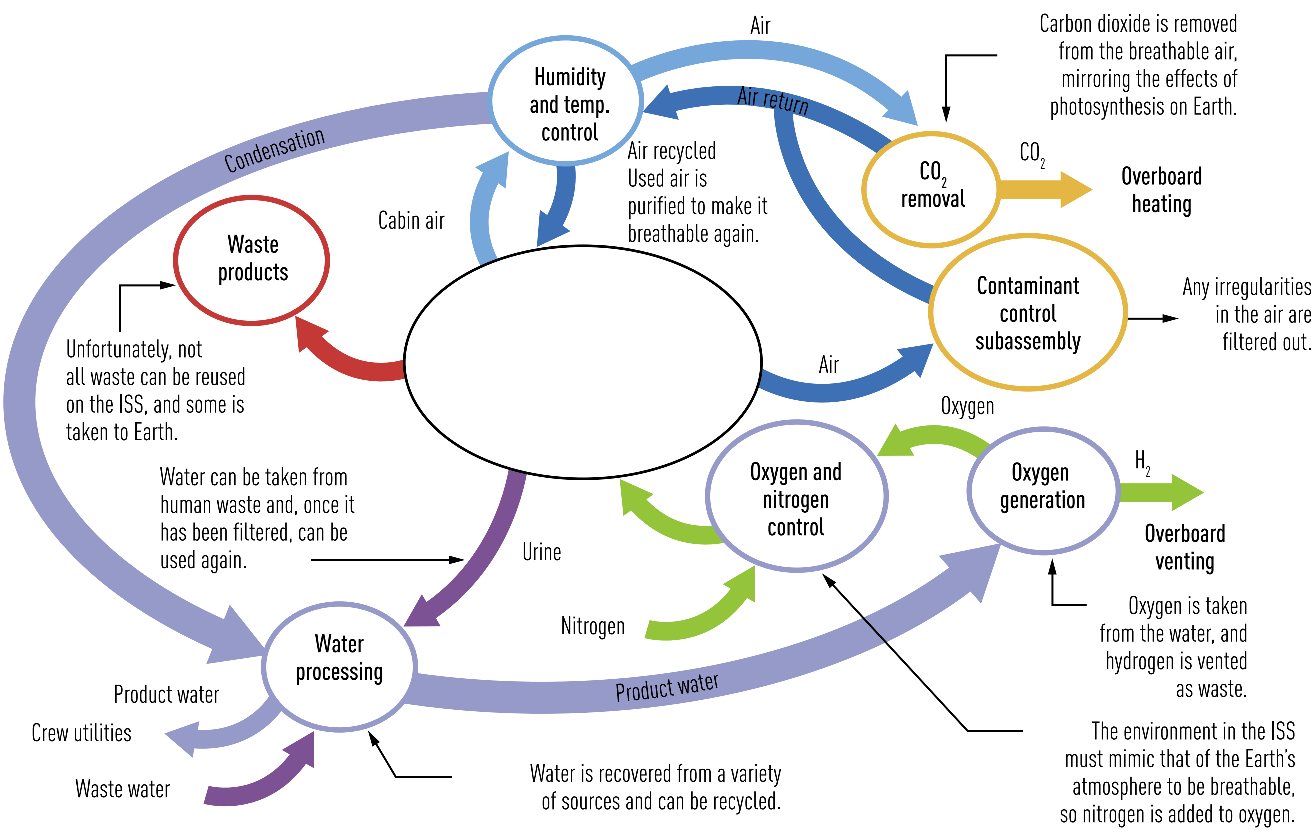


Figure 6.29 How air and water are recycled on the International Space Station.

Future space travel

The Earth will one day be inhospitable to human existence. Short-term concerns range from human activity, with impacts on the global climate, to depletion of our resources and our ability to sustain the growing human population. Long-term factors include the ever-present risk of an asteroid impact on our planet. Earth is no stranger to collisions with extraterrestrial objects, and such impacts have wreaked global havoc and caused mass extinctions throughout the Earth's history. But the death of our Sun will mean the death of our planet, no matter what we do. Humans face many obstacles and, if we are going to overcome them, we must explore our universe for solutions.

The dangers of space travel

We may take the Earth's atmosphere for granted, but it offers protection from radiation, moderates the temperature, provides breathable oxygen, allows water to boil at 100°C and even protects us from small meteors. Humans who travel into space face a number of challenges as they leave the safety of the Earth's atmosphere.

In space, astronauts are bombarded by the solar wind. This is a stream of radiation and particles that come from the Sun. Also, space is a vacuum, which means there is no air so astronauts have to bring this with them. Astronauts also face dangers from within. Since astronauts are in free fall when in orbit, they do not feel the force of gravity. This causes astronauts' bones to lose calcium and after prolonged periods they would not be able to support their weight when they return to the Earth.

It is clear from just these few examples that we face enormous difficulties to leave the Earth. This will not stop us trying though as plans are already underway to take our first steps on another planet.

Why colonise the moon?

Demand for the Earth's resources to sustain human progress is placing a burden on the planet. Many people believe it makes sense to use the many resources on our nearest neighbours: the moon and Mars.

The moon would be an ideal place to set up a permanent base. We could mine its many minerals and use it as a research and training ground for launching missions to Mars, perfecting the many techniques for living on other planets before we venture any further.

Figure 6.30 The Earth's atmosphere provides protection.

Figure 6.31 Astronauts exercise during space missions to reduce bone loss and muscle wastage.

With no atmosphere, the surface of the moon is exposed to a vacuum. In direct sunlight, temperatures climb to 120°C, whereas in the shade they remain below –173°C. Any gas that may have existed is now long gone because the moon's gravity, being one-sixth that of the Earth's, is not strong enough to trap it.

Although the moon has places of perpetual darkness, some parts of its south pole have almost endless daylight. This makes generating electricity from solar energy a viable alternative.

Before we can colonise the moon we need precious water. The cost of transporting water to the moon is unaffordable, at between US$2000 and US$20 000 per litre. NASA has conducted missions to investigate the presence of water on or near the surface of the moon. Although the tests conducted are not conclusive, initial data indicates that ice may be present in permanently dark craters at the poles of the moon. Scientists suspect that water may have been brought onto the moon by meteorites, which have bombarded its surface over the past 3–4 billion years.

Figure 6.32 The moon has a mineral-rich surface and its southern pole has almost continuous daylight.

Figure 6.33 An astronaut's footprint on the moon is similar to one that would be made in mud on the Earth – does this mean there is water on the moon?

STUDENT DESIGN TASK

Moon base

Challenge

A renewed interest in the moon has been sparked by a recent announcement by the US President to send people to Mars and to establish an extended presence on the moon. Your challenge is to create a moon base with an Earth-like environment.

Questioning and predicting

Because the moon has no atmosphere, you will need to create a sealed and pressurised living environment with the right mixture of gases. The living and working chambers will not be buildings like on the Earth, but will be pressure chambers. The loads on the walls of such structures will be immense because the internal pressure applies a stress on the external walls. The leakage of essential gas will be a constant problem.

You must also offer the inhabitants protection against the dangers of UV radiation and the constant threat of meteorite impact. Creating a shield for the moon base will add weight to the supporting structures and offset the benefit of a low gravitational field. It is estimated that rock of 2 metres in depth will offer enough protection from radiation.

A self-sufficient moon colony is essential for further space exploration. According to investigations of lunar samples, the moon contains deposits of the elements iron (Fe), manganese (Mn), magnesium (Mg) and titanium (Ti) in the form of ilmenite ($FeTiO_3$). Ilmenite could be used as the source of life-sustaining oxygen.

Obtaining energy for the self-sufficient base should not be a problem because there is an area at the south pole that is almost permanently bathed in sunshine. Solar energy could be captured by carefully placing solar panels at the pole.

Oxygen and water are necessary to sustain a closed ecological life-support system. Oxygen can be obtained by the chemical processes involved in purifying metals from the lunar soil.

Each person will need a daily amount of 0.6 kg of food, 0.85 kg of oxygen and 29 litres of water. Assuming that we can find water on the moon, we then require approximately 20 m^2 of cultivated land for each person in order to produce the required daily amount of food.

Planning and conducting

Design a moon base, either on paper or as a 3D model. In your design, show how you have accounted for:

- transportation, purification and storage of air, water, wastes, supplies and energy
- food production
- water synthesis
- power generation
- water and air purification
- pressurised atmosphere
- radiation and meteorite protection
- water and sewage recycling
- food production
- recreation
- recycling of waste.

Figure 6.34 You could work as a team to ensure that all the needs of the moon base are met.

Processing, analysing and evaluating

1 What do you think is the main difference between building a structure on the Earth and building it on the moon?
2 Engineers believe that any long-term habitat on the moon will need to be buried by piling a blanket of rock on top of the structures or in mineshafts. Why is this necessary?
3 Every science-fiction story has moon bases essentially on the surface formed from glass domes. Why is such a structure so impractical?

Communicating

Present your moon base plan and/or model to the class.

Figure 6.35 The moon's surface is covered in craters.

QUESTIONS 6.2.3: FUTURE EXPLORATION

Remember

1 List some of the technology needed to meet the everyday needs of humans during space exploration.
2 Name some technology needed to protect humans during space exploration.
3 Identify what is thought to exist in the dark craters on the moon and explain why scientists believe this is the case.

Apply

4 Identify some good reasons to explore the solar system.
5 Propose three reasons for colonising the moon.
6 Describe some possible careers that would be involved in future space exploration and what their involvement might be.

INVESTIGATING THE UNIVERSE

6.2
CHECKPOINT

Remember and understand

1 Describe how humans gathered information about the universe before the invention of the telescope. [2 marks]

2 Outline how technology has enabled humans to understand more about the solar system. [3 marks]

3 Describe how advances in technology associated with space science and astronomy have affected our everyday lives. [2 marks]

Apply

4 In your own words, explain why the International Space Station is an important tool for scientists and astronomers. [2 marks]

5 The *Mariner* space probes launched towards Mercury and Venus carried large solar panels to supply energy. The *Voyager*, *Pioneer* and *Galileo* space probes sent to explore the outer planets did not have solar panels or use solar energy. Why? Explain your answer. [2 marks]

Analyse and evaluate

6 Assess the significance of the telescope to astronomers. [2 marks]

7 Many ancient cultures had legends about the origin of constellations. Investigate Indigenous Australian, Polynesian or Ancient Greek legends about constellations. Evaluate the influence of these legends on how we view and understand the constellations today. [3 marks]

8 On 27 September 2007, the space probe *Dawn* was launched from Cape Canaveral at a cost of US$357 million, excluding the cost of the rocket. *Dawn*'s 4.8 billion kilometre journey includes exploration of the asteroid Vesta in 2011 and the dwarf planet Ceres, between Mars and Jupiter, in 2015. Evaluate whether knowledge gained from space exploration enhances our civilisation and whether space exploration is vital to our survival. [4 marks]

9 With current rockets it is unlikely that humans will travel to other stars in the near future. Suggest reasons why humans cannot leave the solar system. [3 marks]

Critical and creative thinking

10 Investigate some telescopes that view the universe from above the Earth's atmosphere. Identify them by their name, the date they were launched and their specific purpose. You may like to include some images. [5 marks]

11 Research some space probes that are currently exploring our solar system. Prepare a presentation on one of them, including as much interesting information as you can. Include a bibliography of your sources. [5 marks]

12 NASA is planning to send a manned mission to an asteroid in 2025. Propose reasons why it will take until about 2025 to be ready for manned missions beyond the moon. [3 marks]

13 Research some of the discoveries that followed from the development of the astronomical telescope. Construct a timeline to summarise this information and evaluate the importance of several of these discoveries. [5 marks]

Making connections

14 A system is made of inputs and outputs that all affect one another. Explain how this relates to what you have just learned about the universe. Why might an understanding of systems on the Earth be beneficial to those investigating areas beyond our planet? [4 marks]

Figure 6.36 The *Dawn* space probe is on an 8-year interplanetary cruise.

TOTAL MARKS
[/45]

6.3 HISTORY OF THE UNIVERSE

The Big Bang theory predicts that the universe has evolved over approximately 14 billion years. According to the theory, the universe started as a tiny speck with enormous energy, then expanded and cooled. The force of gravity then pulled matter together into structures such as stars and galaxies. This theory is based on observational evidence and has developed through scientific method.

We are the first generations of humans to be able to understand the history of the universe. In the beginning, the chemical elements needed for life did not exist. The stars have produced all that was needed to eventually make you. The story of the universe, the Big Bang theory, is actually the story of how we came to be. As our understanding of the universe develops, so does our understanding of where we came from.

THE MOVEMENT OF GALAXIES

When looking at the night sky, you may have noticed a whitish hazy band that is the billions of stars in the Milky Way. The Milky Way was once thought to be the entire universe, but it is only one galaxy – the galaxy in which we live. Other galaxies appeared only as fuzzy objects and were called spiral nebulae (meaning ‘clouds’).

In the late 1700s, William and Caroline Herschel discovered that many of these ‘clouds’ were made up of billions of stars. In 1925, Edwin Hubble determined the distance to the largest of these spiral nebulae and found it was outside the Milky Way. The size of the known universe increased enormously with this single discovery. Other nebulae were identified as clouds of gas and dust within our galaxy, and they are still called nebulae today. They are considered to be some of the most beautiful objects in the night sky.

Figure 6.37 The Milky Way, our galaxy, is a spiral galaxy. It contains many emission nebulae (pink), dark nebulae (dark splotches easily visible near the centre) and stars of different ages (young and blue in the spiral arms, and old and orange in the centre).

After Hubble's discovery that the universe was much larger than the Milky Way, he set out to explore the universe he had uncovered. In the 1920s, using the most powerful telescope available, he examined the spectra of light emitted by the galaxies.

Each element emits its own unique **emission spectrum**. As the electrons of the atoms move between electron shells, they absorb or emit energy in the form of electromagnetic radiation, which can be detected as coloured light. The elements within stars give out light and, if that light passes through a gas on its way to the Earth, the gas absorbs some of the wavelengths of light. The specific wavelength a particular substance absorbs is the same as the wavelength it emits when heated. The result is an **absorption spectrum**. The vertical black lines in the continuous spectrum indicate where light of a particular wavelength has been absorbed by the substance.

Compare the emission spectrum and the absorption spectrum of helium in Figure 6.38. You will notice that the absorption spectrum contains lines in exactly the same positions as in the emission spectrum.

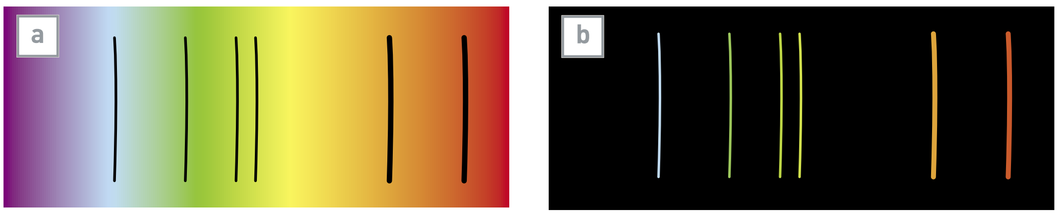


Figure 6.38 (a) Absorption spectrum and (b) emission spectrum of helium. The dark lines in the absorption spectrum of any element match exactly the bright lines in its emission spectrum.

EXPERIMENT 6.3.1: INVESTIGATING EMISSION SPECTRA

Aim

To investigate the light emitted by various elements by using spectroscopy.

Materials

- Spectroscope
- Discharge tubes for different elements – hydrogen, helium and neon
- Power supply for discharge tubes

Method

Connect the equipment and darken the room. Aim the spectroscope at the discharge tube and observe the emission spectrum. Repeat for each tube.

Results

Record the position and colour of the emission lines for each element. Present the results in a table.

Discussion

1 Each element has a distinct emission spectrum. How is this used to identify the elements present in the universe?

2 If the light from a distant star had lines missing from its spectrum, what would that mean?

Conclusion

Write a few sentences outlining the key ideas of this experiment, using your results as evidence. Relate your conclusion back to the aim.

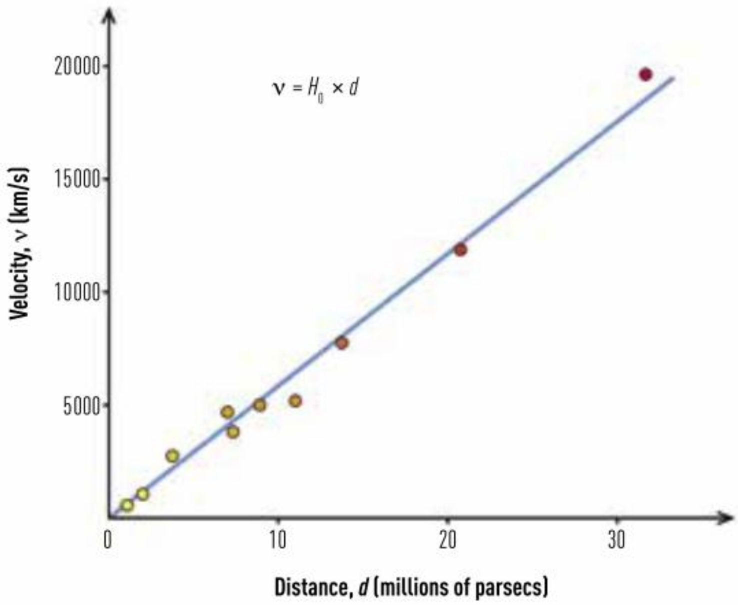


Figure 6.39 Hubble graphed his data and saw a strong positive correlation between the distance from the Earth and the speed at which the object was moving away. This data was the basis of Hubble's law.

Figure 6.40 The Hubble Space Telescope was named in honour of Edwin Hubble. Hubble's observations were made using the Hooker Telescope – an older, less powerful telescope than this one.

The importance of red shift

Just as emission spectra can, absorption spectra can be used to identify the elements present in objects such as stars and galaxies. Absorption spectra can also reveal another important aspect of a distant star or galaxy – its velocity, which Hubble discovered.

When Hubble looked at the absorption spectra of distant galaxies, he saw that the lines were shifted towards the red end of the spectrum. Red light has a lower frequency; blue light, at the other end of the visible spectrum, has a much higher frequency. A shift in the red direction, which is known as a **red shift**, indicates that the galaxy is moving away from the Earth. The velocity of the galaxy moving away from us is given by the size of the red shift. The greater the red shift, the greater the velocity of the galaxy.

Edwin Hubble's big discovery was that the more distant galaxies tended to have more red-shifted spectra and, hence, appeared to be travelling faster away from Earth. In his 1929 book *The Realm of the Nebulae*, Hubble indicated that this relationship can be considered an 'observational basis for theories of an expanding universe'. This discovery became known as Hubble's law (see Figure 6.39) and provides compelling evidence, along with the existence of **cosmic microwave background radiation (CMBR)**, for the expansion of the universe and the **Big Bang theory**. Hubble also determined an age of the universe based on his observations. Originally calculated at approximately 1.8 billion years old, astrophysicists now estimate that the universe is 13.8 ± 0.04 billion years old.

We have seen the main evidence that the universe is expanding. The space between the galaxies is getting bigger and the galaxies appear to be moving away from each other. Hubble's data showed that the more space there was between two galaxies, the faster they appeared to be moving away from each other. This can be explained if the universe is expanding.

The development of scientific theories

A scientific theory is very different from an everyday theory. Here is a simple everyday example to look at how scientists develop theories.

An observation

Suppose you and a group of friends are walking on a warm sunny day and you come across a puddle on the ground. There is nothing around that indicates how the puddle got there.

A question

You and your friends are puzzled. You ask, 'How did that get there?'

You have already carried out the first two steps of the scientific method (see Figure 6.41).

A hypothesis

To find an answer to your question, you need to propose a testable prediction (a hypothesis).

Experiment

You then need to develop an experiment that can test the prediction. You come up with a way to make a puddle and you try it out. You find it works, so your experimental evidence supports your hypothesis.

Is this a viable theory for how a puddle could be there in front of you?

Someone in your group comes up with another way to make a puddle, which was not incorporated into your original hypothesis. If you try this new method and it works, it does not support your original hypothesis and you must generate a new hypothesis to include this second method of puddle formation.

This process could continue for a while but eventually you run out of ideas on how to make puddles. Your final hypothesis includes all the ways you can think of to make puddles, and all your experimental evidence that supports it. You could now consider this a theory for how to make puddles under the conditions you have performed your investigations. Someone else could provide evidence to say that your theory is not correct and you would need to refine it again. This is the basic process of the scientific method.

Your turn

In a group, make or think of an observation that leads you to a question you would like to answer.

Follow the steps of the scientific method by generating a hypothesis and performing experiments to work towards your own theory.

Present your findings to the class and see if your theory stands up to questioning. You may have to revise your hypothesis many times. Include information in your hypothesis that defines what specific situation your theory applies to or the conditions to which it is applicable.

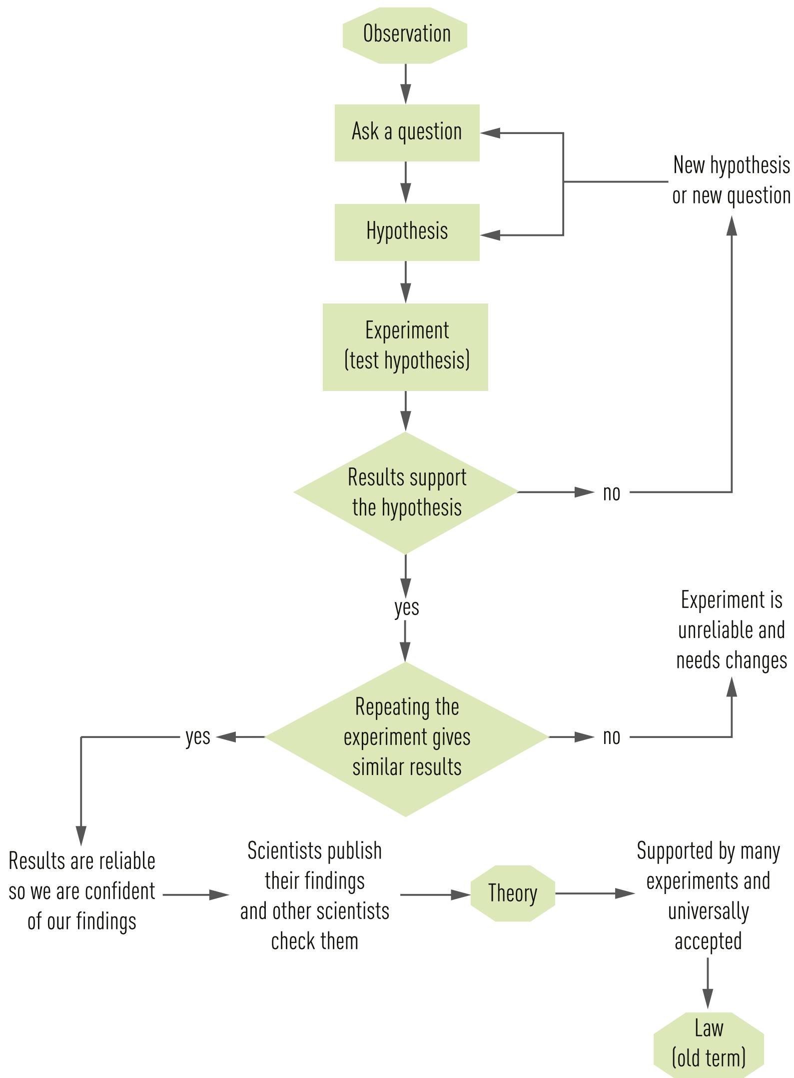


Figure 6.41 The process of developing a scientific theory.

ACTIVITY 6.3.1: MODELLING THE EXPANSION OF THE UNIVERSE

Scientists often use models to help them understand what is happening when they cannot see something occurring. You can make a model of the expanding universe.

What you need: balloon, permanent marker

1 In groups, use the permanent marker to make a number of small dots on one side of the balloon. Each of these dots represents a galaxy. Choose one dot to represent the Milky Way and make sure the others are at various distances from it.

2 Blow up the balloon slowly. Note what happens to these dots. You may like to record the changes with a camera.

3 Explore how this model demonstrates what occurs in the universe. Go through the steps again and observe what happens to other galaxies if one of the dots is chosen as the Milky Way. Think about how astronomers would observe the movement of other galaxies by measuring their red shifts.

- List the features of the model and your observations. Link these features to what we observe in the universe.
- Your balloon model behaves in a similar way to the real universe. But like any model, it has its limitations. What observation did you make that shows this model has a limitation? Can you identify any other limitations? Hint: Galaxies do not expand as the universe does, as gravity holds galaxies together.

4 See if you can come up with a model that has fewer limitations. If you can, explain it to others and see what they think. Hint: Think about a type of food that expands as it cooks. This type of food can contain small pieces inside it that could represent galaxies.

- How would this model be improved? Explain its features and what they represent.

ACTIVITY 6.3.2: INVESTIGATING HUBBLE'S LAW

The aim of this activity is to observe evidence for the expansion of the universe through galaxy red shifts.

This investigation can be done two ways: Part A is a qualitative (descriptive) way, and Part B is a more challenging quantitative (numerical) way. Choose one or both to complete this activity.

Part A: Qualitative

In 1929, Edwin Hubble found a relationship between the red shift (or velocity of recession) of galaxies and their distance from the Earth. This relationship can be seen in the graph in Figure 6.42. When expressing a relationship between two variables, the simplest way is to describe what happens to one as the other changes.

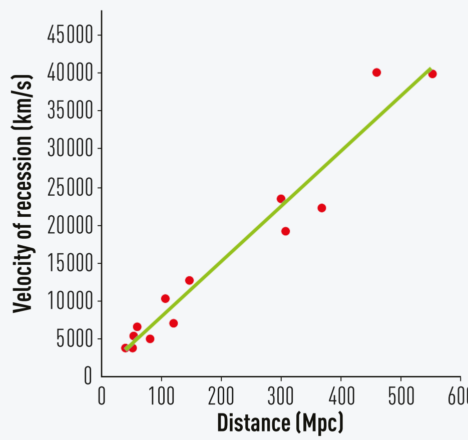


Figure 6.42 The relationship between distance from the Earth and receding velocity of moving astronomical objects.

1 Look at the graph in Figure 6.42 and describe what happens to the variable on the vertical axis as the variable on the horizontal axis changes.

Another way to describe the relationship between variables is by expressing them as proportionality. If one variable increases as the other increases, they are proportional.

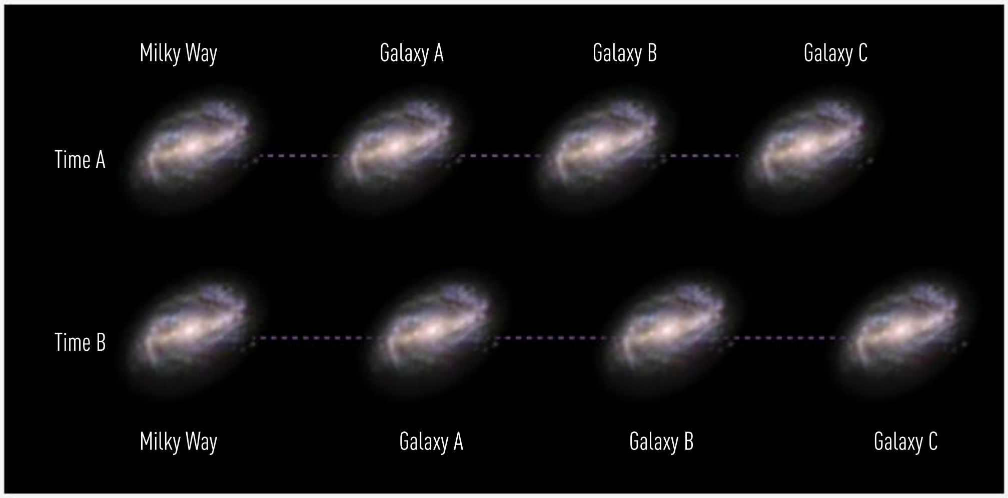


Figure 6.43 Changes in distance between galaxies over time.

2 Use the information above to describe the relationship in the graph using proportionality.

Look at the two diagrams in Figure 6.43. The space between galaxies is expanding. Time A shows galaxies at one point in time and Time B shows these galaxies at a later time. If the dotted line represents the amount of space between galaxies, you can see that each galaxy has moved the same distance from its neighbour. If we compare the distance of each galaxy from the Milky Way, we can see that galaxy C has moved much further from us in that time than galaxies A or B.

3 If all the distant galaxies in the universe appear to be moving away from us and the universe is expanding, how is this supported by the evidence shown in the graph?

4 Summarise your findings and write a statement that addresses the aim.

Part B: Quantitative

In 1929, Edwin Hubble found a relationship between the red shift or velocity of recession of galaxies and their distance from the Earth. He found that velocities are proportional to distances. His law can be expressed as follows:

$$v = H_0 d$$

where v is the velocity of recession (km/s), d is distance from the Earth (Mpc, megaparsecs, where 1 parsec = 3.26 light years) and H_0 is the Hubble constant.

Hubble's original value of H_0 was 550 (km/s/Mpc), but the value has been revised and is now approximately 68 (km/s/Mpc). Hubble's original data contained a lot of errors. Improved technology and methods of measurement have led to improvements in the accuracy of this value each time 'expanding' the size of the universe by several times its previously value.

This value of 68 for Hubble's constant means a galaxy or cluster of galaxies moves away from us at a velocity of 68 km/s for each million parsecs of its distance from us.

1 Plot the data in Table 6.3 (page 272) on graph paper or using graphing software with v (on the vertical axis) against d (on the horizontal axis) with a line of best fit.

2 Use this plot to determine the value for H_0 from the slope of the line.

Note that $v = H_0 d$ is in the same form as a straight line on a Cartesian number plane $y = mx$ and therefore H_0 is the slope or gradient (m) of the straight line obtained when you plot v against d. Also remember that the gradient can be determined by using the equation: $m = \frac{y_2 - y_1}{x_1 - x_2}$.

3 Summarise the trend you see in the graph.

Table 6.3 Distance from the Earth and velocity of recession of each reference constellation.

Reference name for each galaxy	Distance (Mpc)	Velocity (km/s)
Pegasus A	38	3810
Pegasus B	46	3860
Perseus	53	5430
Leo A	80	4960
Coma A	58	6657
Leo B	120	7200
Hercules	105	10400
Pegasus C	145	12800
Gemini	300	23400
Coma B	368	22400
Leo C	307	19200
Ursa Major	457	40400
Pegasus D	552	40000

4 The gradient of the graph is the rate at which one variable on the graph changes as the other changes. Explain what your value of H_0 tells you about the universe.

5 Cosmologists explain the red shift of these galaxies as being due to the expansion of the universe stretching the light from the galaxies as it travels through space. Why is the light from more distant galaxies stretched more?

6 To find the age of the universe, take the inverse of your Hubble constant and convert all the units to SI units (seconds, metres, etc.). It will take a few calculations.

Hint: You need to convert Mpc to light years and this to metres using the speed of light and the number of seconds in a year. Convert km/s to m/s and combine this with the distance in metres. You should get a number in seconds. Convert this to years. Is this close to the value that scientists quote as the currently accepted age of the universe?

7 Summarise your findings and write a statement that addresses the aim.

QUESTIONS 6.3.1: THE MOVEMENT OF GALAXIES

Remember

1 List the key feature(s) that would distinguish an absorption spectrum from an emission spectrum.

2 Describe the data that Hubble gathered to discover the relationship between galaxy recession velocity and distance.

Apply

3 Figure 6.44 shows the spectra observed from three galaxies. Galaxy A is at a fixed distance from the Earth, whereas galaxies B and C are moving. Determine whether galaxy B or C is further away from the Earth according to Hubble's law. Explain your answer.

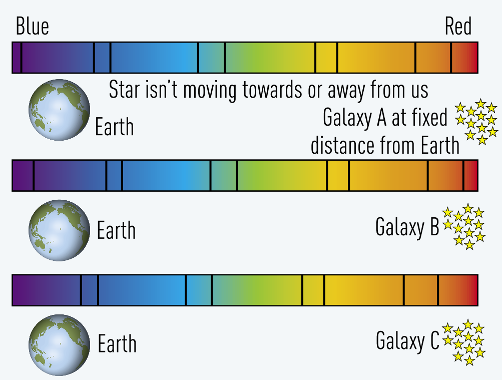


Figure 6.44 Red shift of moving galaxies.

4 Explain why we think the universe is expanding.

THE BIG BANG THEORY

In ancient civilisations, people believed that the Earth was at the centre of the universe. Astronomers today believe there is no centre to the universe and that the universe is bigger than we have been able to see, even with our most powerful telescopes.

Scientific theories of the origins and evolution of the universe first appeared in the early 20th century. These were based on ideas that objects in the universe obey identical physical laws to those that apply on the Earth. Einstein's theories of relativity have led to the development of the field of physical cosmology, which is the study of the origins and evolution of the universe.

The concept of the expanding universe was originally proposed in the 1920s. Edwin Hubble's discovery that the further away galaxies were from the Earth, the faster they were moving, was one of the most significant in the history of science. It means that the universe between the galaxies is expanding. It also implies that if you run things in reverse, everything must have come from the same location, as if the universe was born from some sort of explosion. This idea led to the development of the Big Bang theory – the concept that there was a moment when space and time were created, commonly called the Big Bang.

Of course, the universe did not begin with a big explosion. The event we call the Big Bang was actually the creation of space and time. There was no universe for an explosion to occur in, so the Big Bang could not be an explosion in the familiar sense. The Hot Big Bang model was proposed in 1948. It said that the universe began as an infinitesimally small point with a huge amount of energy. Most of the events that have shaped the evolution of the universe occurred in the first 2 minutes of its existence. This included the conversion of lots of energy into fundamental particles, and then the formation of atomic nuclei (approximately 75% hydrogen and 25% helium). These atomic nuclei, clusters of protons and neutrons, were the centres of what would become the first atoms.

The conversion of energy into matter may sound far-fetched, but we have direct evidence of this in our laboratories. Particles in the Large Hadron Collider in CERN (European

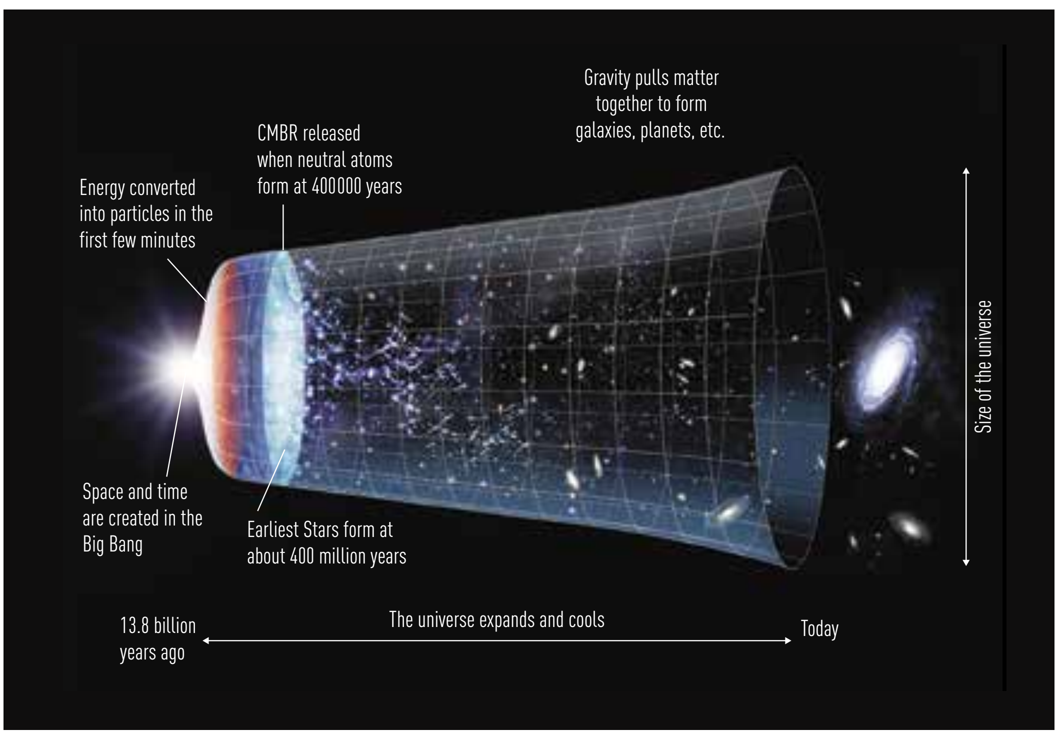


Figure 6.45 According to the Big Bang theory, the universe began as a rapid expansion from a hot, extremely dense state.

Organization for Nuclear Research) are accelerated at almost 99.99999999% of the speed of light and made to collide. The energy of these particles enabled a range of heavier particles to be created through the conversion of this energy into mass. This process can be understood by inspecting the most famous equation in physics: $E = mc^2$. This equation says that an amount of energy (E) in joules is equivalent to an amount of mass (m) in kilograms, and these two quantities are related by the speed of light ($c \approx 3 \times 10^8$ m/s) squared.

Within 400 000 years after the Big Bang, the universe had cooled enough for electrons to combine with atomic nuclei to form neutral atoms. Electromagnetic radiation (such as visible light) was then free to travel throughout the universe, and this radiation is the CMBR we can detect today.

The universe continued to expand and cool, and eventually it cooled enough for gravity to overcome the motion of atoms, and matter began to clump together.

Gravity's attraction

Gravity is the force that is responsible for holding you down on your chair. It holds a drink in a cup unless you tip the cup over. It is an attraction between any two objects that have mass.

If you take two sugar cubes and place them in deep space, 10 cm apart and stationary with respect to each other, the force of gravity between them will slowly bring them together. It will take about 17 hours until they collide with each other.

Any mass exerts a force of gravity on any other mass. We do not feel most of these forces because the smaller the mass, the smaller the force. It is only when a mass the size of the Earth (approximately 6×10^{24} kg) is involved, that we feel the force of gravity as we do every day.

Gravity constantly affects the Earth's oceans. The gravity due to the mass of the Earth's moon pulls on the water in the Earth's oceans and creates a bulge facing the moon. As the Earth rotates on its axis once a day, this bulge can be seen as the rise and fall of sea level.

As well as pulling on the Earth's oceans, this same gravitational force is also responsible for holding the moon in orbit around the Earth. If it were not for this force, the moon would travel off in a straight line instead of moving in a near-circular orbit around the Earth. It is also the force of gravity that keeps the Earth orbiting the Sun. Similarly, the Sun is held in its orbit around the centre of the galaxy, and the Milky Way feels the pull of other galaxies in our neighbourhood.

The force of gravity was first described in a quantitative way by Newton. He realised that the force that makes an apple fall here on the Earth is the same force that makes the moon orbit the Earth. His equation states that gravity is the force of attraction (F), in newtons, between any two objects that have mass (m), that acts with equal magnitude and in an opposite direction on each mass. It is most simply described by the equation commonly known as Newton's universal law of gravitation:

$$F = G\frac{m_1 m_2}{d^2}$$

where G is the gravitational constant (6.67×10^{-11}), m_1 and m_2 are the masses of the two objects in kilograms and d is the distance in metres between the centres of the two masses.

To see how gravity works, we need to inspect the equation above. F is the force of gravity on an object we will call mass 1 (m_1). If the distance (d) between m_1 and the object we will call mass 2 (m_2) is large, then d is large and d^2 is even larger. If d^2 is large, then the fraction on the right-hand side of the equation must be a small number. This fraction is equal to the force (F), so the force is small. Conversely, if the two objects are close together, then d^2 is small and therefore the force F is a large number.

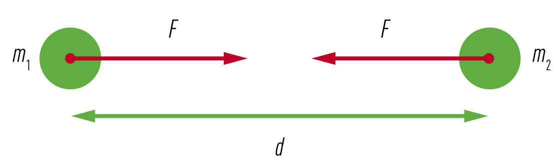


Figure 6.46 Newton's universal law of gravitation.

Gravity and the Big Bang theory

Once the universe had cooled enough, gravity became the driving force for the formation and structure of the universe and the motion of all the masses in the universe. As the universe steadily grew older, it matured as gravity clumped matter into larger and larger structures.

After about 1 billion years, the first stars were born within the first galaxies. Gravity had pulled the hydrogen and helium atoms in the universe into clumps. These clumps had grown hotter and hotter until nuclear fusion could begin and stars were born. Gravity pulled stars and planets together to form galaxies, then pulled galaxies together to form galaxy clusters.

It is this same gravitational force that formed our Sun and some of the planets that orbit around it about 5 billion years ago. A huge nebula full of the gas and dust of previous generations of stars was pulled together. Most of the particles came together to form the Sun. The heavier elements formed the inner rocky planets like the Earth.

Many things had to happen before life could exist on the Earth. In the beginning, the only elements in the universe were hydrogen, helium and a trace of lithium. The elements that make up the Earth had to be created in the core of a star and then spread out into the galaxy. These elements then had to be collected together again by gravity into another star. Fusion reactions in the core of the star created heavier elements and eventually there were enough to form our solar system.

It is clear there was a time in the universe when life was not possible. All this understanding helps us to contemplate where we came from and if we are alone in the universe.

QUESTIONS 6.3.2: THE BIG BANG THEORY

Remember

1. Describe the Big Bang theory in your own words.
2. Describe the evidence that indicates that the universe was once much smaller than it is today.
3. What does the abbreviation CMBR stand for? Explain why its existence is important.
4. Describe the role that gravity has played in the evolution of the universe.

Apply

5. Outline the formation of matter in the universe, beginning with energy after the Big Bang and ending with the formation of atoms.
6. Use the equation $E = mc^2$ to calculate how many joules of energy is produced if 1×10^{-7} kg of hydrogen was converted into energy. Hint: Use $c = 3 \times 10^8$ m/s.
7. Calculate the force of gravity exerted by the Earth on the moon using the following data.
   - mass of the Earth = 6×10^{24} kg
   - mass of the moon = 7.36×10^{22} kg
   - average distance between the moon and the Earth = 384 399 000 m
8. Describe how your answer for question 7 compares to the force of gravity exerted by the moon on the Earth.

Analyse

9. The CMBR has been called 'ancient whispers'. Evaluate whether this name appropriate. Explain your answer.

EVIDENCE FOR THE BIG BANG THEORY

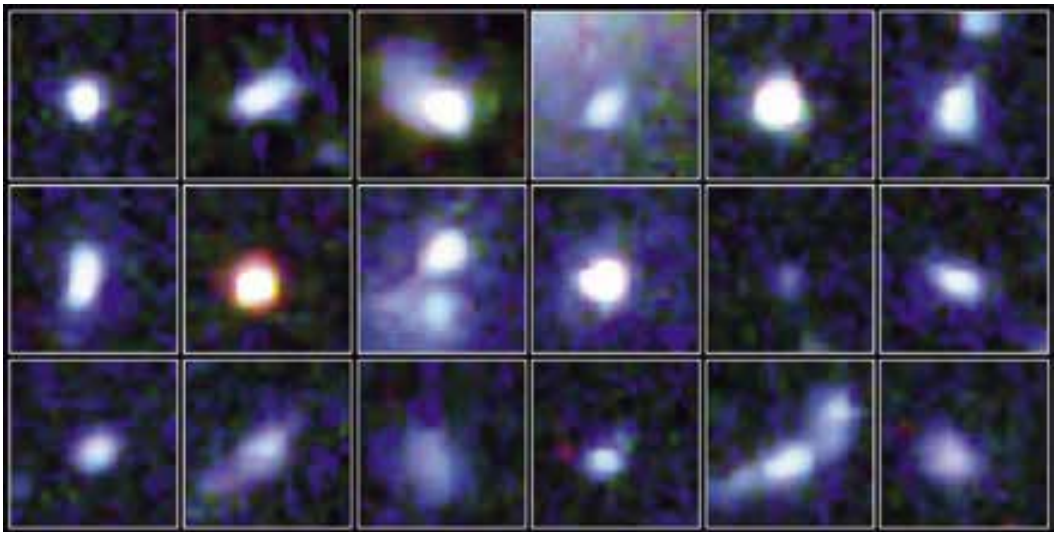


Figure 6.47 A population of small blue galaxies can be seen in the early universe. These small galaxies are thought to have merged to form the large galaxies we see today.

Like any scientific theory, the Big Bang had to be considered and compared against other viable candidates. In 1948, Fred Hoyle, a UK astronomer, proposed his competing **Steady State theory.** In the Steady State theory, Hoyle proposed that the universe has always existed and always will; that the universe had no beginning and has no end. He also proposed that matter is constantly being created in the universe at an enormous rate, and this is what is causing the universe to expand. The Steady State and Big Bang theories were then directly competing to explain how the universe became what it is today.

In the 1950s, the Big Bang theory received a boost from the emergence of radio astronomy. Surveys of large numbers of faint radio sources (radio galaxies) led astronomers to conclude that galaxies had evolved and changed over time. This was significant evidence against any theory that proposed a static and unchanging universe. There was a time in the past when galaxies were much more active. More of them emitted lots of radio waves, much more than we see in the universe today. This supported the idea that the universe began some finite time ago and has been changing ever since.

Observations by the Hubble Space Telescope in more recent years have added more support to the idea that galaxies evolve over time. An enormous number of small blue galaxies can be seen in the much younger universe (see Figure 6.47). A population of these galaxies cannot be seen in the universe today, which indicates again that galaxies have evolved.

In 1946, George Gamow suggested that nuclear fusion must have taken place in the early stages of the universe. Remember, nuclear fusion is when small atoms join to form larger ones. Later theoretical work predicted that the energetic early universe should have led to approximately 25% of the matter in the universe being helium and the remainder being hydrogen.

Studies of spectra in the 1960s and 1970s showed that stars and galaxies consisted of approximately 24% helium. A further prediction was that the universe should contain a trace of an isotope of hydrogen (deuterium). This was confirmed through spectra in 1973 when traces of deuterium were detected in the small amounts of matter between stars (the interstellar medium or ISM). These predictions from our understanding of nuclear physics lent more support to the Big Bang theory following their observational confirmation.

The Hot Big Bang model predicted the existence of some remnant radiation from about 400 000 years after the Big Bang. It was the discovery of this evidence that tipped scientific opinion in favour of the Big Bang over the Steady State theory.

In 1965, two US scientists, Arno Penzias and Robert Wilson, found a faint microwave signal coming from every direction in the

Figure 6.48 Arno Penzias (left) and Robert Wilson (right) in front of the horn antenna they used to discover cosmic background radiation.

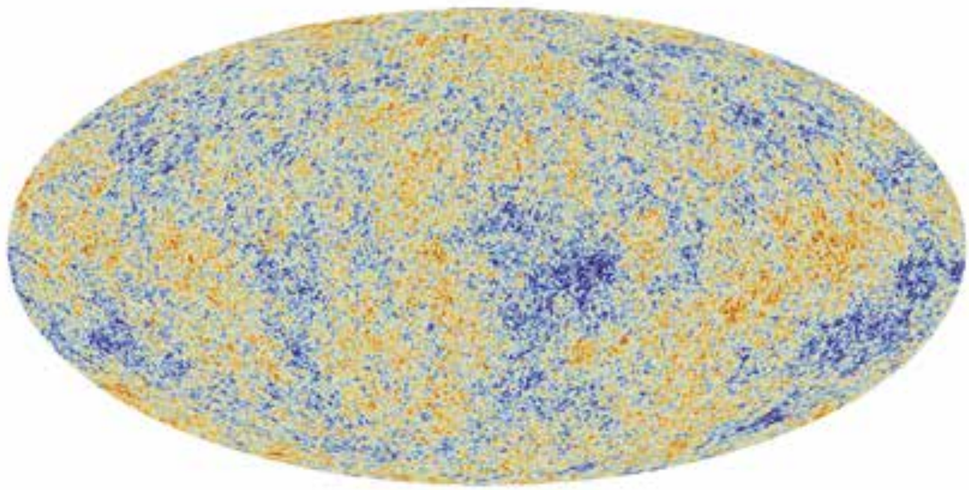


Figure 6.49 Fluctuations in the cosmic microwave background radiation are shown as temperature fluctuations over the sky.

sky. This background noise was the predicted cosmic microwave background radiation (CMBR) of the Big Bang theory. The existence of CMBR was one of the greatest discoveries of all time. Penzias and Wilson were awarded a Nobel Prize for their discovery.

Although the existence of CMBR provided evidence for the Big Bang theory, measurements on the Earth showed that it was too smooth. The overall property of the universe is 'lumpiness'. Much of the visible material in the universe is found in stars, which, in turn, are grouped into galaxies. The universe is not smooth and evenly distributed. Similarly, there should be slight variations in the temperature of the CMBR similar to the fluctuations in the density of matter in the universe. In 1992, the Cosmic Background Explorer (COBE) satellite detected these ripples in temperature fluctuations.

In an endeavour to understand more about our universe, the Planck satellite was launched in 2009. This satellite was designed to examine CMBR in even greater detail to give us a more accurate idea of the origins and evolution of the universe. NASA hopes to build a Big Bang Observer system at some time in the future to detect gravitational waves. It is thought that the information obtained from gravitational waves will also contribute to this theory.

All these efforts will continue to refine our theories of the evolution of the universe. Other theories or more modifications to the Big Bang theory are bound to arise based on new evidence and observations. This is how science works.

Figure 6.50 The Planck satellite was designed to examine cosmic microwave background radiation. The information it provides will give us a better idea of the origins of the universe.

QUESTIONS 6.3.3: EVIDENCE FOR THE BIG BANG THEORY

Remember

1. Recall the name of the opposing theory to the Big Bang theory.
2. Explain why the Big Bang theory became the theory favoured by scientists to describe the evolution of the universe.
3. Explain why theories like the Big Bang theory change over time.

Apply

4. Construct a table, similar to the one shown, to summarise the evidence supporting the Big Bang theory.

Feature of Big Bang theory	Supporting evidence

Analyse

5. Assess the evidence supporting the Big Bang theory and decide which is the most important. Justify your decision.

6.3 CHECKPOINT

HISTORY OF THE UNIVERSE

Remember and understand

1 Define the term 'absorption spectrum'. [1 mark]

2 Describe the trend that Edwin Hubble observed in the spectra of distant galaxies. [2 marks]

3 State the estimated age of the universe. [1 mark]

4 Describe how matter was originally formed in the universe. [2 marks]

5 Explain what Penzias and Wilson are famous for discovering. [2 marks]

Apply

6 Use a diagram to outline the scientific method. [5 marks]

7 If 0.0005 kg of matter is converted into energy in a nuclear explosion, then calculate the number of joules of energy released. [3 marks]

8 Describe the role that gravity has played in the evolution of the universe. [2 marks]

9 Draw an approximate timeline of the events since the Big Bang to summarise the history of the universe. Include the major changes that have occurred over time. [5 marks]

10 Calculate the size of the force on the moon due to the Earth, using Newton's universal law of gravitation, if the variables in the equation have the following values: [3 marks]

- average distance from the Earth to the moon: $d = 3.57 \times 10^8$ m
- gravitational constant: $G = 6.67 \times 10^{-11}$
- mass of the Earth: $m_1 = 6 \times 10^{24}$ kg
- mass of the moon: $m_2 = 7.4 \times 10^{22}$ kg

11 Rewrite the following paragraph by selecting the correct word from the options given. [3 marks]

Most galaxies are moving towards/away from the Earth. The further away the galaxies are, the faster/slower they are moving. This is known as Einstein's/Hubble's law.

Analyse and evaluate

12 Assess the significance of Hubble's discovery of the relationship between distance and galaxy recession velocities. [3 marks]

13 Discuss blowing up a balloon as a valid model for an expanding universe. [3 marks]

14 Create a table that compares and contrasts the Steady State and Big Bang theories. [4 marks]

15 Explain why the Big Bang theory was eventually favoured over the Steady State theory of the universe. [2 marks]

Critical and creative thinking

16 Propose a reason why it is impossible to know what happened before the Big Bang. [3 marks]

17 Explain how the evolution of the universe is related to the existence of life on the Earth. [3 marks]

18 Describe a universe where the laws of physics are different from those we are used to, where forces don't work the way they do in our universe. For example, where gravity repels rather than attracts, or planets are held together by magnetism not gravity. Present your response as a comic strip, a newspaper article or any other creative format. [4 marks]

19 Can you imagine an alternative explanation for the origin and evolution of the universe? Think of the sorts of explanations that ancient civilisations must have had and propose your own. Write it down as a timeline. [4 marks]

TOTAL MARKS
[/55]

1 Fill in the gaps, using the words in the Word Bank below:

When you look up at the night sky, you should realise that the stars in our ________________ are separated by huge _________________. Astronomers have toiled for hundreds of years, building larger and larger ___________________ to study the universe. These astronomers have found evidence that the universe is ________________ and this means it was once much smaller – so small that all __________ must have been created from energy in the first _____________ of the universe's existence.

The force of ______________ has shaped the objects and structures in the universe. This force of ___________________ is responsible for keeping you in your seat, and for the moon orbiting the Earth. The force that the Earth exerts on you is ______________ in size to the force that you exert on the Earth.

The details of the Big Bang ___________ continue to be uncovered. When new ________________ is found, the theory is modified if the current theory is not supported. This is the process of the scientific ___________ at work, and is how the Big Bang theory has become the accepted theory for the evolution of the ______________ and everything in it.

WORD BANK

attraction	expanding	method	universe
distances	galaxy	minutes	
equal	gravity	telescopes	
evidence	matter	theory	

6 CHAPTER REVIEW

Outline the main features of the universe, like galaxies, nebulae, stars and solar systems

2 Compare and contrast stars and planets. [3 marks]

3 Outline the steps that a star the mass of the Sun goes through during its life cycle. [4 marks]

4 Identify the main property of a star that determines its life cycle and fate. [1 mark]

5 Identify the mass of star that can create a black hole. [1 mark]

Use appropriate scales and units to describe sizes and distances within the universe

6 Calculate the number of kilometres in 1 light year. [3 marks]

7 If the Sun is 149 600 000 km from the Earth and light travels at 300 000 km/s, calculate how long it takes for light to reach us from the Sun. Express your answer in minutes. [4 marks]

8 Identify how many kilometres from the Earth each of these celestial objects are.

  a The star Altair at 16.7 light years [2 marks]

  b The Jewelbox star cluster at 7600 light years [2 marks]

9 Explain why we do not use light years for measuring distances within our solar system. [2 marks]

10 If the solar system is 30 000 million kilometres wide, calculate if it is bigger or smaller than a nebula with a diameter of 6 light years. Hint: Convert the given values into the same units. [3 marks]

Relate the colours of stars to their age, size and distance from the Earth (additional)

11 Identify the factors that affect the brightness of a star when we observe it from the Earth. [3 marks]

12 Recall what the colour of a star can tell you. Identify which colours indicate a hot star and which indicate a cool star. [3 marks]

6 CHAPTER REVIEW

13 Use the Hertzsprung–Russell diagram in Figure 6.7 (page 242) to determine the relationship between the mass of a star and its temperature. Explain this relationship. [2 marks]

Describe recent contributions of Australian scientists to the investigation of the universe (additional)

14 Name an Australian astronomer who has received the Nobel Prize for work related to the Big Bang theory. [1 mark]

15 Describe a recent significant contribution to astronomy made by an Australian scientist. Some additional research may be required. [3 marks]

Describe some technologies that are used to investigate the universe

16 Describe how stellar parallax is used to investigate the universe. [3 marks]

17 Explain the cause for the observed recession of galaxies as first seen by Edwin Hubble. [3 marks]

18 Assess the significance of the telescope to the development of astronomy. [3 marks]

19 Choose one technology, other than the telescope, that has led to the development of our understanding of the universe. Describe this technology's role in this development and how significant this has been. [3 marks]

Identify that all objects in the universe exert the force of gravity

20 List two objects or structures in the universe that were formed due to the effect of gravity. [2 marks]

21 Describe the force of gravity acting on any two objects that have mass. [2 marks]

22 Explain how gravity affects the movement of objects in the universe. [2 marks]

Use scientific evidence to explain the Big Bang theory as the origin of and a method of ageing the universe

23 Explain how Hubble's observations led to the conclusion that the universe is expanding. [2 marks]

24 If 0.0005 kg of matter is converted into energy in a nuclear explosion, calculate the number of joules of energy released using $E = mc^2$ (where $c = 3 \times 10^8$ m/s). [1 mark]

25 Density is a measure of the amount of mass in a certain volume. As the universe expands, does the density increase or decrease? Justify your answer. [3 marks]

26 Describe the evidence of energy being converted into matter, as it was in the early universe. [2 marks]

Outline how reviews by the scientific community have refined ideas about the origin of the universe

27 State the first step towards a new scientific theory. [1 mark]

28 Describe the role of evidence or experimental results in the scientific method. [1 mark]

29 Explain how the scientific method leads to the development of new theories. [2 marks]

TOTAL MARKS [/67]

6 CHAPTER REVIEW

RESEARCH

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

Dark matter

Scientists believe there is extra matter in the universe that is invisible. This is called dark matter. What is the difference between ordinary matter and dark matter? What evidence do scientists have for the existence of dark matter? What is the composition of dark matter? Scientists believe that the universe started from the Big Bang and that it will expand before gravitational forces pull it back in to start the entire process all over again. What effect does dark matter have on the future of our universe?

Dark energy

Astronomers have discovered that the expansion of the universe is actually getting faster and faster. Research what dark energy is and what it could mean for the fate of the universe. What is the Australian connection with the discovery of the accelerating expansion of the universe? What did we think was the possible fate of the universe before this discovery?

Australian observatories

The Parkes Radio Telescope is a well-known Australian telescope. Find out a brief history of this telescope and what it is used for. The movie *The Dish* might be helpful in your research.

REFLECT

Me

1. What was the most surprising thing you found out about the universe?
2. What were the most difficult aspects of this topic?
3. How has your understanding of the universe changed?
4. What new science skills have you obtained from this chapter?

My world

5. Why is it important to know about the origins and evolution of the universe?
6. How has a quest to understand the universe helped us develop new technologies that are useful on the Earth?

My future

7. Why is it important to understand what might happen in the future with the universe?
8. What sort of careers might a study of the universe lead to?

KEY WORDS

absolute magnitude
absorption spectrum
apparent magnitude
Big Bang theory
black hole
charge-coupled device (CCD)
constellation
cosmic microwave background radiation (CMBR)
electromagnetic radiation
emission spectrum
galaxy
Hertzsprung–Russell diagram
light year
nebula
neutron star
planetary nebula
red giant
red shift
star
Steady State theory
stellar parallax
Sun
supernova
telescope
white dwarf

6

MAKING CONNECTIONS

Are we alone?

The question 'Are we alone in the universe?' has been contemplated for thousands of years. However, it is only recently that scientists have begun to work towards an answer to this question in a new field of science called astrobiology.

Astrobiology is the study of the origin, evolution and distribution of life in the universe. This new field involves scientists from all four of the main branches of science – biology, chemistry, physics and earth sciences. Astrobiology takes the existence of other life in the universe beyond science-fiction stories and involves the use of scientific research and data to explore the conditions required for life to arise, the likely place in the universe where this may occur and how much life could be in the universe.

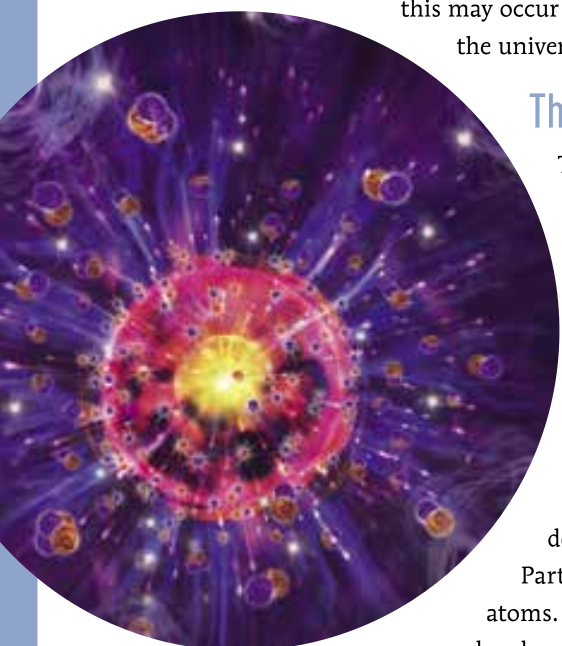


Figure 6.51 Particles such as protons and neutrons, and the atoms they created when combined together, were formed in the first few minutes of the universe after the Big Bang.

The raw materials of life

The origin of any life in the universe can be traced back to the origin of matter. Our understanding of the Big Bang theory tells us where matter came from, what matter was formed in the universe and what conditions were like throughout the formation and development of the universe. Particles formed and gave rise to atoms. Atoms eventually gave rise to molecules, which in turn gave rise to cells, but the right atoms had to exist before this could happen.

Stars like our Sun are basically factories for elements heavier than helium. They take light elements and combine them into heavier ones in the process called nuclear fusion. When stars end their lives as an explosive supernova, they spread these newly created elements into the galaxy. These elements eventually become part of the next generation of stars and their planets.

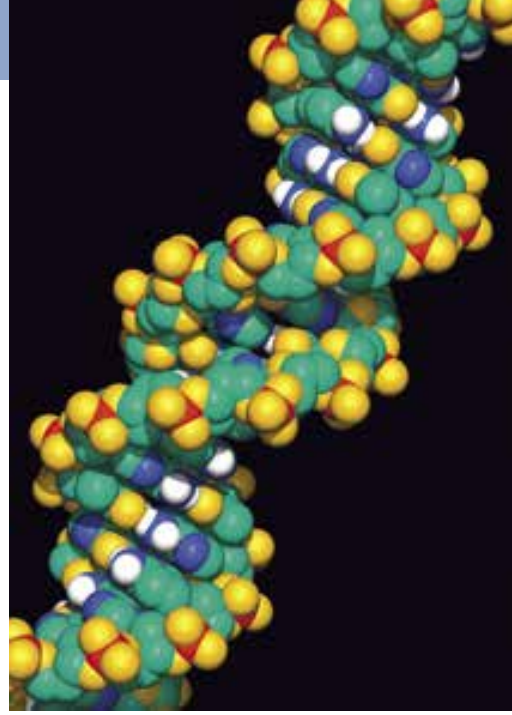


Figure 6.52 The most important compound for the existence of life on Earth is DNA, which is made up of carbon (green), hydrogen (white), oxygen (yellow), nitrogen (blue) and phosphorus (red).

The main elements for life as we know it can be summarised by the mnemonic CHONP (carbon, hydrogen, oxygen, nitrogen and phosphorus). All five elements are vital components of DNA, the molecule of life on Earth. It is clear that if the Big Bang only produced hydrogen, helium and lithium, the other elements must have been formed later. This means there was a time in the universe where we could not have possibly existed because the elements we are made of were not yet available.

Finding other life

Many astronomers today are working hard to be the first to discover a planet around another star that could support life. Just finding planets around other stars is a huge challenge. Despite this, we now have thousands of planet candidates, even some that have been seen directly.

The history of the universe is our history

The science that predicts the history of the universe, from the Big Bang through to today, tells us where we came from and how we got to where we are today. With such an immense

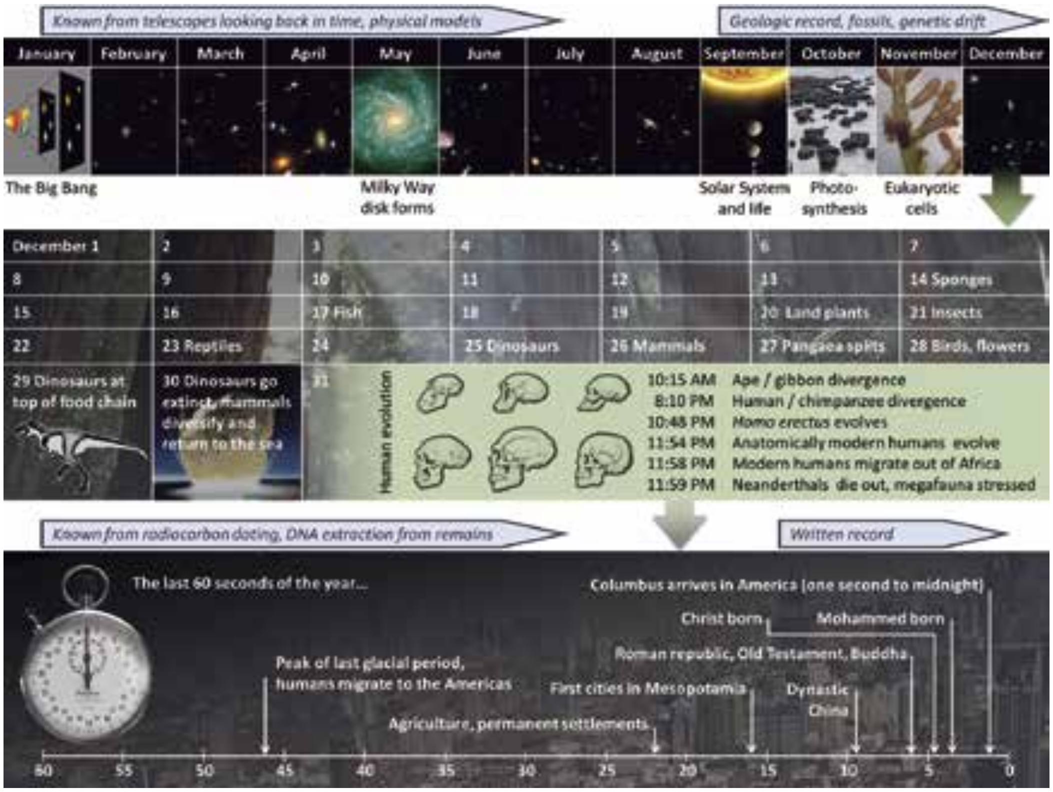


Figure 6.53 To make it easier to comprehend the life span of the universe, it can be condensed into a single Earth year. Each month represents slightly more than a billion years.

timeframe since the beginning of the universe, we need to look at things differently to be able to understand it.

Figure 6.53 condenses the history of the universe into one calendar year here on the Earth, starting on 1 January with the Big Bang and ending with the present at midnight on 31 December.

Your turn

Now it's your turn to be an astrobiologist and join in the quest to answer the ultimate question: Are we alone? Use your research skills and your knowledge of science to answer the following questions.

1 Explain how atoms are arranged in molecules and identify the forces involved.

2 Determine the types of stars that produce the main elements needed for life.

3 Identify the importance of DNA for life. Evaluate whether or not life could exist without it.

4 Explain the role of gravity in the formation of a planet and the development of life on the Earth.

5 Many planets are detected by the wobble they cause in the motion of the star they orbit. Investigate how this wobble occurs, how is it related to the force of gravity and how astronomers detect it.

6 Research some of the signals that could be detected to indicate that life exists elsewhere in the universe, and the technology needed to detect these signals.

7 Propose the type of life you think would be most abundant in the universe. Explain your reasoning.

8 Propose how finding life elsewhere in the universe would change humanity.

9 From what you have learned so far, identify the events that had to occur before you could exist in the universe.

10 Calculate the percentage of the age of the universe that humans have existed.

And now for the million-dollar question ...

11 Do you think life exists elsewhere in the universe? Justify your answer with scientific evidence and data.

7

GLOBAL SYSTEMS

Throughout human history, one thing has held our interest and curiosity like no other: our home, planet Earth. At one time we thought the Earth was flat, for thousands of years parts of it went unmapped and unexplored and, recently, we have started to see that the actions of humans can seriously harm it. The Earth is the only planet we know of that supports life, and living things have changed the planet in many ways. The manner in which matter cycles through the Earth's spheres is similar to the way it cycles in living organisms.

THE EARTH'S SPHERES AND NATURAL EVENTS 7.1

The Earth is made up of four distinct spheres: the lithosphere, atmosphere, hydrosphere and biosphere. Global systems and natural events involve interactions between two or more of the spheres, where a change in one sphere can cause changes in the others.

Students:

» describe the effects of natural events on the Earth's different spheres

» examine the links between deep ocean currents, climate regulation and marine life (additional content)

MATTER CYCLES AND INTERACTIONS BETWEEN SPHERES 7.2

The Earth's spheres interact in many different ways, the most obvious being the cycling of matter. As water, carbon, oxygen and different nutrients cycle through the spheres, the atoms and molecules are rearranged into different molecules and compounds before moving into the next sphere.

Students:

» outline how global systems, like the carbon cycle, rely on interactions between the Earth's spheres

» discuss how different groups in society may make decisions about issues involving the interactions between the Earth's spheres

CLIMATE CHANGE 7.3

Humans are a part of the biosphere of the Earth and our actions affect all the spheres. Many human activities have altered the flow of matter and energy in the Earth's spheres, resulting in global changes. However, as technology and scientific understanding improves, we have the opportunity to undo some of the damaged caused and slow the progression of other changes.

Students:

» evaluate the scientific evidence of the results of human activities on global systems

» research evidence of links between weather pattern changes and global warming, including El Niño and La Niña (additional content)

» discuss some of the international biodiversity and climate change agreements (additional content)

» research how computer modelling is used to monitor and predict changes in global systems, like ocean salinity, climate change and atmospheric pollution (additional content)

» outline examples where advances in science and technology generate new career opportunities (additional content)

7.1 THE EARTH'S SPHERES AND NATURAL EVENTS

Everything on the Earth can be considered within four spheres: the lithosphere (land), atmosphere (air), biosphere (living things) and hydrosphere (water). Earth and Environmental Science is the study of the interactions between these four spheres. Each sphere maintains a balance and can interact with other spheres. Humans, like all organisms, affect the Earth's systems. The ability of humans to manipulate their environment sometimes stretches these spheres to their limits and beyond.

THE LITHOSPHERE

A cross-section of the Earth reveals its multiple layers (Figure 7.1). The outermost rocky layer of the Earth is the **lithosphere** and is made up of the upper **mantle** and the **crust**. **Tectonic plates** are slabs of lithosphere an average of 100 km thick. Although that may seem very thick, in terms of the scale of the size of the Earth, it is actually a very thin layer.

Towards the middle of the Earth, it gets hotter and the rock becomes more molten (melted). However, the **inner core** does not melt or boil because the pressure from the weight of the rest of the Earth is pushing in on it so strongly from all directions. Next time you are complaining about a summer day getting close to 40°C, consider that the inner core is almost 10 000°C!

The heat in the mantle creates convection currents that slowly stir the molten rock called magma, dragging the tectonic plates around the surface as well. The speed of movement of the tectonic plates (around 2–10 cm/year) is similar to the growth of your fingernails. These slabs of lithosphere interact at the edges to form mountain ranges and deep-sea trenches. As the large plates are slowly stressed and strained, the surface of the Earth is changed. Major changes to the lithosphere happen on a time scale of thousands to millions of years. However, a volcanic eruption or earthquake can change the local landscape very quickly.

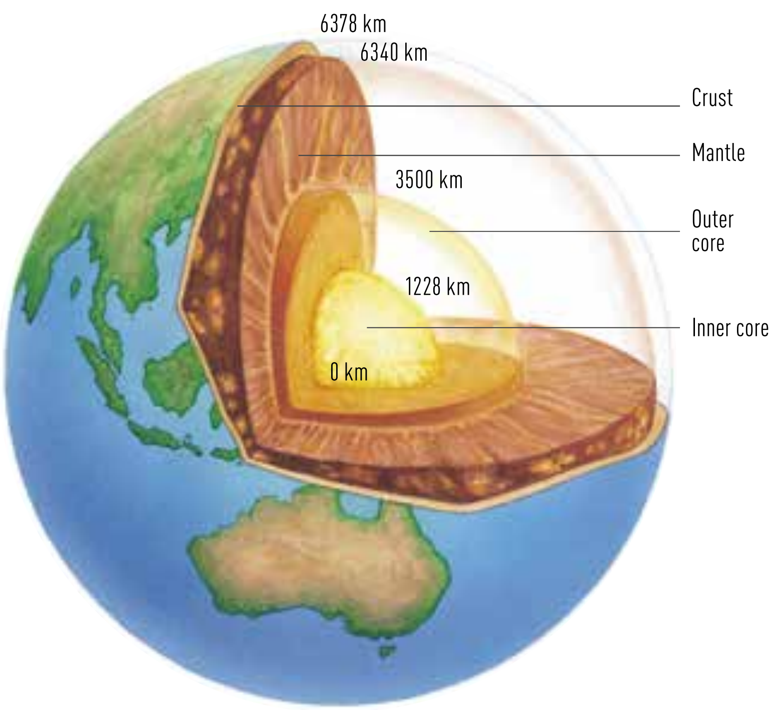


Figure 7.1 The layers of the Earth.

ACTIVITY 7.1.1: REMEMBERING THE SPHERES

What you need: an observable landscape or image of one, A3 paper, coloured pens

1 Go outside or look at a photo of a landscape. List the different aspects of the environment that you can see or that you know are present (such as air).
2 Create a Venn diagram showing the four interconnecting spheres of lithosphere (land), atmosphere (air), biosphere (living things) and hydrosphere (water). Use Figure 7.2 as a reference.
3 Place everything you have observed into the spheres plus more items that you may not be able to observe.

- Some elements will be in two overlapping spheres. For example, clouds are in the atmosphere and the hydrosphere. How many other aspects of the environment can you identify as belonging to more than one sphere?
- Discuss this with your classmates and try to identify at least one feature of the environment that fits in the overlap of all four spheres.

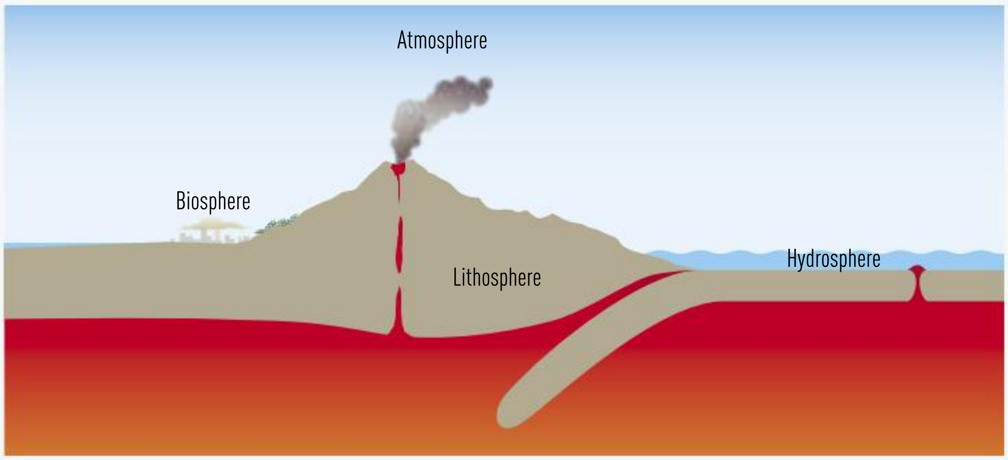


Figure 7.2 The four spheres – lithosphere, biosphere, hydrosphere and atmosphere.

SCIENCE SKILLS

Using computer simulations

Scientists can't always find answers to big questions by doing experiments. Often the risks are too great, it would take too much time or the experimental method is outside the limits of current technology. Answers to problems like this can sometimes be found by computer simulations.

A computer simulation takes an established pattern and extends it to make a prediction about future events. A simulation is a type of model and, just like other models, it isn't always accurate, but it is the best possible inference or answer to a big question that cannot be tested in any other way. Computer simulations can also be used for experiments that require a lot of repetition that would take a scientist a long time to complete manually, or to infer data about places we can't go to, such as other planets or below the crust of our own planet.

Scientists know that the Earth's mantle is 2800 km thick and that the temperature near the point where the crust and mantle meet is approximately 500°C. Your job is to find out the temperature of the mantle at its deepest point: 2800 km below the Earth's surface.

What to do

1 Enter the information from Table 7.1 into a spreadsheet program, such as Microsoft Excel or similar.
2 Create a scatter graph of this information using the graphing function of the computer program. Make sure that temperature is on the vertical axis and depth is on the horizontal axis.

3 Extend the data in the table until you reach a 'Depth under mantle' of 2800 km. Do this by using the 'fill handle' tool (select the cells in the Excel spreadsheet and click and drag the small square that appears in the lower right corner of the selection).

4 Update your graph to represent this new data.

Table 7.1 Temperature measurements at mantle depths of the Earth.

Depth under mantle (km)	Temperature (°C)
100	500
200	598
300	696
400	794
500	892
600	990

Questions

- Do some research about the average temperature at different depths under the mantle. Explain why there is a variance.
- The process you have just followed only works for data that increases or decreases at a regular rate. This process is also called extrapolation or interpolation, depending on whether you are examining data that can be found within the graph (interpolation), or by extending the graph (extrapolation). Suggest another experiment you have conducted this year that could have been extended by this process.
- Similar modelling is conducted using weather and climate data. What predictions would scientists want to make about weather and climate? Why would these predictions be useful?

More complex computer simulations are also available to process much more complicated, or non-linear, data.

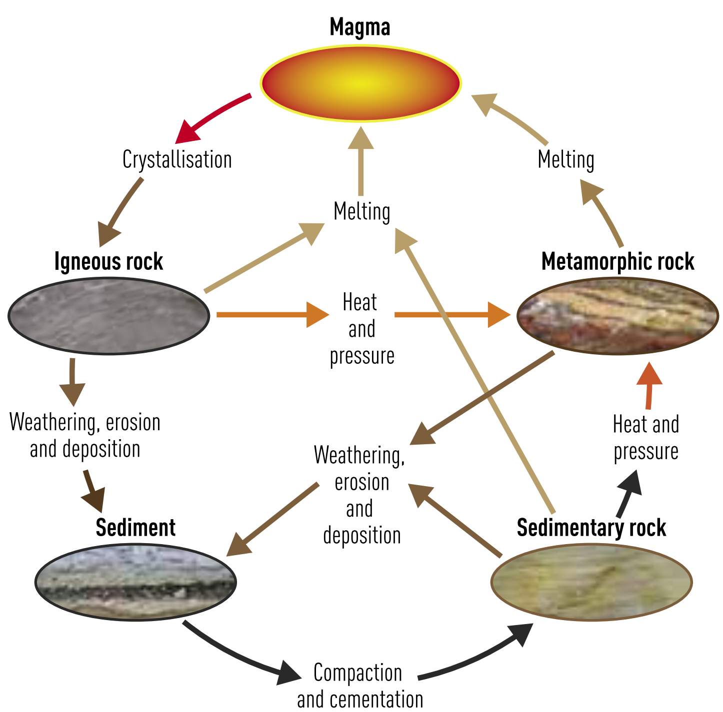


Figure 7.3 Rocks change in structure as they move through the rock cycle.

The rock cycle

As you will recall from year 8, the rock cycle is a model used by scientists to describe the formation and destruction of rocks. **Igneous rocks** are formed when magma, also called lava when it is found above ground, cools. Underground rocks may be brought to the Earth's surface by uplift from tectonic movement or erosion of overlying sediments.

Rocks exposed at the surface break down to form sediments. These sediments are deposited in layers and, over time, they cement together under pressure to form **sedimentary rocks**. When rocks are under extreme heat or pressure, they change into very hard **metamorphic rocks**. If too much heat or pressure is applied to rocks, they melt and form magma and the whole cycle begins again (Figure 7.3). Someone who studies rocks and the components of planets is called a **geologist**.

QUESTIONS 7.1.1: THE LITHOSPHERE

Remember

1 Identify the components of the lithosphere.

2 Describe the rock cycle in your own words.

Apply

3 Outline ways in which animals and plants interact with the lithosphere.

4 Deep mines are much warmer than the surface. Explain this using your knowledge of the Earth's structure.

Analyse

5 Soil contains broken-down rock, air, water, organic material and living organisms. Is soil part of the lithosphere? Justify your answer.

THE ATMOSPHERE

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

The Earth is the only planet in our solar system that has an atmosphere that sustains life. It keeps us warm, controls our **weather**, protects us from dangers from space (e.g., meteorites) and carries sounds. The moon has no atmosphere, so there is no wind, no noise, no life and no protection from meteorites, which crash into the moon's surface.

The atmosphere is made up of many different gases. Oxygen (O_2) allows organisms to respire; **ozone** (O_3) offers protection from the Sun's UV radiation; and water vapour (H_2O), carbon dioxide (CO_2) and other **greenhouse gases** trap heat to keep us warm. Nitrogen (N_2) makes up 78% of the atmosphere, whereas oxygen, which is arguably the most important gas for humans and other animals, only makes up around 21% of the atmosphere.

The early Earth had an atmosphere of mostly nitrogen and carbon dioxide. The earliest photosynthetic bacteria changed the composition of the atmosphere over millions of years. Carbon dioxide decreased, while oxygen and ozone were formed, making the Earth suitable for more complex organisms like us.

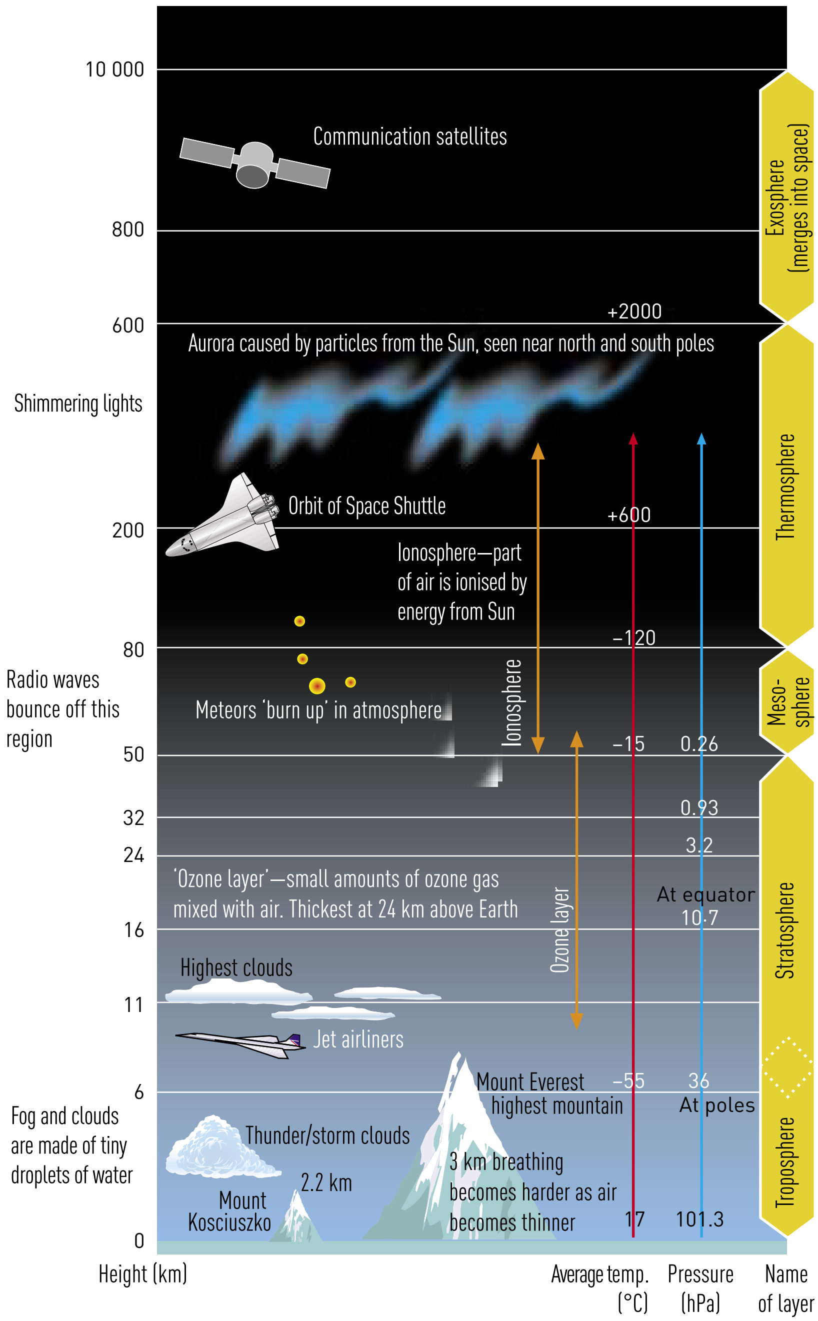


Figure 7.4 Each layer of the Earth's atmosphere has different characteristics.

Layers in the atmosphere

The atmosphere is most dense at ground level and thins out the higher you go above the Earth's surface: 99% of all the air in the atmosphere is found within 80 km of the Earth's surface. There is not really a clear end to the atmosphere; the air just thins out, with decreasing pressure, until you reach the emptiness of space. These changing conditions are identified as several atmospheric layers (Figure 7.4. Note: The vertical scale representing the height above the Earth's surface is not a linear scale).

Troposphere

The troposphere is the bottom layer of the atmosphere, where we live. This layer contains most of the air in the atmosphere and is where all weather occurs. Most aircraft fly in the troposphere. As altitude increases, the density of the air decreases, as does temperature.

Stratosphere

The stratosphere extends from the troposphere up to around 50 km above the ground. The ozone layer, which blocks most of the Sun's harmful UV rays, is found in this layer.

Mesosphere

The mesosphere sits above the stratosphere and the temperature here again gets colder. Millions of meteors burn up daily as a result of the heat caused by friction with the gas particles that are contained here.

Thermosphere

The thermosphere is the largest of the atmospheric layers. Space shuttles and some satellites orbit in this layer.

The ionosphere is the part of the thermosphere extending from approximately 50–300 km above the Earth's surface. In this region, some gases are ionised by energy from the sun. These ionised gases reflect radio signals and are also responsible for the aurora (a glow in the sky at the poles, Figure 7.5).

Exosphere

The exosphere is the top of the atmosphere. This layer merges with space and most communication satellites orbit in here.

Figure 7.5 *Aurora australis*, also known as the Southern Lights, is seen here over icebergs in Antarctica. Auroras occur in the ionosphere and are caused by high-energy solar wind ion particles, which get trapped by the Earth's magnetic field around the poles and collide with atmospheric gases, causing them to emit light.

QUESTIONS 7.1.2: THE ATMOSPHERE

Remember

1 Identify the layer of atmosphere in which we live.

2 Describe what happens to the amount of air as you go higher in the atmosphere.

3 Identify the gases that make up the atmosphere.

Apply

4 Explain how the evolution of the first photosynthetic organisms changed the Earth's atmosphere.

5 Explain why mountain climbers often have difficulties breathing in the atmosphere of high mountains, such as Mount Everest.

Analyse

6 Without the troposphere, we would not be able to breathe. Evaluate the roles of the stratosphere, mesosphere and thermosphere for maintaining life on the Earth's surface. Could we do without any of these layers? Justify your answer.

THE HYDROSPHERE

Figure 7.6 All the Earth's water makes up the hydrosphere.

The **hydrosphere** is made up of all the Earth's water. This includes not just the obvious oceans and lakes, but also frozen glaciers, soil moisture, underground water and even moisture in the air. Life evolved in water, and the hydrosphere is home to most plants and animals on the Earth. The hydrosphere covers approximately 70% of the Earth's surface, making the Earth the 'blue planet' when viewed from space.

The hydrosphere interacts with and is influenced by each of the other spheres. For example, in the atmosphere you can find water in all three different states: liquid, vapour and solid (hail and snow).

The hydrosphere plays an important role in controlling the Earth's **climate,** which is the long-term pattern in temperature, wind and rain in an area. The oceans hold a lot of heat and influence climate on a large scale. Deep ocean currents move warm water from the equator to the poles; the water then cools and travels from the poles back to the warmer areas of the Earth.

Figure 7.7 The frozen ice shelf extends well past the edge of the landmass of Antarctica, but melts and refreezes with the summer and winter seasons.

The cryosphere

The part of the hydrosphere that is made up of frozen water is called the **cryosphere**. The cryosphere is important in regulating the climate on the Earth and it does this in a number of ways. It influences atmospheric and ocean circulation and currents; it affects the amount of moisture in the atmosphere; and it reflects rays from the sun. When measuring changes in the climate, scientists carefully monitor what is going on in the cryosphere, such as the breaking of huge ice shelves and melting sea ice in the Arctic. We will look at this further in the final unit of this chapter, which considers human impacts and changes to our climate.

Deep ocean currents

Large conveyer belt-like deep ocean currents carry heat through various parts of the world and regulate temperature. A famous example is the Gulf Stream; there has even been a Hollywood movie about the Gulf Stream – *The Day After Tomorrow* (2004). The movie depicts the importance of the Gulf Stream in heating a vast area of Europe. In the film, the Gulf Stream shuts down and, in just a day, plunges most of Europe into a new Ice Age. Frozen birds fall from the sky and people freeze in the streets, with most becoming instant refugees in countries with warmer climates.

Ocean currents have the important job of moving warm water from equatorial regions towards the poles; the water then cools and travels from the poles back to the warmer areas of the Earth. These large 'conveyer belts' of water are driven by the differences in temperature and salinity (Figure 7.8).

Colder water is dense and heavy and moves downward in the ocean; warmer water is less dense and so moves up towards the surface, completing the conveyer belt-like movement. Heat from the Sun evaporates water from the top-most layer of the ocean. The salt in the remaining water is therefore more concentrated. Less salty water is less dense and rises, whereas salty water is more dense and so sinks.

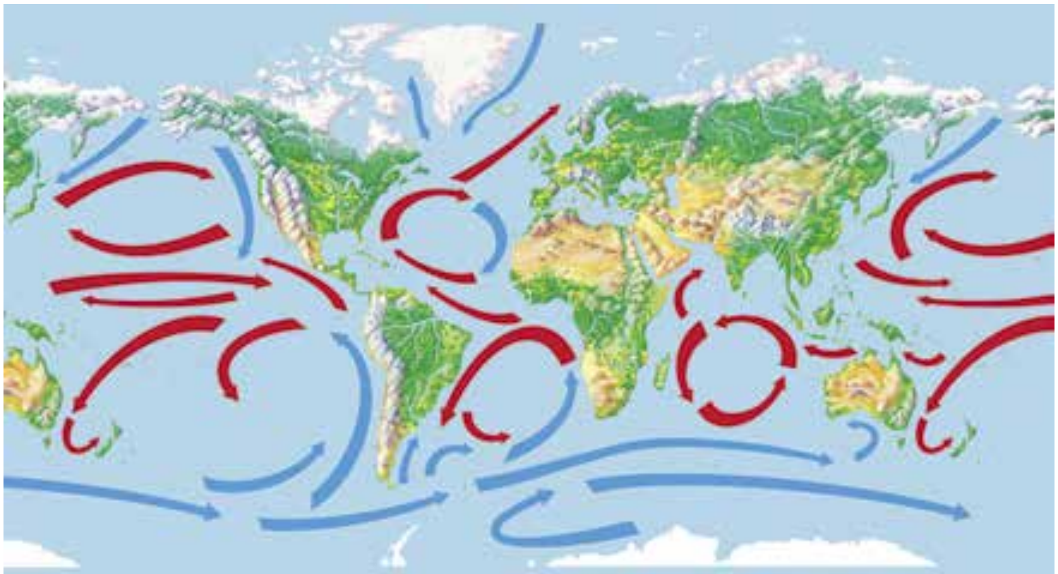


Figure 7.8 The path of the ocean 'conveyer belt', in which differences in temperature and salinity drive the movement of large deep ocean currents (red = warm, blue = cold).

El Niño and La Niña

El Niño and **La Niña** variations are changes in ocean currents that have a great effect on Australia. El Niño occurs when a warm current appears off South America. As the central and eastern Pacific warms, northern Australia and the western Pacific cool. With little temperature difference, the trade winds that normally blow from South America decrease and Australia receives little moisture and therefore less rainfall (especially on the eastern coast). La Niña is the opposite pattern, with warming and wet weather in Australia (especially in the north) and drier, cooler weather for South America. In La Niña, the trade winds blow more strongly.

The Southern Oscillation Index is calculated from atmospheric pressure readings in the Pacific and allows the Australian Bureau of Meteorology to estimate when the pattern will change from El Niño to La Niña. This happens about every 3–8 years.

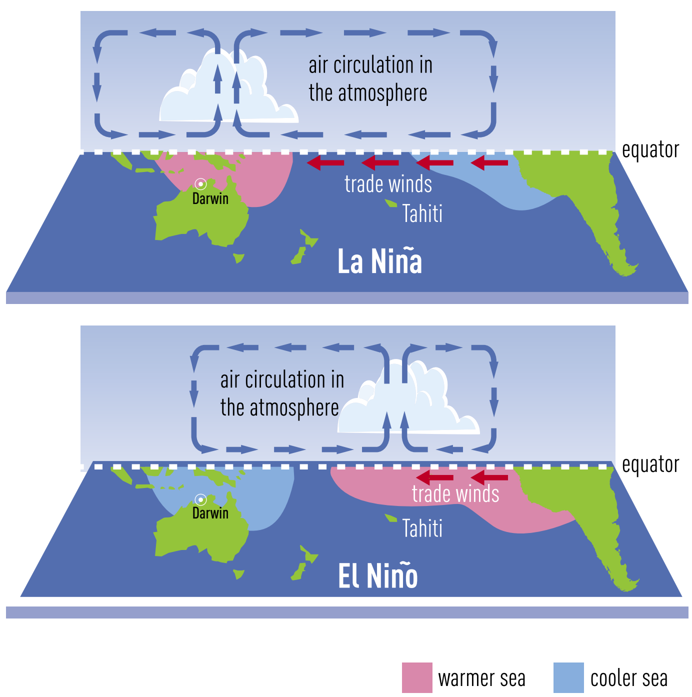


Figure 7.9 El Niño and La Niña climate variations.

Upwelling

Strong surface winds, often near coastlines, can push the top layers of ocean water along. Cold water often rises to the surface to replace this relocated water, bringing nutrients that have sunk back to the surface. A patch of rising cold water is called an upwelling. The extra nutrients in areas of upwelling increase biological activity because they can support larger or more diverse populations of marine organisms (Figure 7.10).

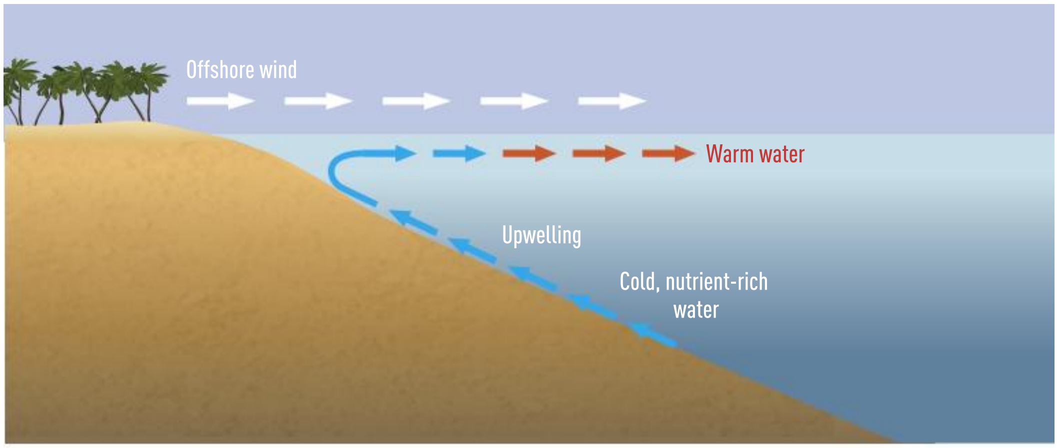


Figure 7.10 Ocean surface winds can cause upwelling of cold water, which brings nutrients back to the surface where most marine organisms live.

ACTIVITY 7.1.2: HOW DO WE USE WATER?

What you need: 2 packets of stick-on notes per group, some pens

1. Divide the class into groups of four or five. Each person needs a small pile of stick-on notes and a pen.
2. In 2 minutes, write down every use of water you can think of. (Hint: As well as the water that humans use, think about animals, the environment, business, farms etc.) Write each use on a separate stick-on note. Spread the notes out on the table in front of you.
3. When the time is up, arrange the notes into common topics.
4. Display your group's uses of water on a wall (temporarily) or on poster paper.
5. Check the displays created by other groups. Make a note of any uses your group did not include.
6. Count up the number of different uses of water that the whole class has described.
7. Use your information to identify examples of the hydrosphere interacting with each of the other spheres.

QUESTIONS 7.1.3: THE HYDROSPHERE

Remember

1. Define the term 'hydrosphere'.
2. Distinguish between the hydrosphere and the cryosphere.
3. Identify two factors that determine whether water sinks or rises.

Apply

4. Explain why currents are partly responsible for global temperature.

Analyse

5. Suggest why the best fishing areas tend to be where regular upwelling occurs.

THE BIOSPHERE

The **biosphere** is made up of all the living things on the Earth, including plants, animals and microorganisms. Within this sphere, there is an enormous degree of organisation and amazing biodiversity. There is also great interdependence between different parts of the living world. From food webs to more obscure dependencies, there is a fine balance between organisms, which must be maintained.

Although life is able to exist in all spheres on the Earth, most living things can only survive in a fairly narrow range – from deep under the ocean to the top of high mountains. The wide range of conditions that exist in all these habitats is reflected in the wide range of living things: *biodiversity* (*bio* = life; *diversity* = variety).

The interactions and interconnections between the Earth's spheres can also be considered to be interactions between the **biotic** (living) and **abiotic** (non-living) parts of the Earth. Living things require a number of non-living things to survive, for example water and gases such as oxygen and carbon dioxide. Scientists who study this interaction between living things and their environment are called **ecologists** and they consider the various levels of **ecology**, including single organisms, populations, communities, ecosystems and even the entire biosphere. Humans rely on the biosphere for food, medicines, building materials and fuel.

Figure 7.11 The Pompeii worm is able to withstand temperatures of up to 80°C. It is considered a 'thermophile' because it thrives in hot conditions.

Figure 7.12 Tardigrades are tiny invertebrates found almost everywhere. They have been known to survive without water for over 100 years and can live at temperatures ranging from as low as −272.8°C to as high as 151°C, under massive amounts of pressure, in vacuums and even at radiation doses that would kill all other known life forms!

QUESTIONS 7.1.4: THE BIOSPHERE

Remember

1 Identify the component that makes up the biosphere.

2 Define 'biodiversity' and explain why it is so important.

3 List five biotic factors and five abiotic factors within the environment.

Apply

4 Give examples of three different levels of ecology and explain the importance of studying each level.

5 Give examples of how the biosphere interacts with each of the other, abiotic, spheres.

6 Humans rely on the biosphere for a lot of reasons. Aside from those listed above, give examples of how humans rely on the biosphere.

NATURAL EVENTS AND THE EARTH'S SPHERES

Earthquakes, volcanic eruptions and cyclones are natural events that can have huge effects on the Earth's spheres; if they occur in inhabited areas, they can cause significant loss of human life.

Earthquakes

Every year the Earth experiences more than a million earthquakes! Most of these are far from cities or so small that people don't realise they have happened.

Earthquakes occur when stress or strain builds up at the edge of lithospheric plates or (less often) in the middle of a plate. The force builds up until the rocks break and the plate moves with a jolt. The jolt causes vibrations on the Earth. Most of the damage caused by earthquakes happens near the epicentre, which is the point on the surface of the Earth directly above where the earthquake occurred. Scientists monitor plate movements so that they can predict where earthquakes are *likely* to occur. However, we can't predict *exactly* where and when an earthquake will occur.

We can see how earthquakes affect the lithosphere where there are broken rocks and cracks in the ground. Sometimes they affect the hydrosphere, too. Undersea earthquakes can push up the water to form deadly waves known as tsunamis, such as the one that devastated the north-east coast of Japan in 2011.

Figure 7.13 The city of Christchurch in New Zealand was devastated by a magnitude 6.3 earthquake on 22 February 2011.

Figure 7.14 An undersea earthquake off the coast of Japan in March 2011 triggered massive tsunamis that engulfed many coastal communities.

Volcanoes

Volcanic eruptions are common at convergent plate boundaries where one plate melts as it is forced down (subducted) into the mantle. Other eruptions occur as plates split apart or pass over hot spots in the mantle. Volcanoes are classified according to their different shapes. These shapes are influenced by how the magma chambers form.

In an explosive eruption, the red-hot magma rushes out through the **vent** (Figure 7.15). Larger pieces of rock often explode from the crater as volcanic bombs, and dust, ash and steam are thrown high into the air. Volcanic eruptions also ooze lava and ash onto the surrounding land. The lava forms solid igneous rock in the cooler temperatures on the Earth's surface. When igneous rock is broken down by the action of wind and water, and mixed with organic material from plants and animals, it forms some of the richest soil in the world. Volcanoes affect the lithosphere by adding new rock, the atmosphere by releasing ash and gases, and the biosphere by creating fertile soils.

When Mount Pinatubo in the Philippines explosively erupted in 1991, ash fell up to 3500 km away and 4% of the Earth's sunlight was blocked for an entire year. Other volcanic eruptions are much quieter because molten rock oozes slowly from the vent.

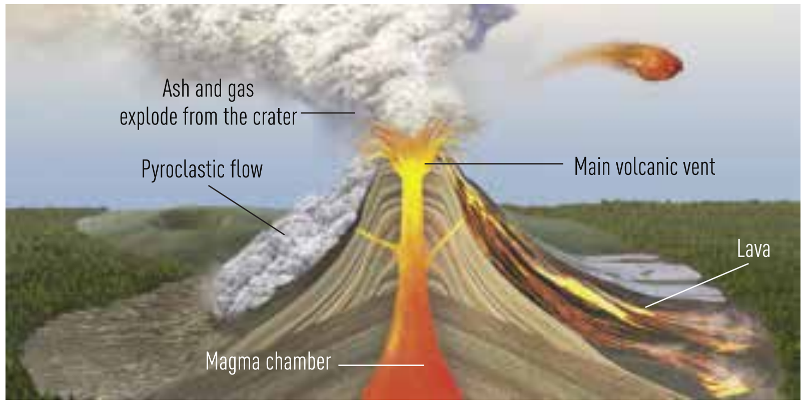


Figure 7.15 A cross-section through an active volcano.

Figure 7.16 Mount Pinatubo is an active volcano in the Philippines that last erupted in June 1991.

Cyclones

Cyclones form over warm tropical seas when there is a low pressure system. Water evaporates from the ocean and forms clouds, which release some of their heat energy into the air. This reduces the pressure even further and causes the process to speed up. The low pressure and the Earth's rotation combine to make the clouds spiral inward to the centre of the low pressure zone.

Tropical cyclones in the Southern Hemisphere spin clockwise. The same weather patterns are called hurricanes or typhoons in the Northern Hemisphere, where they spin anti-clockwise. A storm officially becomes a cyclone when winds reach 63 km/h and a severe cyclone at 118 km/h. These winds

Figure 7.17 Typhoon Haiyan devastated parts of the Philippines in November 2013, killing over 3500 people and injuring a further 12 000.

Figure 7.18 Cyclone Yasi as it makes its way towards the east coast of Queensland.

are strongest near the centre, or eye, of the storm, but may extend hundreds of kilometres outward.

At sea, the destructive winds of cyclones cause large waves and heavy rain. As a cyclone nears land, heavy winds cause extensive damage to trees and buildings, while the torrential rain can lead to flooding. A storm surge that is 2–5 metres higher than normal tide and up to 80 km across is one of the greatest hazards, causing more deaths than any other feature of cyclones. After it makes landfall, the cyclone loses energy, as there is less heat and less water vapour available than over the ocean.

A cyclone forms in the atmosphere, but the heavy rain and waves are in the hydrosphere. When it hits land, the cyclone may have devastating effects on the biosphere. Tropical Cyclone Tracy, which hit Darwin on Christmas Eve 1974, was one of the smallest known cyclones in diameter, but was also one of the most destructive. Although gale force winds had a radius of less than 50 km, these winds reached speeds of up to 250 km/h. Cyclone Tracy caused 71 deaths, the evacuation of 35 000 people and about $800 million in damages.

The cyclone that caused the most amount of damage to Australia was Yasi on 3 February 2011. This 600 km wide cyclone hit Queensland with wind speeds gusting to 290 km/h, dumping 471 mm of rain on Mission Beach and bringing a 5-metre storm surge. Hundreds of homes were destroyed and thousands damaged. The damage to public infrastructure was estimated at $1.5 billion and the total cost of Yasi, including loss of tourism, is estimated to be $3.5 billion.

QUESTIONS 7.1.5: NATURAL EVENTS AND THE EARTH'S SPHERES

Remember

1 Describe the common causes of earthquakes.

2 List some of the effects of earthquakes and volcanoes on the Earth's spheres.

Apply

3 Suggest reasons why it is easier for geologists to predict volcanic eruptions than earthquakes.

4 Outline the reasons that cyclones weaken over land.

5 Cyclones Yasi and Tracy were the most destructive to hit Australia. Compare the major features of both storms. Only one person died in Cyclone Yasi. Propose a reason for the different death tolls.

Research

6 Investigate Typhoon Haiyan or another recent cyclone (or typhoon or hurricane). Research where the cyclone formed, where it travelled and where it made landfall. Identify some characteristics of the storm such as the maximum wind speed, diameter, and height of storm surge tides. Present your findings as a short multimedia presentation. Remember to cite all your resources, including any images you use.

THE EARTH'S SPHERES AND NATURAL EVENTS

7.1
CHECKPOINT

Remember and understand

1 What does the ozone layer protect us from? [1 mark]

2 Name the different layers of the Earth. [3 marks]

3 Identify the layer(s) of the Earth that makes up the tectonic plates. [1 mark]

4 What does an ecologist study? [1 mark]

5 Identify three major gases found in our atmosphere and outline their importance for life on the Earth. [3 marks]

6 Describe examples of slow and fast change in the lithosphere with specific reference to the time scale of each example. [2 marks]

7 Even though the Earth's inner core is hotter than its molten outer core, it is thought to be solid. Explain why the inner core is solid. [1 mark]

Apply

8 Explain how the atmosphere protects us from meteorites. [2 marks]

9 The hydrosphere can have a huge effect on the other spheres. For example, Australia is prone to devastating droughts when there is not enough water available.

- **a** Describe how drought affects the biosphere. [2 marks]
- **b** Describe how this then affects the atmosphere. [2 marks]

Analyse and evaluate

10 As you now know, the biosphere includes parts of the lithosphere, the troposphere (the lowest part of the atmosphere) and the hydrosphere. Create a list of organisms you may find in each of these three spheres. [3 marks]

11 Evaluate whether upwelling is a natural event of the hydrosphere, atmosphere or biosphere. Justify your reasoning. [2 marks]

12 An iceberg melts, adding cold freshwater to the ocean. Predict how this water will move through the ocean water. Justify your reasoning. [2 marks]

Critical and creative thinking

13 Draw a mind map showing the potential connections and dependencies between the four spheres of the Earth and their components. Challenge yourself to find as many links as possible. [5 marks]

14 Using an example of a recent natural disaster, explain its impact on the Earth's four spheres. Consider short-term changes to the spheres and the long-term effects of these changes in each sphere. [5 marks]

TOTAL MARKS
[/35]

7.2 MATTER CYCLES AND INTERACTIONS BETWEEN SPHERES

To appreciate the importance of the Earth's spheres, it is necessary to consider how they interact with and depend on each other. Naturally occurring cycles connect the spheres, enabling a flow of matter and energy. These cycles include the water, carbon, phosphorus, oxygen and nitrogen cycles. Human activities influence these cycles and people have different opinions about how to best manage the natural resources in the Earth's spheres.

Figure 7.19 Water is a vital resource that cycles through the whole globe.

CYCLING WATER

Water is an essential part of life and is important for many metabolic processes in your body. It is continuously cycled between the biosphere, hydrosphere and atmosphere. However, this does not mean that there is a never-ending supply of water. This is because the water cycle (see Figure 7.20) is a *global* cycle. This means that water is not equally available in all ecosystems. For example, water that evaporates from the desert may later fall as rain on a forest thousands of kilometres away. For this reason, an ecosystem may have too little water (drought) or too much water (floods) for the organisms within it to continue to survive. This is why it is important to monitor and analyse the patterns of rainfall across the globe to make predictions about weather. The major processes in the water cycle are:

- evaporation from oceans and lakes
- transpiration of water through plants and out their leaves
- condensation
- precipitation
- infiltration
- run-off.

EXPERIMENT 7.2.1: MEASURING TRANSPIRATION

Aim

To observe the effect of environmental conditions on transpiration.

Hypothesis

Read the method carefully and write a hypothesis about the relationship between leaf conditions and rate of transpiration. Write your hypothesis as an 'If … then …' statement.

Materials

- Digital scale accurate to 0.1 g (or better)
- 4 broad, soft leaves (weeds or indoor plants work well)
- Zip-lock plastic bag
- Fan
- Retort stand
- String
- Pegs or tape
- Marker pen

Method

1 Number four leaves and record the mass of each.

2 Place leaf 1 in a zip-lock bag and use pegs or tape to suspend it from a line strung between two retort stands in a dark location in the classroom, such as inside a cupboard.
3 Suspend leaf 2 from the same line as leaf 1 in a dark location.
4 Suspend leaf 3 from a line in a sunny spot near the window.
5 Suspend leaf 4 from a line that is away from the window, but has the fan blowing on it. Make sure that only leaf 4 is affected by wind from the fan.
6 After 1 or 2 days, remove the leaves from the lines and bags. Record the final mass of each.
7 Calculate the percentage loss of mass for each leaf.

Results

Record the leaf masses and percentage losses in a suitable table. Describe any qualitative differences you notice between the leaves and other relevant observations.

Discussion

1 Analyse the effect of conditions on water loss in leaves.
2 Predict what would happen if you repeated this experiment with eucalypt leaves, which are adapted to conserve water.

Conclusion

Write a statement linking this experiment to the process of transpiration and the effect of weather conditions on the water cycle.

Clouds and rain

Water vapour (a gas) is the source of all clouds and precipitation, and is therefore one of the most important gases in the atmosphere when it comes to understanding atmospheric processes. Water vapour forms when water evaporates from rivers, lakes and oceans or from plant leaves (transpiration). Water vapour rises until it reaches the cooler parts of the atmosphere. The water vapour particles lose kinetic and heat energy to the cold air, and so vibrate less. The water vapour turns back into liquid water – condensation. These tiny drops of water then form into **clouds**.

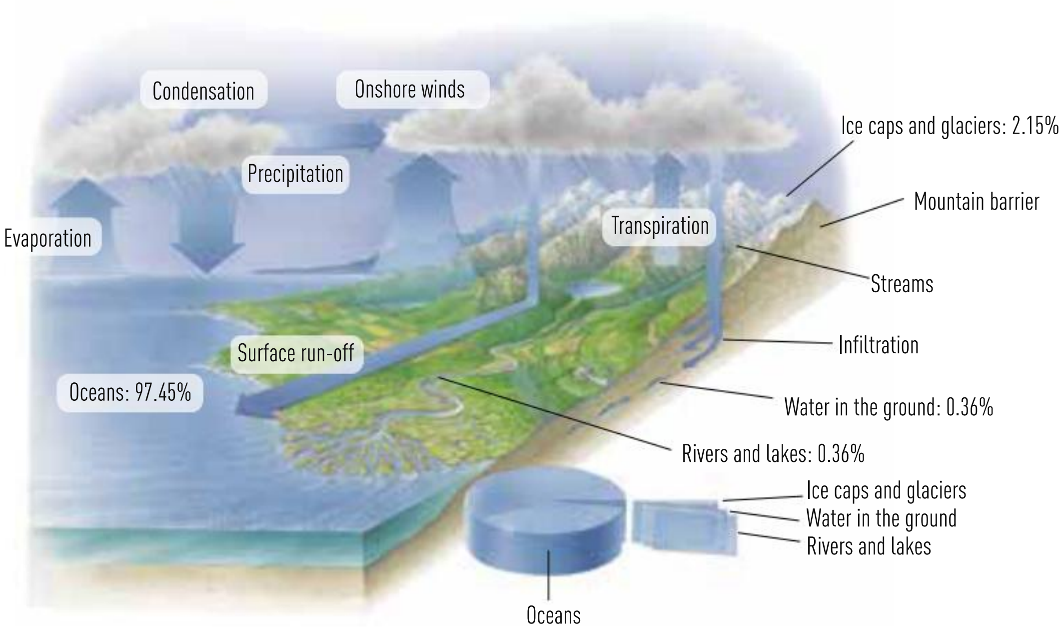


Figure 7.20 The distribution of water on the Earth and the water cycle.

The clouds may be carried onto land by winds and may be forced to rise when they reach a mountain barrier or another air mass. When the clouds rise further into colder air, the water droplets lose more energy and combine until the clouds can no longer hold the condensed droplets. The droplets then fall as **precipitation**, i.e. rain, hail or snow. The precipitation runs off into lakes and oceans or infiltrates into the ground. Ground water eventually flows to lakes and oceans, and the process begins again.

EXPERIMENT 7.2.2: MAKE YOUR OWN CLOUDS

Aim

To simulate the process of condensation and cloud formation.

Materials

- Ice cubes
- Heatproof mat
- Bunsen burner
- Tripod
- 250 mL beaker
- Gauze mat
- Evaporating dish or watch glass big enough to cover the top of the beaker
- Safety glasses
- Digital camera (optional)

Method

1 Set up the equipment as shown in Figure 7.21.

2 Add around 100 mL of water to the beaker and heat until it boils.

3 Turn the gas and the Bunsen burner off and place an ice-filled evaporating dish or watch glass on top of the beaker.

4 Carefully observe what happens. You may like to record or take photographs of the setup at various stages.

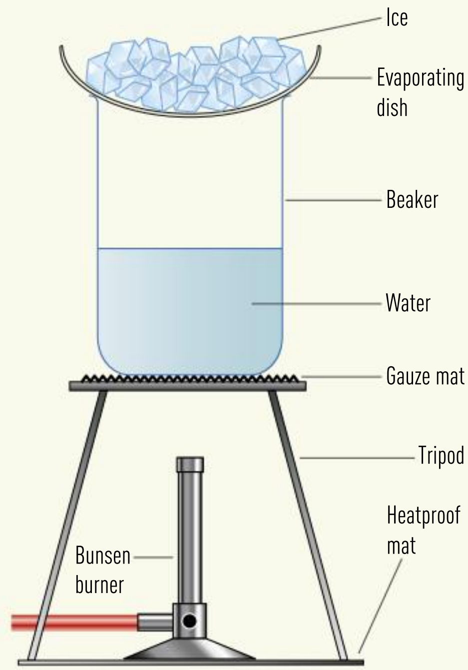


Figure 7.21 Experimental setup.

Results

Include your observations in an appropriate format.

Discussion

1 Describe how water vapour was produced.

2 Explain why the vapour became visible.

Conclusion

Write a brief statement linking this experiment to natural cloud formation in the atmosphere.

Water management

Fresh water is a precious resource in Australia. Waterways cross state lines, and actions in one community may influence the water supply thousands of kilometres downstream. The federal government has worked to develop a long-term plan to manage water in the Murray–Darling Basin and other areas of Australia. The plan has to balance the needs of different stakeholders.

Farmers need to irrigate their crops to produce food for people and livestock. When water supplies are limited, less food is available and the price of food rises. Farmers without adequate water may suffer such great losses that they give up farming altogether.

Waterways are an important part of Aboriginal Australian culture. Many groups traditionally lived along the banks of waterways that provided food, transport and building materials. European settlement ended traditional Aboriginal life along many of Australia's rivers and wetlands. Heavy water use for irrigation and damming of waterways has altered the flow of rivers and destroyed wetlands.

Many environmental scientists believe that enough water must be left in natural waterways to maintain the health of ecosystems. Impacts of heavy water use include increased salinity of river water, collapse of river banks, acidification of soil and mud, death of trees and plants, and the endangerment of many species of animals that live in or near rivers and wetlands. These environmental issues affect humans, by endangering the water supply of cities and reducing the groundwater in distant areas.

People living in cities need a reliable supply of fresh water. Reservoirs are fed from natural waterways. They need an adequate supply of water and that water needs to be clean to use for drinking.

Figure 7.22 Severe or prolonged drought can kill even large, well-established trees.

QUESTIONS 7.2.1: CYCLING WATER

Remember

1 Outline the processes in the water cycle. You may like to use a flow chart or diagram to show the different pathways water may take within the cycle.

2 Explain the difference between condensation and precipitation.

3 Describe the ways humans have changed the natural water cycle in Australia.

Apply

4 Identify all of the ways you use water both directly and indirectly (e.g. water for food crops).

CYCLING CARBON

Carbon is the fourth most abundant element on the Earth and is the basic component of all living organisms. It is the basis of carbohydrates, proteins, lipids and nucleic acids. Carbon can cycle through all four of the Earth's spheres over both long and short timeframes:

- Geological carbon cycle – this is a long-term cycle that occurs over hundreds to millions of years and has resulted in the bulk of carbon being locked in rocks or in sediments as fossil fuels.
- Biological/physical carbon cycle – this is a short-term cycle that occurs over days, weeks, months and years, and involves the cycling of carbon through photosynthesis and cellular respiration.

Humans tap into the geological carbon cycle by extracting oil, natural gas and coal, all of which are hydrocarbons, for use in cars and energy production. Large-scale extraction and the use of these fossil fuels has led to increased levels of carbon dioxide in our atmosphere. Coupled with an increase in deforestation, this increase in carbon dioxide has caused an **enhanced greenhouse effect**. The enhanced greenhouse effect is believed to have caused rising global temperatures and changing rainfall patterns. More information about the enhanced greenhouse effect is discussed later in this chapter.

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

Carbon is stored over the long term in the trunks, branches and other tissues of long-lived trees. It is also temporarily stored in the bodies of other organisms, such as herbivores or carnivores. Carbon is returned to the atmosphere as carbon dioxide when these organisms respire. When these organisms die, carbon is returned to the lithosphere as soil (organic carbon) by decomposers. All of these forms of trapped carbon are known as **carbon sinks**.

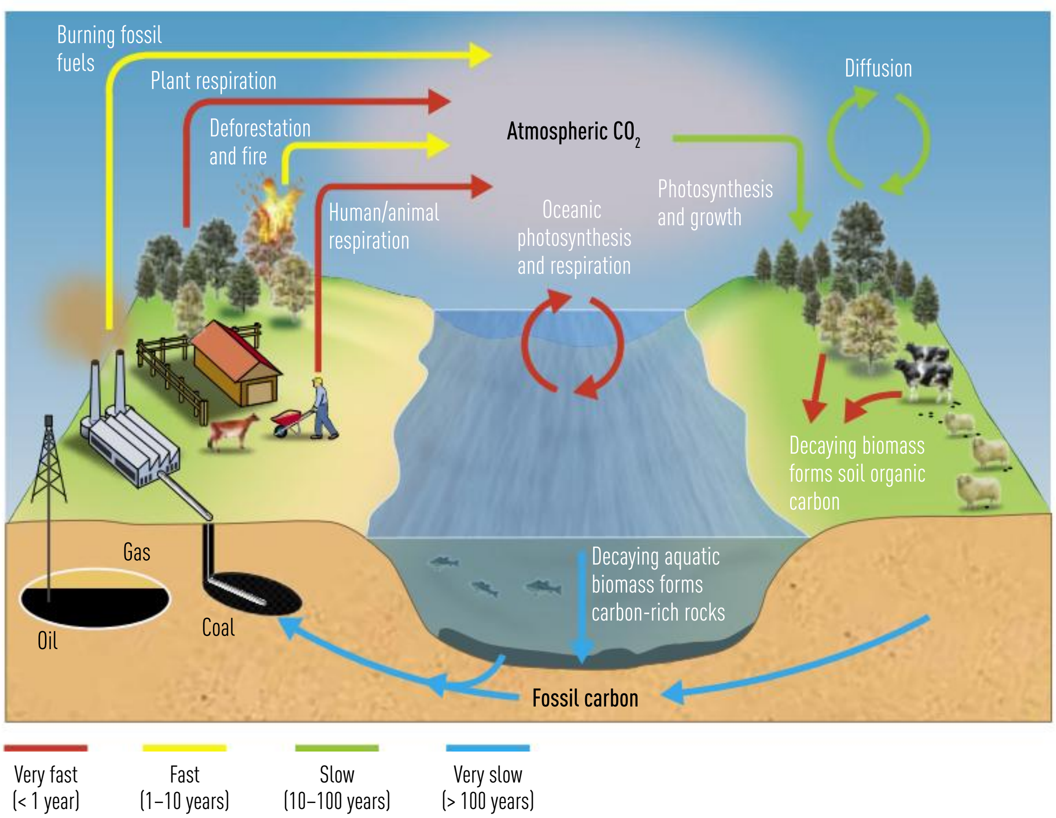


Figure 7.23 The carbon cycle and its various timeframes.

Carbon is also stored in carbon sinks, such as:

- fossilised decomposed organic matter, such as coal, natural gas, petroleum, shale oil
- rocks, such as limestone, marble, dolomite, chalk and other carbonates
- dissolved carbon dioxide in the oceans and other waters
- the shells of marine organisms and some terrestrial organisms.

Figure 7.24 Bushfires have a two-fold effect on increasing atmospheric carbon. The fire releases carbon dioxide and the death of the plants reduces the amount of carbon removed from the air through photosynthesis.

ACTIVITY 7.2.1: UNDERSTANDING THE CARBON CYCLE

What you need: A3 paper, coloured pens

1. In small groups, identify as many carbon sinks (which absorb carbon from the atmosphere) and sources (which release carbon into the atmosphere) as you can.
2. Brainstorm the processes by which carbon is transferred from one form to another.
3. On an A3 sheet of paper, create a mind map of the carbon cycle, showing the many forms of carbon and how it is transformed from one form into another.

- Compare your results to those of other groups in the class. Do they all look the same? How many ways can carbon move through the Earth's spheres?
- Consider the processes in the carbon cycle. Identify those that are fast (minutes to months) and those that are slow (many years).
- Are fast or slow processes more common?
- Is there a balance between the processes that release carbon and those that capture it?

Coal seam gas

Coal seam gas (CSG) has been mined in Australia for more than 30 years, but has recently come under public scrutiny as the industry expands operations. CSG is mainly composed of methane. The gas collects in coal deposits underground and is bound to coal particles. The coal seams are full of water and the pressure of this water keeps the gas stuck in a thin film on the coal.

In order to mine CSG, a well is drilled into the water in the coal seam, relieving the pressure so that the gas is released from the coal. The water and gas are pumped to the surface, where they are separated. The gas goes to a processing plant and the water to a water-treatment plant.

If the gas is tightly stuck to the coal, the process of fracture stimulation or 'fracking' is used (see Figure 7.25). A high-pressure mix of water, sand and chemicals is injected into the well in order to break the rock and release the gas. The mining of CSG, particularly by fracking, is highly controversial in the Hunter Valley, New South Wales.

Those in favour of exploiting CSG argue the following:

- Burning CSG as a fuel produces half the carbon dioxide of coal or oil, making it a more environmentally friendly fuel.
- Australia has large reserves of CSG, which can be exploited relatively cheaply.
- Fracking is a well-established process that has been used internationally for more than 60 years and in Australia for more than 15 years.
- Wells are encased in cement and steel to protect aquifers from possible water contamination.

- CSG production provides much-needed jobs and a resource for potential export.

Those opposed to CSG mining argue the following:

- Methane released from leaking gas wells and through surface sediments adds to the greenhouse effect.
- Gas extraction uses large amounts of water, which is highly polluted and unsuitable for re-use.
- There is the potential to break into and pollute groundwater aquifers during the fracking process.
- The steel casings can corrode and cement can crumble when exposed to saline water and high pressure during gas extraction.
- The process of gas extraction requires use of heavy equipment and can affect the surrounding environment, including farmland.

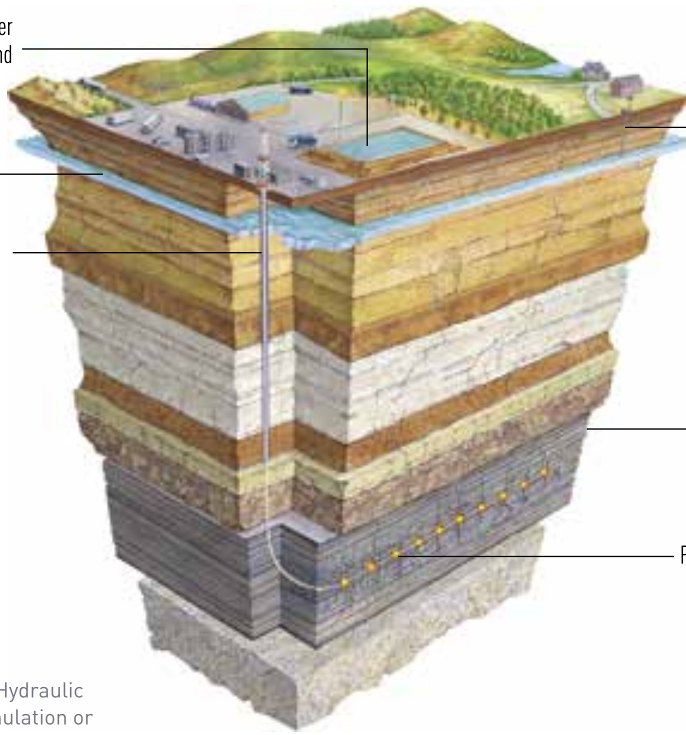


Figure 7.25 Hydraulic fracture stimulation or 'fracking' of coal seam gas.

QUESTIONS 7.2.2: CYCLING CARBON

Remember

1. List the four categories of molecules that contain carbon.
2. Identify the carbon-based compound that is most common in the atmosphere.

Apply

3. Explain how you are part of the carbon cycle.
4. Distinguish between the processes and time scale of the geological and biological carbon cycles.
5. List the carbon sinks and sources around your school.

Analyse

6. Identify the processes in the carbon cycle and, if applicable, describe how humans influence each process.
7. Do you think fracking to extract CSG should be allowed in the Hunter Valley? Which factors do you see as most important? Justify your answer.

CYCLING OXYGEN AND NUTRIENTS

The cycling of oxygen and nutrients through the Earth's spheres is essential to sustaining life. If every time we inhaled oxygen, it was lost from the atmosphere forever, all aerobic (oxygen-dependent) organisms would die and the biosphere as we know it would collapse. But this is not the case. Plants photosynthesise and convert carbon dioxide into oxygen, which they release back into the atmosphere. Similar interactions between the various spheres enable the cycling of the nutrients nitrogen and phosphorus that are vital for life.

The oxygen cycle

Oxygen is the essential reactant in cellular respiration, the process by which most organisms obtain energy for life. The Earth has a fixed supply of 'useful' oxygen even though it can be found almost everywhere. There are three main reservoirs of oxygen:

- the Earth's crust or lithosphere (99.5%)
- the atmosphere (0.49%)
- living organisms – the biosphere (0.01%).

In the atmosphere, oxygen exists as the molecules O_2 and O_3 (ozone) and in compounds such as water (H_2O) and carbon dioxide (CO_2). Oxygen is also able to dissolve into water, where it becomes available for uptake by aquatic organisms.

The oxygen cycle is influenced heavily by processes in the biosphere and atmosphere. In the biosphere, photosynthesis releases oxygen, and cellular respiration absorbs oxygen. In the atmosphere, oxygen is formed when UV light breaks down water and other oxygen-containing molecules in a process known as **photolysis**:

water + UV light → hydrogen + oxygen

$$2H_2O + \text{energy} \rightarrow 2H_2 + O_2$$

Oxygen is removed from the atmosphere through the processes of cellular respiration, the decay of organisms, fire and the chemical **weathering** (breaking down) of exposed rocks.

Figure 7.26 Almost all the oxygen on the Earth is locked in the compounds that make up the lithosphere.

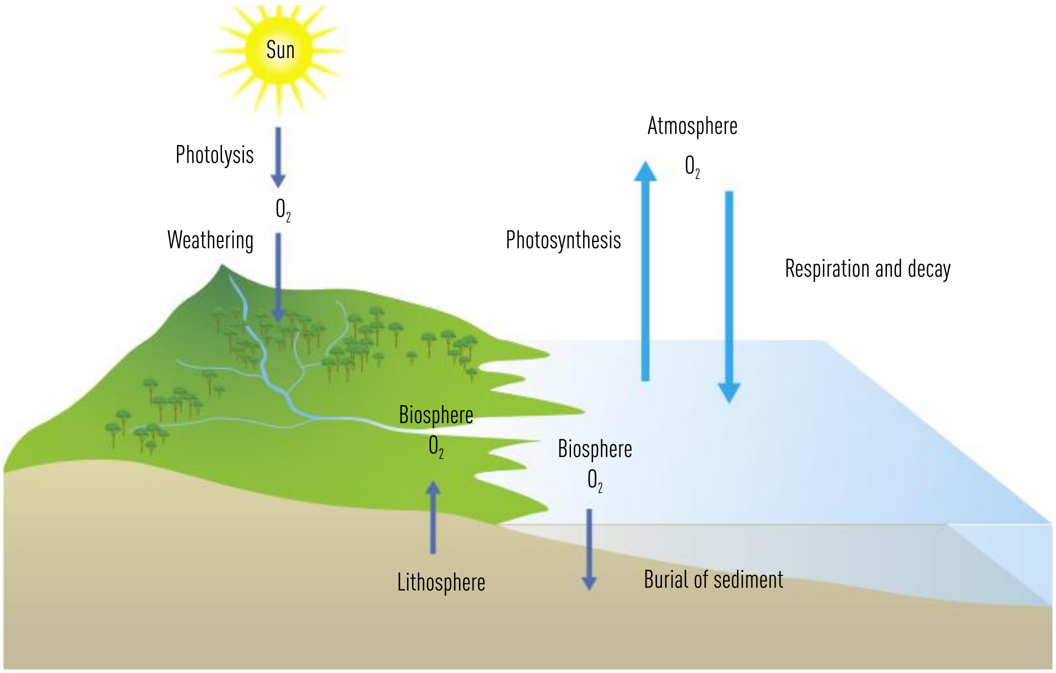


Figure 7.27 The oxygen cycle.

Figure 7.28 Legumes, such as peas and beans, have nitrogen-fixing bacteria living in the nodules on their roots. Consequently, farmers will often plant legumes between crops to maintain healthy nitrogen levels in the soil.

The nitrogen cycle

Nitrogen is necessary for the synthesis (construction) of proteins and nucleic acids, vital building blocks for all organisms. Although nitrogen gas (N_2) makes up around 78% of the gases in the atmosphere, it is not in a form that is usable for most living organisms. Bacteria play an important role in changing nitrogen gas into usable forms – nitrate, nitrite and ammonium ions – and returning it to the atmosphere.

Nitrogen-fixing bacteria are able to 'fix' or convert nitrogen gas from the atmosphere (N_2) into nitrate (NO_3^-) ions, nitrite (NO_2^-) ions and ammonium (NH_4^+) ions. **Denitrifying bacteria** are able to break down nitrogen-based compounds and return the nitrogen back into the atmosphere.

Many human activities increase the amount of nitrogen in the atmosphere, hydrosphere and lithosphere. In fact, humans have doubled the amount of global nitrogen fixation. Excess nitrogen from fertilisers leads to nutrient imbalance, algal blooms and decreased biodiversity. Human emissions of nitrous oxide (N_2O) have increased the concentration of this greenhouse gas and also resulted in more smog in our cities.

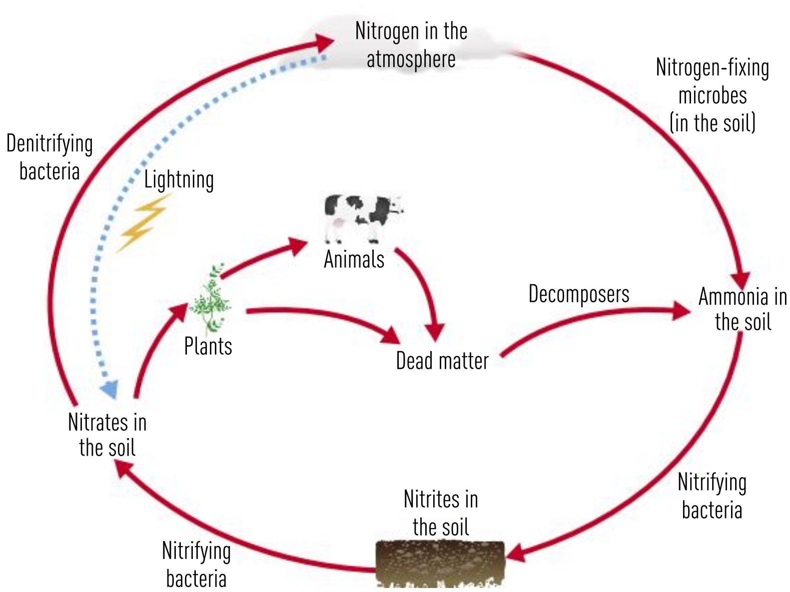


Figure 7.29 The nitrogen cycle.

The phosphorus cycle

Phosphorus is an essential component of the energy molecule ATP (adenosine triphosphate), as well as the molecules DNA and RNA. Without phosphorus, an organism cannot use available energy-containing molecules. Approximately 80% of the phosphorus in humans is stored in our bones and teeth.

Most of the phosphorus available to living organisms comes from sedimentary rocks and soils. Unlike in the other biogeochemical cycles, phosphorus does not have a gaseous phase. Phosphorus is not a common element and its availability is often the limiting factor for plant growth. Many native Australian plants are adapted to soil with low phosphorus, but farmers often need to apply phosphate fertilisers to crops.

The phosphorus cycle is the slowest of the biogeochemical cycles. Weathering and decay are lengthy processes compared to photosynthesis and respiration.

In the phosphorus cycle:

- rain breaks down rocks (weathering), releasing phosphate ions into the soil
- plants absorb phosphate ions via their roots and phosphorus enters the food chain
- phosphorus absorbed by organisms returns to the soil through urine, faeces and the decomposition of an organism's body
- phosphorus is locked in sediments and rocks for millions of years before being released by weathering and erosion, thus completing the cycle.

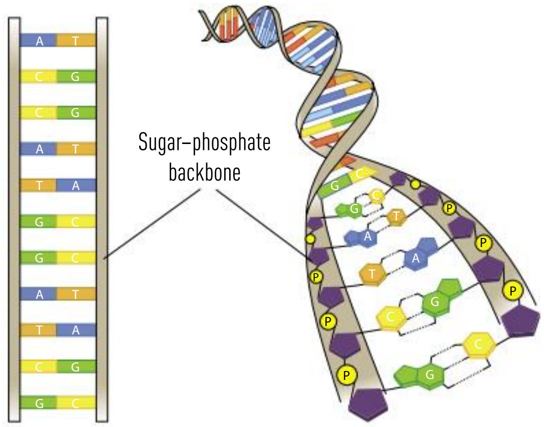


Figure 7.30 Phosphate, a compound of phosphorus, combines with sugars to form the backbones of DNA molecules.

Phosphorus is mined for use as a fertiliser. Run-off from agricultural land can lead to excessive levels of phosphorus in waterways. Because phosphorus encourages plant growth, excess levels lead to the increased growth of algae, phytoplankton and floating plants. The photosynthetic organisms grow quickly and spread out in a layer at the surface of the water, blocking sunlight from bottom-dwelling plants, which die. The decomposition of dead plants uses up oxygen in the water, causing fish and other aquatic organisms to die. This process is known as **eutrophication**. To reduce this problem, phosphorus is no longer included in most detergents.

Figure 7.32 The green may be misleading – this algal growth is blocking sunlight from all other organisms that live in this irrigation channel.

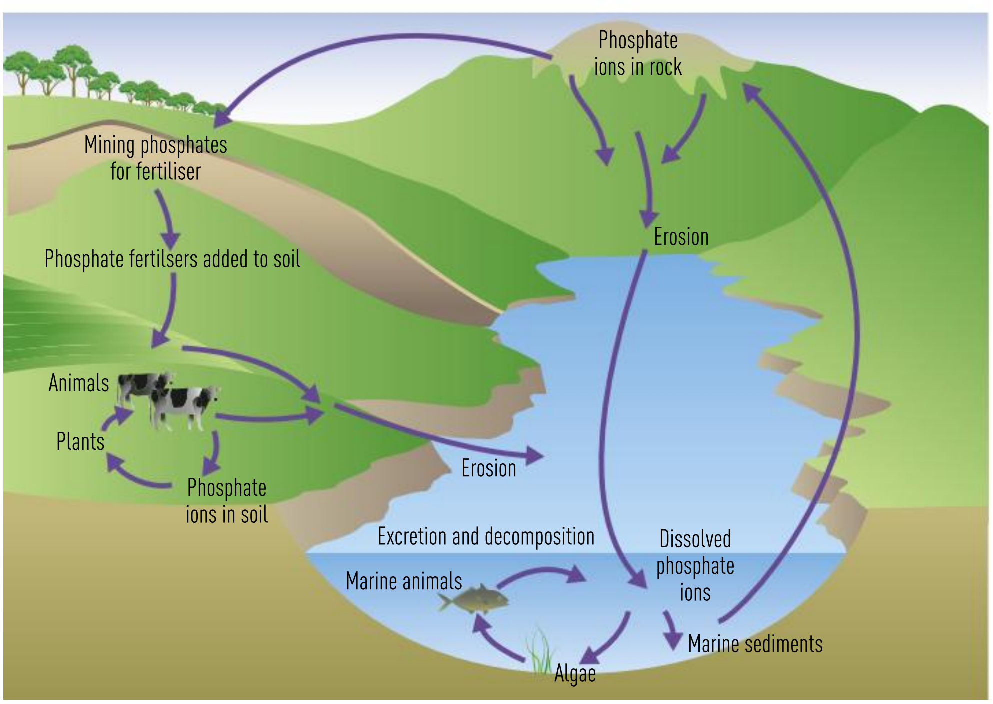


Figure 7.31 The phosphorus cycle.

Peak phosphorus

For most of human history, populations were small and crops were fertilised with human and animal waste, which contains phosphorus. The modern population explosion has been made possible by increased crop yields, largely due to synthetic fertilisers that contain nitrogen and phosphorus.

We have plenty of nitrogen in the atmosphere, but phosphorus is not so plentiful. Although manure is still used as a fertiliser, most high-intensity agriculture relies on mining phosphate rock. Some scientists estimate that phosphorus production will peak around 2030 and then begin declining. If production declines, the cost of fertiliser will rise, directly affecting food prices. Food production may fall, leading to famine in some parts of the world. Are we really going to run out of phosphorus in the near future? Suggested solutions to solve this phosphorus supply issue include:

- recycling our waste to re-capture phosphorus
- being more efficient in our use of fertiliser, as much ends up in waterways when it runs off from agricultural land
- genetically modifying food crops so they absorb phosphorus in the soil more efficiently and require less fertiliser
- promoting organic farming methods that use animal waste and decaying plant material to maintain phosphorus levels
- searching for additional phosphorus deposits to increase the world supply and delay the time of peak phosphorus production.

QUESTIONS 7.2.3: CYCLING OXYGEN AND NUTRIENTS

Remember

1 Identify three reservoirs of oxygen.

2 Where in your body is phosphorus mostly found?

3 Identify which two nutrients are commonly found in fertilisers and explain why crop plants often require artificial addition of these nutrients.

Apply

4 Explain why the cycling of nutrients is referred to as a 'biogeochemical' cycle. Use an example to explain your answer.

Analyse

5 Identify the best solution to the problem of peak phosphorus production. Justify your decision.

Create

6 Draw a concept map that shows the contribution of microorganisms to the cycling of nutrients in an ecosystem.

MATTER CYCLES AND INTERACTIONS BETWEEN SPHERES

7.2
CHECKPOINT

Remember and understand

1 List three processes in the water cycle and explain where each may occur. [3 marks]

2 Identify the processes that produce oxygen gas (O_2) that we can breathe. [1 mark]

3 Explain how nitrogen from the air is converted into usable forms. [2 marks]

4 Recall why organisms need phosphorus. [2 marks]

Apply

5 Nitrogen and phosphorus are both important nutrients in the biosphere, but they cycle through the spheres very differently. Compare the nitrogen and phosphorus cycles with references to the major sources of these nutrients. [3 marks]

6 Distinguish between water and water vapour. Would you find both in the atmosphere? Explain your answer. [2 marks]

7 Describe a small portion of the carbon cycle involving plants and animals. In your answer, clearly identify the forms in which carbon passes through this part of the cycle. [3 marks]

8 Identify which of the natural cycles is the most like a simple cycle with one step after another. Which is more like a web, with many possible paths from one form to the next? Justify your answers. [4 marks]

Analyse and evaluate

9 Many farmers apply manufactured fertilisers to their crops, supplying additional phosphorus and nitrogen. Outline the benefits and risks of fertiliser use, then assess the use of fertiliser in crop production. [3 marks]

10 Identify ways in which human activity has altered the natural carbon cycle. Using the terms 'sink' and 'source', describe the overall impact of humans on the global carbon cycle. [3 marks]

Critical and creative thinking

11 The Sun is responsible for much of the weather and climate of the Earth. The Sun also affects other cycles directly or indirectly. Brainstorm all the impacts of solar energy and represent these effects in a flow chart. [5 marks]

12 The Earth's cycles are the result of global interactions. Outline how this supports the argument that major environmental change in a particular country, for example logging a rainforest, is the concern of everyone on the planet. [4 marks]

TOTAL MARKS
[/35]

7.3 CLIMATE CHANGE

Modern humans evolved more than 150 000 years ago. In that time, the Earth has undergone many changes as humans moved from a hunter–gatherer lifestyle to agriculture and eventually to the industrial way of life we know today. Up to half of the Earth's land has been transformed by human actions, such as urbanisation and farming. Many of these changes have significantly altered the way energy and matter flow through the environment.

CLIMATE CHANGE AND THE ENHANCED GREENHOUSE EFFECT

Climate change is being talked about nearly everywhere we go: from families fleeing their homes from record-breaking floods to some of the worst bushfires we have ever seen. Changes to the climate as a result of natural and human influences are having many different effects on the face of the Earth.

The greenhouse effect and the enhanced greenhouse effect

The **greenhouse effect** is critical for maintaining life on the Earth. Solar energy passes through the atmosphere and warms the Earth's surface. Heat gradually leaves the Earth's surface and is radiated back into space. A blanket of greenhouse gases traps some of this heat. If no heat was trapped, the average world temperature would be around -18°C, rather than the more comfortable 15°C that we experience now.

Evidence from polar ice, among other sources, demonstrates that fluctuations in carbon dioxide and other greenhouse gas levels in the atmosphere are natural. The main greenhouse gases are water vapour, carbon dioxide, methane and nitrous oxide. Human activity has changed the balance of these gases and has added synthetic substances, such as chlorofluorocarbons – which are potent artificial greenhouse gases.

Figure 7.33 Environmental scientists take core samples from permanently frozen regions. Each year's snowfall compacts into distinct bands that can be analysed for greenhouse gas concentration.

Since the Industrial Revolution, the level of greenhouse gases has been increasing, causing an *enhanced* greenhouse effect. The enhanced greenhouse effect has been linked to an overall average increase in the planet's temperature, i.e. global warming. The concentration of carbon dioxide in the air has increased by approximately 38% since 1750. The bulk of that increase has happened since 1959. The concentration of methane in the atmosphere has also risen dramatically over the past century, more than doubling. Table 7.2 shows some other changes in climate.

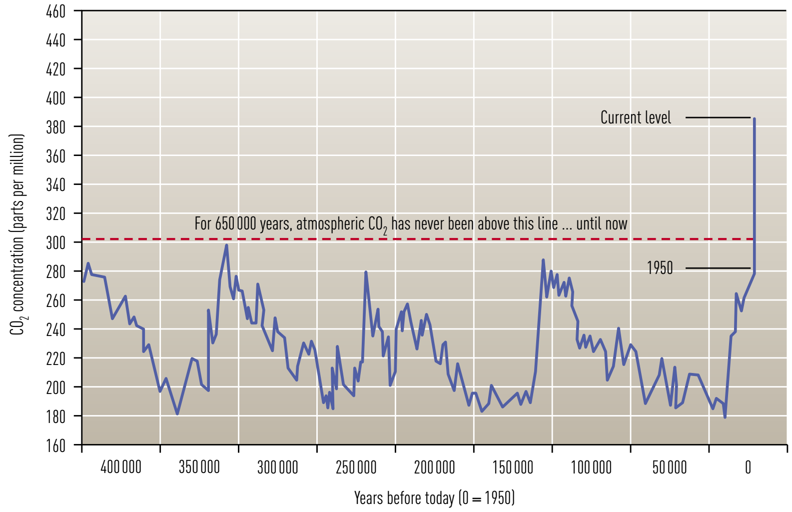


Figure 7.34 Changes in carbon dioxide levels in the atmosphere.

Table 7.2 Climate change trends.

Phenomenon and direction of trend	Likelihood that the changes occurred (typically since 1950)	Likelihood of a human contribution to the observed trend	Likelihood of future trends in the late 21st century
Warmer and fewer cold days and nights over most land areas	Very likely	Very likely	Virtually certain
Warmer and more frequent hot days and nights over most land areas	Very likely	Very likely	Virtually certain
Warm spells/heat waves; frequency increases over most land areas	Likely in Australia Medium confidence globally	Likely	Very likely
Heavy precipitation events; increase in the frequency, intensity, and/or amount of heavy precipitation	Likely	Medium confidence	Very likely
Increases in intensity and/or duration of drought	Likely in Australia Low confidence on a global scale	Low confidence	Likely
Intense tropical cyclone activity increases	Low confidence for long term, but virtually certain for North Atlantic	Low confidence	More likely than not
Increased incidence and/or magnitude of extreme high sea level (excludes tsunamis)	Likely	Likely	Very likely

IPCC, 2013: Summary for Policymakers, p. 5. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental panel on Climate Change* [Stocker, et al. (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Although water vapour is responsible for about half of the greenhouse effect, the amount of water in the atmosphere is dependent on temperature, with warmer temperatures leading to more evaporation and therefore more water vapour in the atmosphere. When greenhouse gases such as carbon dioxide and methane warm the atmosphere, water concentration also increases, amplifying their effect.

Carbon dioxide is the most important greenhouse gas that affects global temperature. The amount of carbon dioxide in the atmosphere has increased due to the use of fossil fuels to produce energy. We use this energy for heating, lighting, transport, industry and communications. Burning carbon-based fossil fuels, such as coal, gas and petroleum, releases energy, usually as heat, and produces carbon in the form of carbon dioxide, and sometimes carbon monoxide, or solid carbon particles.

Forests absorb carbon dioxide through the process of photosynthesis. Massive deforestation for farming and urban land has also led to an increase in carbon dioxide levels because these forests are no longer available to act as a carbon sink.

Natural sources of methane in the Earth's atmosphere include the decay of organic materials in wetlands, emissions from the oceans and the melting of methane hydrates, which are ices made of methane found in the ocean floor. Human activity also produces methane through increased emissions from livestock (e.g. cattle), landfill and waste treatment.

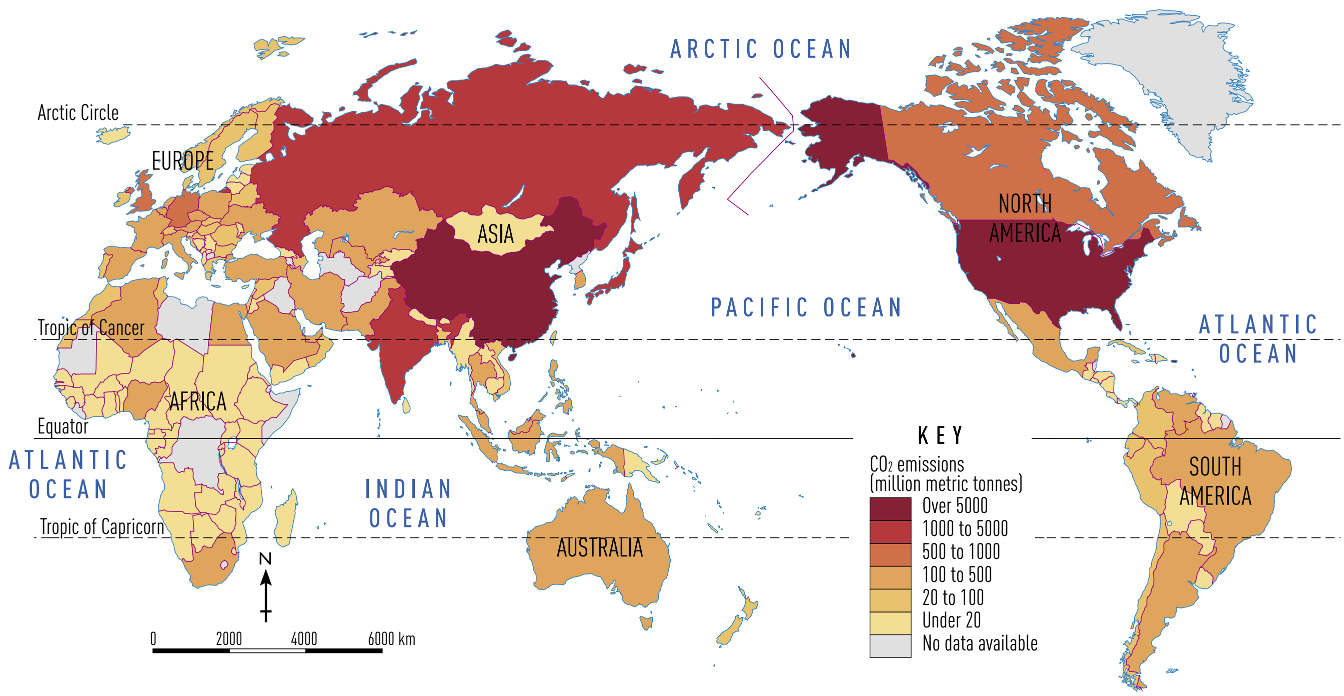


Figure 7.35 Global CO_2 emissions.

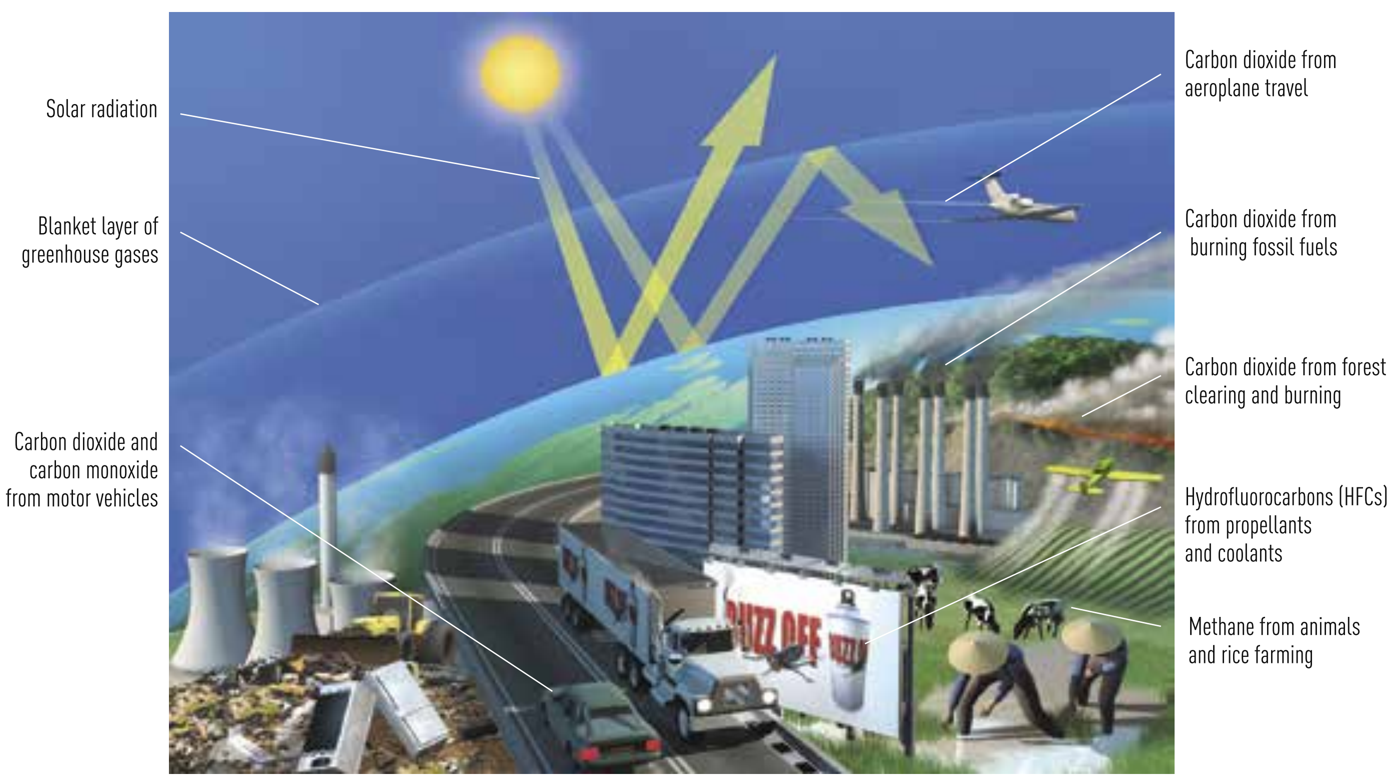


Figure 7.36 Human-induced climate change.

ACTIVITY 7.3.1: UNDERSTANDING THE ENHANCED GREENHOUSE EFFECT

What you need: poster paper, coloured pens

1 Working in small groups, brainstorm your understanding of the enhanced greenhouse effect.
2 Use this knowledge to produce a poster that shows:
    - how the atmosphere works to protect the Earth from getting too hot or too cold
    - how human activities are adding to the natural greenhouse effect
    - the impact of these human activities on ecosystems and organisms.

Evidence for climate change from increased carbon emissions

The evidence for a link between carbon dioxide and temperature comes from several sources. In recent times, we been able to take direct measurements, such as those made by thermometers and gas sampling at Mauna Loa, Hawaii. Hundreds of direct measurements have been made across the globe at weather stations. In addition, satellites and aircraft have been used to measure the temperature and concentration of gases in the atmosphere for the past 40 years.

Ice core samples from Vostok in Antarctica are used to measure gas levels and temperatures for the past 400 000 years. Tiny bubbles are trapped in the ice, allowing direct measurement of past carbon dioxide levels. The temperature is measured by using oxygen isotope ratios, which change with temperature. Information from the ice core samples allows scientists to see that carbon dioxide concentration and temperature have been closely linked in the past, as well as today.

Figure 7.37 A store of ice core samples at Vostok in Antarctica.

EXPERIMENT 7.3.1: WHAT FACTORS AFFECT A GREENHOUSE?

Aim
To determine which surfaces of the Earth absorb energy and radiate it as heat, and so are likely to contribute most to the warming of the atmosphere.

Hypothesis
Read the method carefully and make a prediction about which condition will increase in temperature the most. Formalise your prediction by writing an 'If ... then ...' statement as your hypothesis.

Materials
- 6 identical empty 600 mL clear plastic bottles
- 6 single-hole rubber stoppers with thermometers inserted that fit securely into the stopper, or data logging equipment using long steel temperature probes with Blu-Tack to secure the probe in place
- White paint
- Funnel
- 3 cups of dark soil
- 3 cups of white sand or perlite
- Water
- Sunlight or one 150 W floodlight bulb in portable reflector lamp

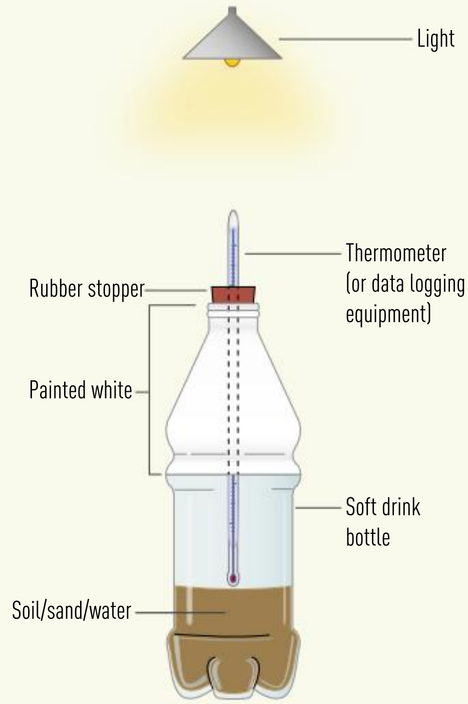


Figure 7.38 Experimental setup.

Method
1. For each group, you will need six experimental chambers; the empty bottles with the labels removed.
2. Label the bottles A, B, C, D, E and F. Paint the upper one-third of bottles B, D and F white to represent cloud cover.
3. Use a funnel to fill the base of bottles A and B with dark soil, bottles C and D with white sand or perlite, and bottles E and F with room-temperature water. Ensure that you use the same depth in each bottle – approximately 5–7 cm.
4. Put the thermometers inserted in the rubber stoppers into the bottle tops, ensuring the bulbs are just above the top of the dirt, water, perlite/sand. If the bulbs are below the base, they may record the heat absorbed directly by the soil or water, which will affect your data. You want to measure the temperature of the air (atmospheric temperature). If using a data logger temperature probe, secure and seal it into the top of the bottle with Blu-Tack.
5. Leave the apparatus for a few minutes until the readings have stabilised. Record the initial baseline atmospheric temperature of each bottle in a table.
6. If it is a sunny day, take your bottles outside and record the temperatures of each bottle in a table every 2 minutes for at least 20 minutes. Alternatively, set up the 150 W light source on a stand facing down. Place the bottles underneath the light source approximately 15 cm away from the lamp. It is important that all bottles receive equal light. Depending on your light source, you may be only able to do one or two bottles at a time. If this is the case, ensure the two bottles have the same base, for example, dirt.

Results

Draw a graph of time (in minutes) versus temperature to record your observations for each condition. You may like to use a graphing computer program to do this.

Discussion

1. Compare the graphs for the different bottles. Describe the differences. What do these graphs indicate?
2. Which situation produced the lowest temperature? Which situation would lead to the least heating of the atmosphere?
3. Suggest some possible explanations for your results.
4. Explain how this experiment demonstrates the effect of the oceans, and dark and light surfaces on air temperature.
5. If the deserts are increasing and ice is melting, exposing dark soil, what effects would you expect these changes to have on atmospheric temperature?
6. Explain the effect of clouds (bottles B, D and F) upon the greenhouse effect.
7. Discuss the reliability and validity of your results. Suggest ways in which to improve the validity and/or reliability of your data.

Conclusion

Summarise your key findings from this experiment.

QUESTIONS 7.3.1: CLIMATE CHANGE AND THE ENHANCED GREENHOUSE EFFECT

Remember

1. Name the two most significant carbon-containing greenhouse gases.
2. Explain why the gases you listed in question 1 are called greenhouse gases.
3. Explain why the normal greenhouse effect is actually a good thing for life on the Earth.

Apply

4. Identify three fossil fuels and three alternative energy sources that can be used for the same purposes.
5. Scientific evidence is considered stronger if there are many types of evidence supporting one conclusion. Does evidence for the link between carbon emissions and rising temperature come from only one source? Outline the type(s) of evidence for the link.
6. Copy and complete the following table, showing the direct uses of fossil fuels you make in a 24-hour period.

Activity	What did I use/do?	What fossil fuel provided the energy?
Transport		
Heating or cooling		
Cooking		
Communication		

EFFECTS OF GLOBAL WARMING

Global warming can have many effects on ecosystems, such as:

- changes in the distribution and abundance of species, e.g. the migration of species southwards or northwards, to higher elevations or to more suitable locations due to increasing temperatures
- species loss due to inability to adapt to rapidly changing environmental conditions
- changes in population variation as species adapt to new climatic conditions
- changes in the composition of ecosystems (e.g. due to species competition for resources or invasion of weeds/pests)
- increased weeds and other invasive species (i.e. pests)
- changes in life-cycle events (e.g. breeding, migration)
- increased coral bleaching (Figure 7.39), destruction of and/or changes to coral reefs
- a decrease in coastal/mountain rainforests
- changes in river flows, sediment formation and nutrient cycles
- flow-on effects, such as eutrophication and algal blooms
- drying of ecosystems
- ocean acidification.

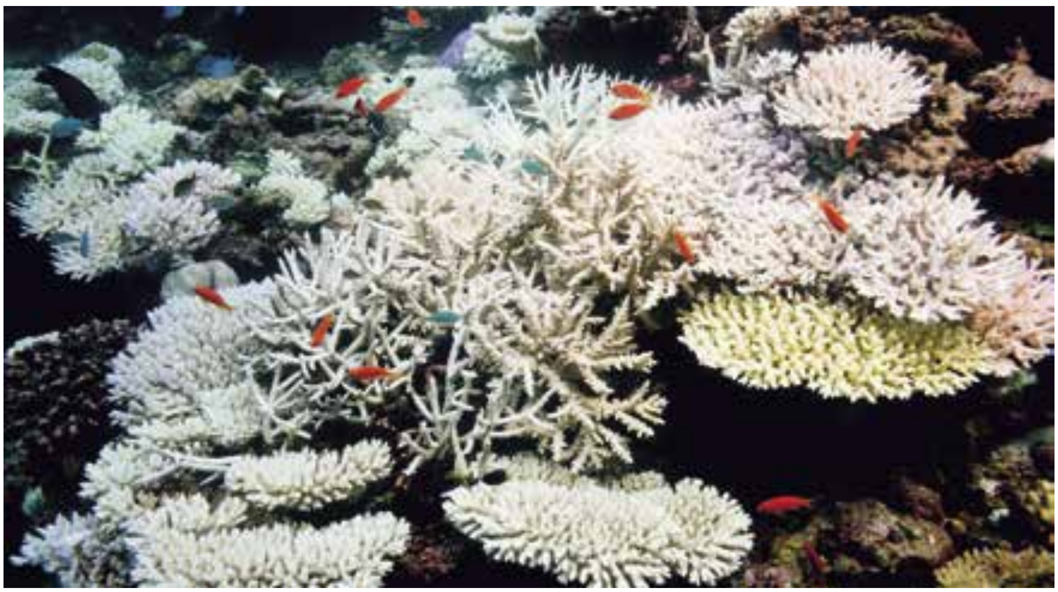


Figure 7.39 Coral bleaching along the Great Barrier Reef is likely to be the result of rising sea temperatures. The extremely temperature-sensitive symbiotic algae leave the coral, taking their colour and their ability to photosynthesise with them. Bleached coral does not survive long.

Figure 7.40 The mouth of the Murray River near Goolwa in South Australia. Recent years have seen a decrease in the amount of water flowing into the river and an overall increase in salinity, which affects plant and animal life.

LITERACY BUILDER

Cold-blooded climate change surprise

Monday, 28 May 2012
Stephen Pincock, ABC

Climate change may have a more unpredictable effect on the distribution of cold-blooded animals than scientists had previously thought.

Marine biologist Dr Amanda Bates and colleagues set out to explore how global warming will affect the distribution of animals such as fish, frogs and lizards.

'Although people had assumed that the ranges of species are limited by temperature, this had not been tested at a global scale,' says Bates, who worked on this study from Deakin University and the University of Tasmania.

In a new analysis, Bates and colleagues from Simon Fraser University in Canada report that things are not as simple as people assumed.

The researchers first looked at what temperature ranges 142 different animal species could live within. They then compared those findings with the actual temperature ranges where those species live in the wild.

Not filling their real estate

For cold-blooded animals living in the oceans, it turned out that the lab measurements and the real-world distribution patterns matched closely.

But the correlation was not so good on land. Terrestrial cold-blooded animals did not live as close to warmer equatorial regions as the laboratory research suggested they could.

'As my colleague Jennifer Sunday puts it, they're not filling their warm real estate,' says Bates. One factor is low rainfall in the hotter regions.

Surprises ahead

In the oceans, the researchers predict that animals will tend to move away from the equator in a relatively orderly way. On land, they predict a more chaotic response.

When the researchers collected 648 examples of climate-induced range shifts that have occurred around the world, they found that this was indeed happening.

As cooler areas warmed, animals on land have tended to move into newly comfortable regions. But they do not leave the warmer areas behind.

'On land, we're going to find that animals' ranges will stretch,' says Bates. 'That means that you're going to mix species up with animals they've never seen before. We're going to have some surprises.'

'We still don't have a clear picture of why animals live where they do on our planet,' she says. 'That's information we're going to need if we want to manage the effects of climate change on species distribution.'

Questions

1 Summarise this article in your own words.

2 Why do you think that the researchers studied cold-blooded animals when looking at the effect of climate change?

3 Do animals living in the oceans and those living on land use all of the habitats within their possible temperature range? Account for differences in their response.

4 Were the authors able to find cases of range shift in order to test their hypothesis? Describe their findings.

5 Discuss the possible effects of a range shift in which species of cold-blooded animals can live. Identify how this will affect food webs and ecosystems.

6 Analyse the validity of this article. What features indicate that it is a reputable source that is likely to have good information?

7 Identify some advantages of collaboration between researchers from Australia and Canada for this study.

Figure 7.41 How will the distribution of lace monitors in Australia change?

Increased global temperatures

Due to increasing concentrations of greenhouse gases, each of the last three decades has been successively warmer than any since 1850. The average global temperature has increased by 0.78°C from 1850 to 2012. Although 0.78°C may not sound a lot, we are already seeing the effects of this on our environment. This increase in temperature has led to an increase in the temperature of the oceans, causing a loss of glaciers and sea ice and an average rise in sea levels of 19 cm from 1901 to 2010.

Evidence that climate change is actually occurring includes:

- melting of the polar ice caps
- rising sea levels
- increasing intensity and frequency of storms and bushfires
- changes to weather patterns.

Temperature and climate changes affect the survival of plants and animals in certain habitats, the carrying capacity of ecosystems (the number of organisms ecosystems are able to sustain), the amount of light available for photosynthesis and the rate of biogeochemical cycling of nutrients.

ACTIVITY 7.3.2: RESEARCHING EL NIÑO AND GLOBAL WARMING

Ocean temperatures are rising on average due to global warming. Will warming ocean temperatures affect El Niño and the Southern Oscillation? Will Australia experience more dramatic climate fluctuation or less?

Research the factors that affect El Niño and the Southern Oscillation and the impact of global warming on these factors. Present your findings in a poster with diagrams explaining the El Niño effect or prepare a news segment telling the 10-year climate forecast for Australia.

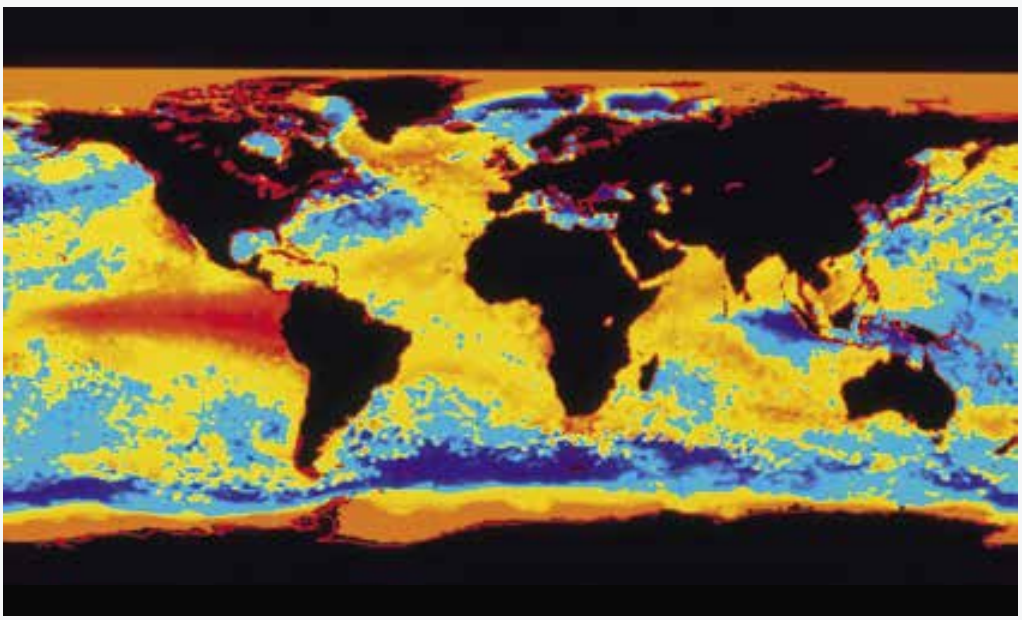


Figure 7.42 A satellite image showing the 1997 El Niño event in the east Pacific Ocean. The difference between normal sea temperatures and those during the El Niño are shown as purple (furthest below normal) through blue and yellow to red (furthest above normal).

Melting sea ice

The ocean is very important in the regulation of global temperatures and climate control. It is a carbon sink, absorbing around one-third of the carbon dioxide emitted by humans every year. The ocean also absorbs up to 90% of the solar radiation that hits the ocean. It would certainly be a lot warmer on the Earth if it didn't! Unfortunately, with all the changes occurring to the Earth, the ocean is losing its capacity to regulate global temperature and it is starting to warm up.

Warmer water in the ocean reduces the ocean's ability to absorb solar radiation. The warmer water expands, causing sea levels to rise. It also causes sea ice to melt. Sea ice is vast, shiny and bright white. It acts as a big mirror that reflects the sun's radiation back out to space, once again keeping the Earth cooler. When this ice melts, more heat is absorbed by the water, increasing its temperature. The warmer water heats the atmosphere above it, and so a cycle has begun that increases global temperature. Sea ice and glaciers are melting more quickly every decade.

The warming ocean water is resulting in melting of ice in the Arctic – ice which is home to many species. For the first time ever, scientists are finding drowned polar bears. After swimming for days and days without rest, trying to find ice thick enough to climb on to, exhausted polar bears are drowning out in the ocean.

Figure 7.43 Arctic sea ice.

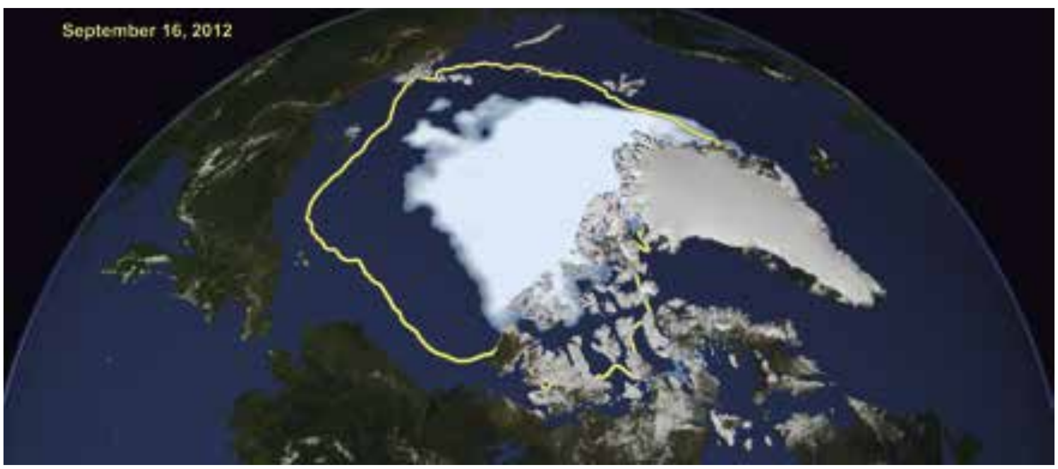


Figure 7.44 In September 2012, Arctic sea ice reached its smallest extent since satellite measurements have been available. The yellow line is the average minimum for the past 30 years.

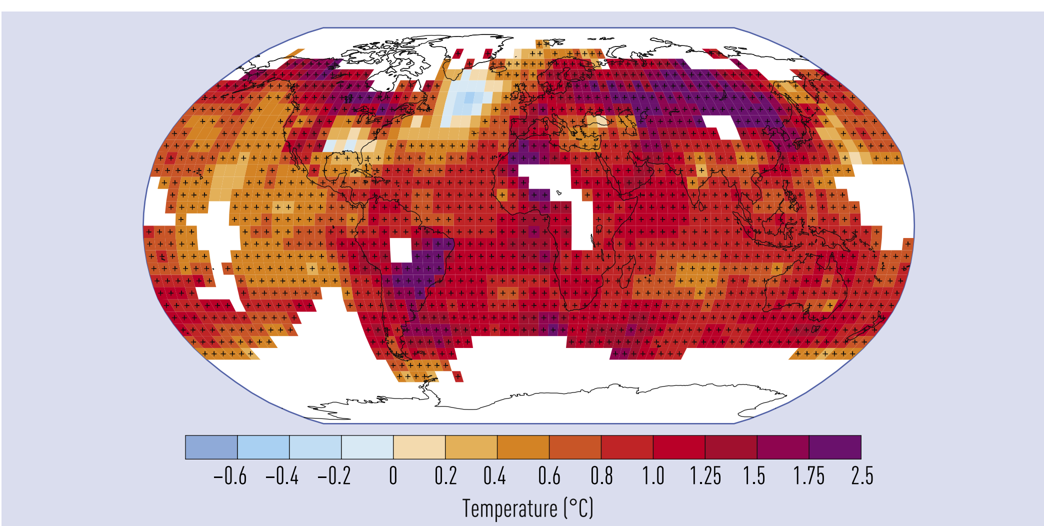


Figure 7.45 Global changes in average surface temperature between 1901 and 2012.

ACTIVITY 7.3.3: THE GULF STREAM

1 Re-read the information on deep ocean currents on page 292. These natural deep sea currents can be disrupted. This occurred 12 800 years ago when a huge lake was created from melting glaciers at the end of the last Ice Age overflowed and poured into the north Atlantic, blocking the Gulf Stream.

2 Research the Gulf Stream and where it is positioned now. Consider any water sources nearby that may disrupt the Gulf Stream. What would have to happen for these to interact with the Gulf Stream? Is this likely to occur and to what effect?

STUDENT DESIGN TASK

Melting ice and its effect on sea levels

Challenge: Sea ice is floating ice, like the ice found in icebergs or pancake ice. Sheet ice and glaciers are ice that rests on top of land. Your challenge is to design an experiment that compares the effects of melting sea ice with the effects of melting land ice.

Questioning and predicting

- Before you start, write an appropriate aim and hypothesis to test.

Planning and conducting

- Plan your method, identifying the variables that should be kept constant.
- Identify the dependent and independent variables of your experiment.
- Make an equipment list to give to your teacher.
- Identify any risks that may be associated with your experiment and address how to minimise these risks.
- Carry out your experiment and record your observations. How can you ensure your data is reliable and valid?

Analysing and problem solving

- Collate and summarise your data.
- Identify which results support or disprove your hypothesis.
- Assess the validity and reliability of your data.
- Use a cause-and-effect relationship to explain the links between melting ice and rising sea levels.
- Describe how your experiment models the effect of melting sea and land ice in the real world. What will happen if all the sea ice melts? What if all the land ice melts?
- Suggest how to improve your experimental design.

Communicating

- Present your findings as a full scientific report.
- Present your data in tables and graphs as appropriate.
- Using your findings as evidence, write a conclusion that explains the relationship between increased global temperatures, melting ice and rising sea levels.

Evidence for rising sea levels

Long-term trends in sea levels are measured using evidence from coral reefs and geological structures. These trends show a fluctuation of greater than 100 m between glacial (ice age) and interglacial times. During the last ice age, the sea level was 120 m below the current levels because a vast amount of water was stored in continental ice sheets.

In order to determine the sea level for the past few thousand years, scientists look at evidence such as ancient Roman fish tanks, salt marshes and wave-cut rocks. These many lines of evidence indicate little change in sea level for the past few thousand years until the start of the 19th century.

Since 1992, satellite altimeters have made highly accurate sea level measurements. These measurements indicate that the average global sea level is rising by 3.2 mm/year. However, the rise is not the same everywhere. Sea levels have risen more in warmer areas like the western Pacific and changed little in cooler areas. This pattern, shown in Figure 7.46, reflects heat storage in the oceans.

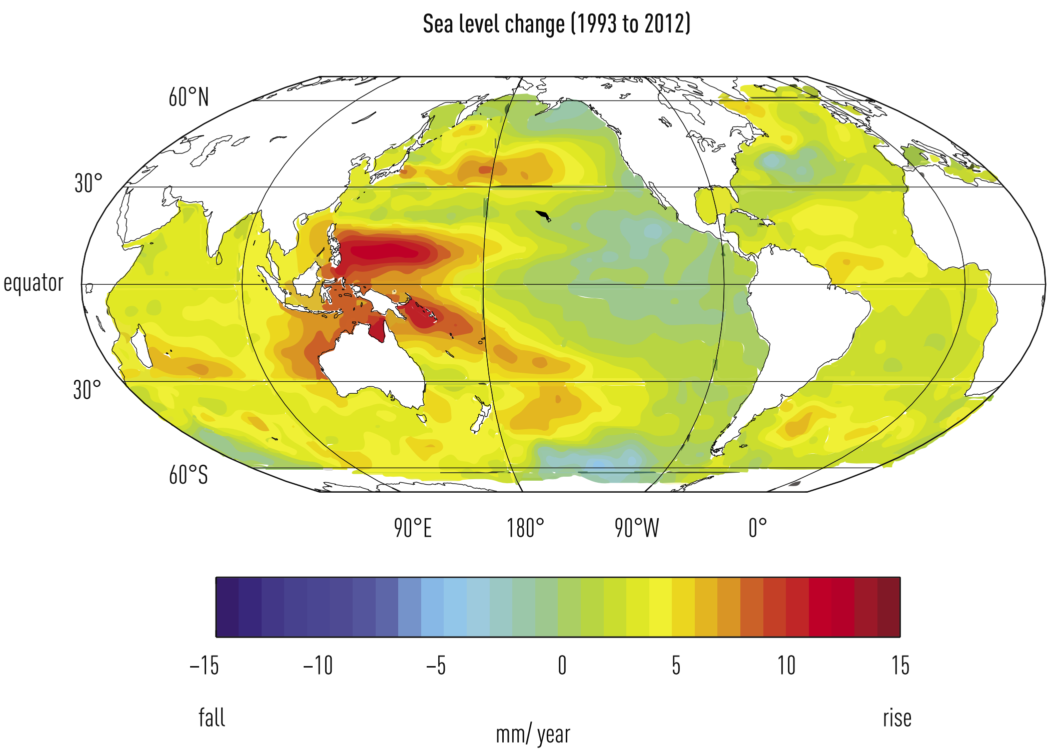


Figure 7.46 Sea level changes from 1993 to 2012 show greater rises in the western Pacific near Australia.

Predicting future trends

Scientists gather data from many different sources to understand how climate and ecosystems have changed over time. This information is also helpful for predicting the future. Scientists develop computer models by applying basic laws of physics and test these using data from the past. They then run the simulation into the future to predict what will happen. Computer models are constantly updated with new data in order to make the simulations more accurate. The better that models fit with past events, the more likely they are to give an accurate prediction of the future.

You created a simple computer model in the Science Skills on page 287 and used it to predict the temperature deep in the Earth.

ACTIVITY 7.3.4: MODELLING AUSTRALIA'S CLIMATE

The Australian Community Climate Earth-System Simulator (ACCESS) is a computer model of the Earth's climate developed by scientists for the Australian government. It helps provide information about weather and climate in Australia.

Research the ACCESS model to answer these questions.

1. Why does Australia need its own computer model for climate?
2. What sort of questions can be answered using ACCESS?
3. What information is included in the model now? What may be added in the future?

QUESTIONS 7.3.2: EFFECTS OF GLOBAL WARMING

Remember

1. Identify which type of ice increases sea levels if melted. Explain why this is the case.
2. What was the average increase in global temperature over the past century?
3. Explain how climate change will affect the temperature on the Earth.
4. Explain the effect of global warming on sea levels.

Apply

5. Outline the techniques used to measure sea level in the distant past, during human history and in the past 20 years. Evaluate the accuracy of each group of techniques.

Analyse

6. In your own words, explain what 'an average increase in global temperature' really means for different parts of the planet. Explain why some places may experience decreased temperatures.
7. Consider the list of effects on ecosystems caused by climate change on page 320. List these in order from what you think is the most to least critical. Justify your decision.

LONG-TERM EFFECTS OF HUMAN ACTIVITIES

It is difficult to separate the effects of human activity on the natural environment from unpredictable or even long-term cyclic natural events. This is because all the systems and cycles on the Earth are connected in some way. Some relationships are complex and some more straightforward. Many human activities directly affect one sphere of the Earth, but have a 'flow-on effect' to other cycles or spheres.

Human impact on the ozone layer

The ozone layer in the stratosphere protects us from harmful UV rays. Ozone (O_3) absorbs UV radiation and so a thinner ozone layer allows more harmful UV light to reach the Earth causing skin cancers in people and animals, as well as damage to plants.

Normally, ozone is formed and destroyed in a balanced amount, maintaining a high enough concentration to protect terrestrial life. Ozone forms oxygen gas and a molecule of oxygen as it absorbs the energy of UV rays:

$$O_3 \xrightarrow{\text{UV light}} O_2 + O$$

The molecule of oxygen is known as a free radical and reacts readily with additional oxygen in the atmosphere to re-form ozone:

$$O_2 + O \rightarrow O_3$$

Thus the chemical reaction of ozone formation is naturally reversible:

$$O_2 + O \rightleftharpoons O_3$$

Scientists first began noticing a thinning in the ozone layer in the 1970s. Each year, less and less ozone was being regenerated to restore the natural balance of ozone in the atmosphere. Figure 7.47 shows the low values of ozone (referred to as a 'hole'), in blue and purple, over Antarctica.

The main cause of the thinning of the ozone layer over the Earth was the use of CFCs, or chlorofluorocarbons. These chemicals were used in aerosol spray cans and refrigeration units. Scientists discovered that the CFC molecules were diffusing up through the atmosphere until they reached the ozone layer. There, the CFCs reacted with ozone, breaking it down much faster than its natural cycle, and prevented more from forming again.

This was a big issue for the whole world because so many people use aerosol cans and refrigeration in their daily lives. The issue became widely talked about and was reported extensively in the media.

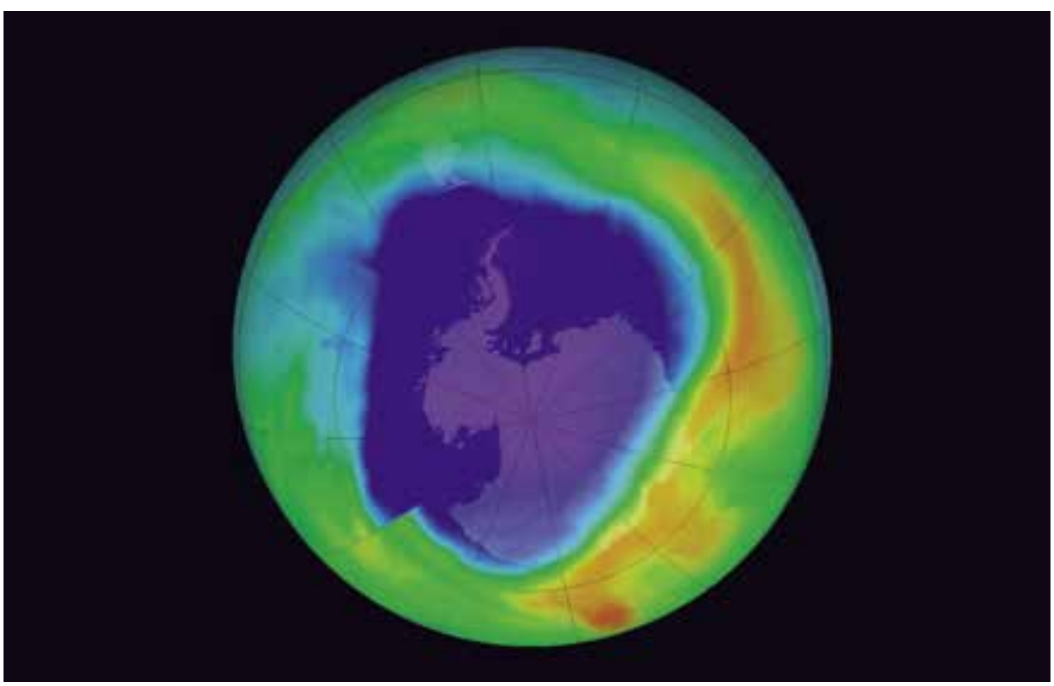


Figure 7.47 The hole (shown as blue and purple) in the ozone layer over Antarctica in 2013. The 'hole' is actually a thinning of the layer, rather than a complete absence of ozone.

NUMERACY BUILDER

Documenting the ozone hole

Table 7.3 shows satellite data collected by NASA from 1980 to 2012. Satellites measure the ozone concentration over Antarctica and scientists used this information to calculate the size of the 'hole' – the area with very low concentrations.

Table 7.3 Ozone concentration over Antarctica, 1980–2012.

Year	Average area of the ozone 'hole' (million km^2)
1980	1.4
1982	4.8
1984	10.1
1986	11.3
1988	10.0
1990	19.2
1992	22.3
1994	23.6
1996	22.7
1998	25.9
2000	24.8
2002	12.0
2004	19.5
2006	26.6
2008	25.2
2010	19.4
2012	17.9

Data from *NASA Ozone Hole Watch*.

Questions

1. Plot the year on the horizontal axis and the area of the ozone hole on the vertical axis of a graph. You may like to use a computer graphing program.
2. Draw a curve of best fit through the data.
3. Describe the overall trend, or pattern, of the data.
4. During what time period did the hole in the ozone layer increase in size the most quickly?
5. Many scientists think that the ozone layer is beginning to recover from the damaging effects of CFCs. What evidence in the data supports this conclusion? What would you hope to see in the next several years to indicate that the ozone layer has really recovered?
6. Using the data in your graph, evaluate the outcome of efforts to limit CFCs and promote recovery of the ozone layer.

The Montreal Protocol

In the late 1980s, an international treaty called the Montreal Protocol was drafted. The protocol set a timeline for countries to phase out the production and use of CFCs and other ozone-depleting substances. Developing countries had slightly later targets than the more affluent nations, who could perfect the technology to replace CFCs and then pass it on. The treaty was ratified by 197 countries and is considered to be the most successful international agreement. Most ozone-depleting substances have been phased out and the ozone layer is beginning to recover, with full recovery predicted by 2050. The Montreal Protocol showed that many nations really can work together to save the world!

Other international agreements

The Montreal Protocol was arguably the most successful international agreement designed to improve our global environment. The successful negotiations and positive international response prompted many more international meetings to improve the environment. Some of these are summarised in Table 7.4.

These conferences and treaties set ambitious goals for protecting our environment. They have helped to promote understanding and cooperation among different nations, as well as spurring businesses and governments to take actions that improve the environment.

Table 7.4 International environment conferences and treaties.

Year	Treaty	Aim
1992	United Nations Conference on Environment and Development (Earth Summit)	To promote sustainable development. Governments and businesses recognised the need to make policies that take into account environmental impact, as well as economic factors. This is especially true for urban planning and development of future infrastructure. The summit led to the Climate Change Convention (which led to the Kyoto Protocol) and the Convention on Biological Diversity.
1997	Kyoto Protocol	To reduce greenhouse gas emissions. During the first commitment period (2008–2012) the goal was to reduce emissions to an average of 5% below 1990 levels. During the second period (2013–2020), the goal is to reduce emissions to 18% below 1990 levels.
2009	United Nations Climate Change Conference (Copenhagen Summit)	To reduce greenhouse gas emissions and global warming. The conference recognised the challenge of climate change and that actions should be taken to keep temperature increases to below 2°C.
2012	United Nations Conference on Sustainable Development (Rio +20 or Earth Summit 2012)	To review progress and move forward with sustainable development on an international scale. The conference set goals for sustainable development and green economic policies.

Loss of biodiversity

Australia is one of the most biologically diverse countries. Species that are found only in Australia (i.e. are endemic to Australia) include:

- 85% of our flowering plants
- 84% of our mammals
- 89% of our temperate zone fish
- 45% of our birds.

Australia's biodiversity is under stress from human behaviour, such as land use, changing river and stream flows, soil salinity, invasive species, overharvesting of commercially valuable species and changes to fire regimens. Climate change is an additional stress. Australia's record of extinctions in the past 200 years is among the worst in the world, with more than 60 plant, 27 mammal, 23 bird and four frog species extinct since European settlement. Many more species are critically endangered.

There are many reasons why animals become extinct or endangered. Thylacines were out-competed by dingoes on the mainland and then hunted to extinction in Tasmania. The Norfolk starling died out as a result of competition from introduced bird species

Figure 7.48 Many species around the world are at risk of extinction as a result of human activities and climate change, including (a) polar bears and (b) emperor penguins, which live in extreme cold climates and rely on ice formation.

and land clearing. Dust from mining has destroyed much of the nesting habitat of the Christmas Island frigatebird, leaving it critically endangered. Frogs are in crisis worldwide and the causes of their decline are poorly understood. The elegant frog lives only on one mountaintop in Queensland, leaving it very vulnerable to climate change and habitat loss. The Murray cod is threatened by overfishing, competition with introduced fish species and changes to river flows.

Plants have also suffered since European settlement, with more than 60 known species becoming extinct and 1180 threatened.

Figure 7.49 Stephens Island wren was thought to have been wiped out by a lighthouse keeper's cat in 1894. It is more likely that the species was hunted to extinction by feral cats on the island.

Changes to drought and flood patterns have threatened the survival of many plants, as have changes to the natural fire regime. Hard-hoofed animals trample native vegetation, compacting the soil, which prevents seedling growth and encourages soil erosion. Invasive weed species have had devastating effects on native plants. Weeds compete for space and resources or stop native plants from recovering after disturbance. Fertilisers, pesticides and pollution of waterways further threaten native vegetation.

Ecosystems are destabilised when their community (the range of different organisms present) is changed or when they are fragmented by human activity. The loss of one or two key species can have flow-on effects, which lead to the loss of many more. One example is the impact of fishing at Clifton Gardens in Sydney. The removal of many large fish has led to an underwater ecosystem dominated by sea urchins, voracious herbivores that eat encrusting algae. These areas, called urchin barrens, offer little habitat for small fish and have low biodiversity. At nearby Balmoral Beach, there is less fishing. As a consequence, sea urchin numbers are kept under control by large fish and the habitat features a large amount of kelp-like algae that provides habitat for small fish and other animals.

Figure 7.50 Many frog species, like this Blue Mountains tree frog, are under threat of extinction from habitat loss and changes to rainfall patterns.

Figure 7.51 It is almost certain that this albatross died because it ate plastic while fishing at sea.

Long-term effects of waste management

When city governments first began to collect rubbish, it was taken to a large pit to be burned and/or buried. This was a reasonable solution when there was plenty of land around cities, but today there are billions of people who need space to live and land on which to grow food, and who produce increasing amounts of waste.

Plastics and many other types of rubbish release toxic substances when burned, so incinerators are a poor choice for disposal. Organic waste in landfill releases methane, a powerful greenhouse gas, as it decomposes. Cities try to compost organic waste rather than letting it decompose in landfill. Methane generated in landfill is collected by pipes and burned, sometimes generating useful power. Glass, paper, metal and plastics can be recycled, so most local councils collect these items separately and send them for recycling rather than to landfill. The great variety and volume of rubbish generated by modern households does not have one simple solution.

Waste that is not properly disposed of poses an even greater threat to the long-term health of the environment. Plastics are a major source of contamination in marine environments. Scientists studying the ocean around Antarctica have found 40 000 pieces of plastic waste on average in every square kilometre of ocean. This pollution entangles and kills more than 100 000 marine mammals in the north Pacific every year. In combination with salt and UV light, plastics release toxic chemicals into the water, which are taken up into the food chain and eventually find their way onto our tables in the fish we eat in a process called bioaccumulation.

Figure 7.52 Many changes are happening to the Earth and its climate, many of which have been contributed to by human activities.


The temperature of oceans to depths of 3000 metres is increasing. Warmer water expands leading to a rise in sea levels. Sea levels rose by about 17 centimetres last century.
Mid-latitude westerly winds have strengthened in both the northern and southern hemispheres. Together with the increase in ocean temperatures, this leads to larger storms and cyclones happening more often.
Extreme temperature events have changed, with fewer cold snaps and frosts and more heat waves and hotter nights.
There is a change in ocean salinity: increased saltiness near the Equator and decreased saltiness closer to the poles, possibly due to changing evaporation and precipitation patterns.

Recycling e-waste

Recycling does more than reduce the amount of waste in landfill and the environment; it also creates up to ten times more jobs than just relying on landfill! The materials that make up phones, computers and other electronic items, known as e-waste include different types of plastics, metals (including toxic mercury and lead) and glass.

There are many job opportunities in e-waste recycling. Materials must be collected and sorted. Technicians take apart devices and delete any stored information in device memory. Specialist engineers design equipment that sorts different types of metal, glass and plastic, and ovens that melt metals and plastics at different temperatures to separate them. Mercury and lead are recovered in specialised centres because these metals are toxic if released into the environment or dumped in landfill. Metals are reused in manufacturing, reducing the need for mining as well as reducing waste. There is more gold in a tonne of computers than in a tonne of ore at a gold mine!

QUESTIONS 7.3.3: LONG-TERM EFFECTS OF HUMAN ACTIVITIES

Remember

1 Describe the importance of the ozone layer.

2 List three factors that may threaten biodiversity and name at least one Australian species that has become extinct or endangered due to each factor.

3 Explain why hard-hooved animals are a threat to native plants.

4 List the different materials that may be found in e-waste.

Apply

5 The media had a big part to play in getting CFCs banned. Suggest why the media is so important in communicating environmental issues.

6 Describe how the loss of one or two species from an ecosystem can affect the entire ecosystem.

Analyse

7 Evaluate the impact of household plastics on each of the Earth's spheres.

8 The Montreal Protocol has been very successful in phasing out CFCs, leading to ozone layer recovery. Analyse the role that CFCs played in everyday life and manufacturing. Were CFCs really necessary? Does the role of CFCs make it easier to replace them? Justify your answer.

CLIMATE CHANGE

7.3
CHECKPOINT

Remember and understand

1 List the ways that increasing industrialisation, particularly since the 19th century, has affected ecosystems. [3 marks]

2 Identify the human activity that you think has most significantly affected the environment. Justify your answer. [3 marks]

3 List some of the consequences of climate change. [3 marks]

4 Explain how the Montreal Protocol offers a model for solving global problems. [2 marks]

Apply

5 The glaciers on Mount Kilimanjaro, Tanzania, are disappearing eight times faster than they were 20 years ago. Explain how cloud cover can affect the atmospheric temperature and hence the melting of glaciers. [3 marks]

6 The Montreal Protocol was enacted in 1987, but CFC concentrations in the atmosphere continued to increase for years after they had stopped being manufactured. Suggest a reason why this may be the case. [2 marks]

7 Suggest why agreements like the Montreal Protocol must be an international effort. [2 marks]

8 Compare and contrast the greenhouse effect, the enhanced greenhouse effect and global warming. [3 marks]

Analyse and evaluate

9 The human population was fairly stable until about AD 1. Then it started to grow, its growth accelerating year after year. In the past century, the human population has almost quadrupled. Discuss the likely effects of the continued population increase on world ecosystems. [2 marks]

10 Find out about biomass as an alternative source of renewable energy. Evaluate whether this would be a good alternative to fossil fuels. [3 marks]

Critical and creative thinking

11 Compare past waste management strategies with that in your community today. [2 marks]

12 If you had to reduce your energy use, which appliance or gadget in your home would you not want to give up? Create an A4 page outlining why this one item is 'essential' to you and then make a list of appliances and gadgets that you could live without. [4 marks]

Research

13 The northern bettong (see Figure 7.53) is a very small, endangered nocturnal marsupial. It is an omnivore that eats small invertebrates, herbs, grasses and a species of fungus, which makes up approximately 45% of its diet. Northern bettongs were once widely distributed throughout Queensland. However, there are now only three populations left along the western edges of the wet tropics of north Queensland. Use the Internet to research the northern bettong. Create a list of human activities you think are contributing to the northern bettong being listed as endangered. [3 marks]

Figure 7.53 The endangered northern bettong.

TOTAL MARKS
[/35]

7 CHAPTER REVIEW

1 Fill in the gaps, using the words in the Word Bank below.

The Earth's spheres include the ____________ (land), atmosphere (air), ____________ (living things) and hydrosphere (water). Natural events like a volcanic eruption may affect several spheres, as lava becomes new rock for the lithosphere, gases are released into the ____________, and volcanic ash enriches the ____________, affecting the biosphere.

The Earth's spheres interact through ____________ of matter. These natural cycles may be affected by human activity and resource use. ____________ management is a major issue in Australia, as rivers are heavily used for irrigation.

Human activity has had a great impact on the ____________ cycle and has led to the ____________ greenhouse effect. This has caused global ____________, affecting ecosystems and weather patterns. Extinction of animals and plants leads to a loss of ____________ and may result in ecosystem collapse. Some environmental problems are now being addressed. One example of this is the Montreal Protocol, which phased out CFCs in order to help the ____________ layer recover. New technologies have led to new jobs, such as in e-waste ____________.

WORD BANK

atmosphere	cycling	recycling
biodiversity	enhanced	soil
biosphere	lithosphere	warming
carbon	ozone	water

Describe the effects of natural events on the Earth's different spheres

2 Describe how a cyclone affects each of the Earth's spheres. [4 marks]

3 Describe how the movement of tectonic plates causes changes to the lithosphere. [2 marks]

4 Outline the ways in which a volcanic eruption might affect cycles of matter on the Earth. [2 marks]

Examine the links between deep ocean currents, climate regulation and marine life (additional content)

5 Regions of ocean upwelling account for only 1% of the area of the oceans, but are responsible for more than 20% of the fish catch. Explain why there are more fish in upwelling areas. [2 marks]

6 Propose changes to fish populations if deep ocean currents change direction. [2 marks]

Outline how global systems, like the carbon cycle, rely on interactions between the Earth's spheres

7 Refer to the diagram of the water cycle on page 301. Make a table listing processes by which water enters the biosphere, atmosphere and lithosphere. [3 marks]

8 Outline two processes that move matter from the lithosphere to the atmosphere. [2 marks]

Discuss how different groups in society may make decisions about contemporary issues involving the interactions between the Earth's spheres

9 Identify two different groups of people who would advocate different ways to meet the world's phosphorus demands and outline the reasons for each solution. [4 marks]

10 India has a high population and a rapidly growing economy. Australia has a relatively low population and a well-developed economy that is

slowly growing. Analyse the effect of population and economic development on each country's approach to global warming. Discuss the ways in which the governments may differ in their response to reducing greenhouse gas emissions. [4 marks]

Evaluate the scientific evidence for the results of human activities on global systems

11 Human activity has changed Australian fire regimes. Traditional Aboriginal Australian societies burned small areas to promote regrowth of vegetation and to provide grazing for herbivores. European settlers allowed few fires to burn, leading to less frequent, but hotter and more damaging fires. Research the effect of fire intensity on native vegetation and compare the effect of these two fire regimes. [5 marks]

12 Identify what you can do today, this week, this month and this year to reduce your impact on the Earth's systems. Share your ideas with the class and keep track of your progress as a group. At the end of the month, calculate your impact as a group. Propose ways to encourage your school to adopt more planet-friendly practices. [5 marks]

Research evidence of links between weather pattern changes and global warming including El Niño and La Niña (additional content)

13 List two ways the weather is being affected by global warming now and one effect that is likely to happen by the late 21st century. [3 marks]

14 Outline the effects of El Niño on eastern Australia. [2 marks]

15 Explain how global warming will affect normal El Niño events. [2 marks]

Discuss some of the international biodiversity and climate change agreements (additional content)

16 Scientists reported the 'hole' in the ozone layer over Antarctica in 1985. By 1987, the Montreal Protocol had been drafted and countries agreed to phase out ozone-depleting substances. Why was an international agreement necessary to fix this problem? Explain why Australia was particularly keen to fix the ozone layer. [5 marks]

17 The Earth Summit of 1992 was not focused on one problem, but aimed to promote sustainable development. Explain how a meeting on sustainability would lead to the Kyoto Protocol to reduce greenhouse gas emissions. [2 marks]

Research how computer modelling is used to monitor and predict changes in global systems, like ocean salinity, climate change and atmospheric pollution (additional content)

18 Recall the Australian Government's climate change model and outline its use. [2 marks]

19 The Bureau of Meteorology uses computer modelling to predict weather patterns. Use the Bureau's website to research one type of computer model used and describe its use. [2 marks]

Outline examples where advances in science and technology generate new career opportunities (additional content)

20 Describe ways in which the quick turnover of computers and phones provides employment opportunities and can minimise environmental damage. [3 marks]

21 Propose a career that may become available in 10 or 20 years as we develop different ways of generating electricity and manufacturing goods. Identify key skills that will be useful for this future job and write an advertisement to recruit applicants. [4 marks]

TOTAL MARKS
[/60]

7 CHAPTER REVIEW

RESEARCH

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

Peak oil

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

Carbon capture and storage

One measure that has been proposed to decrease the amount of carbon dioxide we are adding to the atmosphere is to capture and store it. What does this mean? How will it work? Explain some of the options being considered for storing carbon dioxide.

Responding to climate change

The Kyoto Protocol is an international agreement that aims to stabilise greenhouse gas emissions in the atmosphere at a level that would prevent danger to the Earth's climate system. In late 2007, Australia's newly elected Prime Minister Kevin Rudd ratified (fully agreed to) the Kyoto Protocol. Australia has set a target to reduce greenhouse gas emissions by 60% on 2000 levels by 2050. To date, the United States, the world's largest emitter of greenhouse gases, has not ratified the agreement. What does this mean for the effectiveness of the agreement? Which other countries are also not assisting and what might their motives be? Justify your answer.

Global cooling after explosive volcanic eruptions

When the Indonesian volcano Krakatoa erupted in 1883, the sulfide aerosols and fine ash ejected into the atmosphere caused months of unseasonably cold weather, spectacular sunsets and prolonged twilight around the planet. These sunsets inspired some famous works of art (see Figure 7.54) in Europe. How can a volcanic eruption cause cooling? There are serious proposals to mimic this effect in order to combat the global warming trend. Discuss the advantages and disadvantages of this strategy.

Figure 7.54 The eruption of Krakatoa, Indonesia, in August 1883, resulted in spectacular sunsets as far away as London, UK. This painting by William Ascroft was done in November 1883.

REFLECT

7 CHAPTER REVIEW

Me

1 What new science laboratory skills have you learned or improved on in this chapter?

2 What was the most surprising thing that you learned about the Earth's spheres and climate change?

3 What were the most difficult aspects of this topic?

My world

4 Why is it important to understand global matter cycles?

5 Why do all countries need to work together to address issues like ozone depletion and global warming?

My future

6 Why is changing the way humans interact with ecosystems and how humans use energy important for the future of the global ecosystem?

KEY WORDS

abiotic
atmosphere
biosphere
biotic
carbon sink
climate
climate change
cloud
crust
cryosphere
cyclone
denitrifying bacteria
earthquake
ecologist
ecology
El Niño
enhanced greenhouse effect
eutrophication
geologist
greenhouse effect
greenhouse gas
hydrosphere
igneous rock
inner core
La Niña
lithosphere
mantle
metamorphic rock
nitrogen-fixing bacteria
ozone
photolysis
precipitation
sedimentary rock
tectonic plate
vent
volcanic eruption
water vapour
weather
weathering

7

MAKING CONNECTIONS

The dynamic Earth

One of the greatest concerns about the effects of climate change is the effects on humans. Many populations will be forced to relocate and standards of living will change as resource availability decreases.

Climate change will have a significant effect on the planet's biodiversity. Biodiversity is also directly affected by human activities. The graph in Figure 7.55 highlights the plight of a range of species, including plants, from the International Union for Conservation of Nature (IUCN) Red List of Threatened Species.

Your task

1 Critically analyse the species in the graph, thinking about the reasons for the proportions displayed by each taxa. Global cycles, human impact and other causes should be considered.

2 Select a taxon or species to investigate in greater detail. Some examples of endangered species are presented in Figures 7.56–7.64. Present your research and critical analysis in a format that will engage your intended audience and promote thought and behavioural change.

Some questions to consider:

- What impact could its extinction have on other species?
- How are humans responsible?
- Why is it endangered?
- Why is this an important species?
- Which species are more likely to be saved?
- How is climate change responsible?

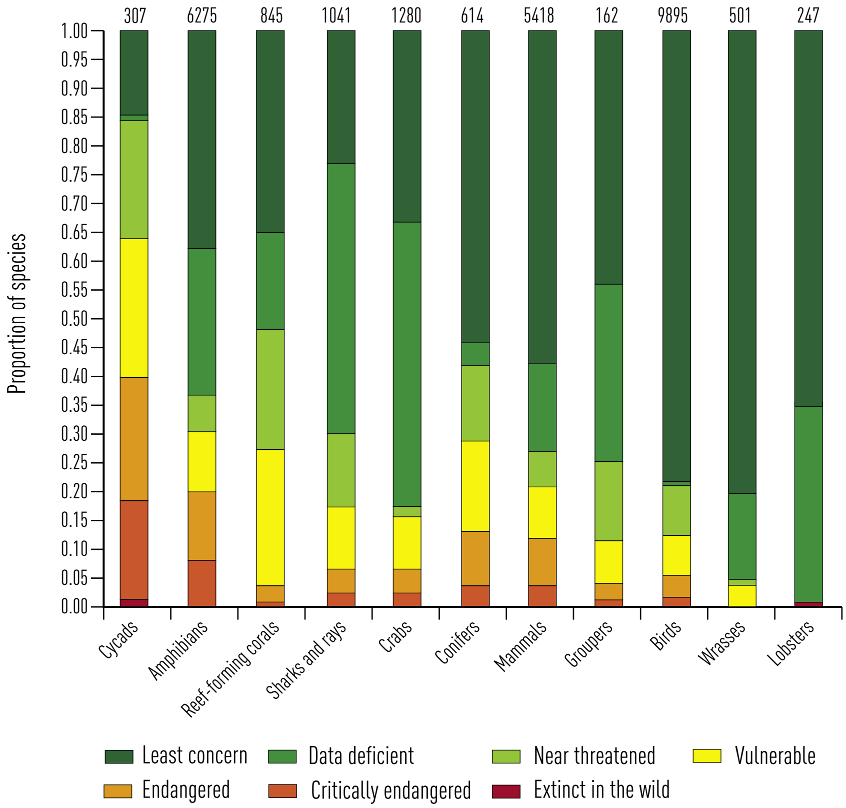


Figure 7.55 The proportion of extant (i.e. excluding extinct) species in *The IUCN Red List of Threatened Species. Version 2013.2* assessed in each category for the more comprehensively assessed groups. Taxa are ordered according to the horizontal red lines, which show the best estimate for proportion of extant species considered critically endangered, endangered or vulnerable. The numbers above each bar represent the total number of extant species assessed for each group.

Figure 7.56 Orange-bellied parrot.

Figure 7.57 Speartooth shark.

Figure 7.58 Lord Howe Island phasmid.

Figure 7.59 Port Davey skate.

Figure 7.62 Oxeylan pygmy perch.

Figure 7.60 Leaf-scaled sea snake.

Figure 7.61 Glenelg spiny freshwater crayfish.

Figure 7.63 Western swamp tortoise.

Figure 7.64 Southern bent-wing bat.

8

INDEPENDENT RESEARCH PROJECT

As part of your scientific studies, you will need to carry out an independent research project. This task will require you to combine all your understanding and knowledge of science so far to complete your own first-hand investigation, just like a real research scientist. But how do you go about this seemingly daunting task? One step at a time!

HOW AND WHERE TO START 8.1

The essential component of a good science project is the topic you choose. You will need to complete some background research to help you determine what topics are appropriate for you to investigate and which ones may be too difficult to complete at school.

Students:

- develop questions and hypotheses to be investigated
- apply scientific understanding and critical thinking to suggest solutions to problems

FAIR TESTS AND EXPERIMENTAL DESIGN 8.2

How do you ensure that an experiment is fair? How do you know that you are gathering valid and reliable results? It is important to determine the independent and dependent variables of your experiment as well as identifying some of the variables that need to be controlled.

Students:

- produce a plan to investigate questions, hypotheses or problems
- undertake first-hand investigations and collect valid and reliable data and information

DEALING WITH DATA AND REPORT WRITING 8.3

How do you collect the data from your experiment? Once you have gathered your data, what do you do with it? Data needs to be analysed in some way that will make sense to your project. Additionally, you will need to discuss the data that you have gathered to help explain the trends in the data. You will also need to complete a final report so that you can present your findings to a wider audience.

Students:

- process, analyse and evaluate experimental and secondary data to develop evidence-based arguments and conclusions
- present scientific evidence to support conclusions using appropriate scientific language, conventions and representations

8.1 HOW AND WHERE TO START

For a successful research project, you need to ensure that you plan your research and experiments carefully before you start. First, decide what topic you would like to investigate. Background research needs to be done to gather as much existing information about your topic as possible and to determine what results you can expect from your experiment. But how do you know whether the information you access is correct?

PROJECT IDEAS

There are many places you can go to find interesting topics to research. Perhaps a friend told you that their steel water bottle keeps water cooler for longer than your plastic water bottle? Or you may have wondered why your parents always water the plants at sunset. A quick Internet search of 'science fair projects' may also give you some starting ideas.

Some project ideas are better than others. As this task is designed to be a long-term project, you need to find an idea that has more than one aspect that can be tested. You may need to design a number of experiments, each modified on the basis of the results of the previous experiment. Additionally, it is important not to research topics that investigate people's 'preferences' or require direct testing on animals.

Run through the following checklist to make sure that the project topic you choose is appropriate. You may also wish to discuss your project idea with your teacher in case they have additional or special requirements.

Project topic checklist

1. Is it a project I can do safely and independently?
2. Can I complete the project in the required timeframe?
3. Is the project on a topic that interests me?
4. Is the project of an appropriate complexity for my year level?
5. Does the project involve animals?
6. Will I need special equipment or chemicals in the experiment?

If the answers to questions 1–4 are 'yes', then you should start to consider what additional materials you may need and start planning your experiment(s). If the answers to questions 5 to 6 are 'yes', then you may need to reconsider your idea.

Figure 8.1 The first step is often the hardest. What will you choose to research?

QUESTIONS 8.1.1: PROJECT IDEAS

Remember

1 Identify where you are likely to find project ideas.

2 Suggest a reason why projects need to be of an appropriate complexity for your year level.

Apply

3 Propose a reason why you would not be able to work with animals.

4 Evaluate the following experiments for their feasibility (i.e. whether they can be completed or not). Explain why you have come to your decision.

   a How does the number of blades on a wind turbine affect the amount of electricity it produces?

   b How does the amount of fertiliser in soil affect the growth of a plant?

   c How does the amount of detergent used in washing affect the drying rate of clothes?

   d Does grey water affect the corrosion rate of copper pipes?

   e What type of dog food does my pet dog prefer?

   f How do soil conditions affect decomposition rates?

Figure 8.2 What effect does the number of blades on a wind turbine have on the amount of electricity it can produce?

WORKING TO A TIMELINE

You will probably have at least 4 weeks to complete your project. Construct a timeline to help you stay on track. Allocate enough time to complete the practical component of the project and allow an appropriate length of time to work on the report itself. Keep in mind that disasters may occur even when you try to plan for everything. Your little sister or brother may decide that your pot plant needs more water; your pet cat or dog may dig up plastics you may have buried; the computer could crash and you may lose your saved work. So, it is always a good idea to factor in some extra time to redo aspects of your project, and back up any electronic work in multiple places!

Table 8.1 shows two suggested timelines: one for a longer project, one for a shorter project.

Table 8.1 Suggested project timelines.

Time (weeks)	Shorter project	Longer project
1	Choose topic. Start background research. Work out an appropriate aim.	Choose topic. Start background research.
2	Identify the variables, design experiment(s) and discuss with your teacher. Organise equipment that you may require from either stores or your school.	Continue background research and work out an appropriate aim.
3	Start experiments and collect results.	Identify the variables, design experiment(s) and discuss with your teacher.
4	Continue experiments and collecting results. Analyse the results. Identify sources of error such as sample size and selection, measurement errors, or poor control of variables.	Organise equipment that you may require from either stores or your school.
5	Write a draft report and obtain feedback from your teacher.	Refine your experiment, including variables that should be controlled and whether replication trials can be done at the same time.
6	Edit the draft report and submit the finalised report.	Start experiments and collect results.
7		Identify sources of error such as sample size and selection, measurement errors, or poor control of variables. Modify experimental design and continue to experiment.
8		Continue experiments and collecting results.
9		Analyse the results and identify any further sources of error. Identify patterns in data and further research you would like to carry out if you had time.
10		Write a draft report and obtain feedback from your teacher.
11		Edit the draft report.
12		Submit finalised report.

ACTIVITY 8.1.1: PLANNING AND TIMELINES

Plan a timeline for your own independent research project. Your teacher will let you know how much time you have to work on your project, as well as any key dates for when things are due. You may like to glue your timeline in the front of your logbook.

KEEPING A LOGBOOK

A **logbook** is a record of the work you have done to complete your research. It should be a notebook used specifically for recording information about your project, starting with ideas for your project and ending when you have finished your report.

It is important to use an exercise book that will only be used for your project. A logbook does not have to be neat or have artistic drawings in it; it is simply a record of how you completed your work and some of your thought processes behind each stage. Even in the age of technology, scientists working in laboratories use hand-written logbooks.

What should go in your logbook?

Your logbook should include relevant research, diagrams, sketches, photos, notes and data – everything related to your project. It gives a good indication of how long you spent on each aspect of the project, and gives you somewhere to truthfully record the information and any issues you may have experienced.

Figure 8.3 An example of a working scientist's logbook.

Some tips and hints for keeping a logbook

1 Find a durable exercise book with ruled lines. Avoid spiral bound books, which will not last long with frequent use. It is very easy to tear pages out of these books and you could accidentally lose important pages.

2 Record everything in pen and do not use liquid paper. If you make a mistake, simply cross it out. This is to ensure that nothing in the logbook is forged, including your results!

Figure 8.4 A detailed logbook can make writing a scientific report much easier.

3. Number the pages of your logbook.
4. Date every entry you make.
5. Entries should be brief, and concise. You do not even need to use full sentences.
6. Glue, staple or tape any loose paper to your book so it can't fall out and get lost.
7. Include notes about anything you've changed during your project. There are many places where your project can go wrong. Make sure you document anything you have changed or fixed!
8. Record all observations made during your experiment. Your logbook is your first source of data collection.
9. Use your logbook to help you write up your final report.

Remember that the more detailed and accurate your logbook is, the easier it will be for you to write your report!

QUESTIONS 8.1.2: KEEPING A LOGBOOK

Remember

1. Suggest a reason why scientists need to keep a logbook.
2. Identify some features found in all logbooks.
3. Explain why even in the age of technology, scientists will hand write their logbook.

Apply

4. The following entry was taken from a student's logbook. Suggest at least two improvements to it.


A website was found that contained great ideas for an experiment. It didn't give you the method straight out, rather suggested ideas however these ideas were as simple as a sentence but for each idea there was a short paragraph briefly explaining possible ideas in regards to designing an experiment. From this website I chose to do something with parachutes. The idea given was to investigate the descent of a parachute and how that changes as changes are made to the variables I thought it'd be an interesting experiment to do and study and so I settled for it

Walding, Dr R., n.d., Senior Physics, <http://seniorphysics.com/physics/ ... .html, date accessed 05/03/09

Mindmap of parachutes

Figure 8.5 Can you suggest how this logbook entry could be improved?

BACKGROUND RESEARCH

One key feature of a good experiment is background research. This involves using all available resources to find relevant information about your topic. While it is tempting and very easy to rely heavily on the Internet for all your research, it is important to use other sources as well. But how do you know your sources will provide reliable information?

It's often too simplistic to say that information from a book is trustworthy, or that open-source information on the Internet is not trustworthy. It's good practice to **verify** information by checking it with at least two other sources to ensure that your information is thorough and correct. The author of the information you are using is also important. Is the author an expert in that field? A simple web search will help you to determine that. You should not rely on any information where the publisher or author is 'unknown' or not mentioned.

When evaluating the trustworthiness of websites, do not just rely on the domain name of a website. Websites ending in .gov or .edu tend to be more trustworthy than websites ending in .com or .org, but not necessarily. All information should be verified. Reread the Scientific Research Literacy Builder on pages 18 and 19 of *Oxford Insight Science 8* for some more tips on how to conduct research.

Figure 8.6 The Internet is a powerful research tool, but all information should be verified with books and/or other websites.

References

It is also very important to reference the information that you use in your research. This ensures that any other person looking at your research can scrutinise your work. Science is all about transparency and repeatability. Your work needs to be able to be repeated for it to be upheld and considered **valid** (appropriate) and **reliable** (consistent).

Referencing your sources also ensures that you do not go around in circles finding the same resources later in your research. There are many different ways of formatting your references. Many major universities have their own preferred format, but the basic information included for each type of reference is very similar. Your teacher will specify the style you should use for a list of references in your report.

QUESTIONS 8.1.3: BACKGROUND RESEARCH

Remember

1 Suggest a reason why it is very important to check and verify all your background information.
2 List the pieces of information that are required for your background research.
3 Identify some places other than the Internet where you can find reliable information.
4 Explain why referencing your information is important when writing a scientific report.

Apply

5 Identify the style you will be asked to use for citing references in your report and provide an example resource for each type.
6 A student referenced a website as: http://www.sciencedaily.com/releases/2014/02/140228103206.htm. Identify what other information is required for this reference to be valid.
7 Go to the website www.dhmo.org. Read through the information and assess the accuracy, reliability and validity of the website.

MAKING A HYPOTHESIS

A **hypothesis** is a statement that describes the relationship between two or more variables. This relationship can be tested. More simply, a hypothesis is a cause-and-effect statement between the **independent variable** (the experimental variable) and **dependent variable** (the variable that is measured).

Making a hypothesis is an important initial step in finding something out through experimentation. The key thing to remember is that a hypothesis is not just a guess. It is made after considering all the available information gathered from the background information, previous experiments, ideas of other scientists as well as results of related experiments. A hypothesis is also a general statement. It doesn't try to explain just one observation or one situation. It will explain many observations related to the question posed.

A hypothesis needs to be tested through experimentation. If it cannot be tested, then the hypothesis is unscientific, and cannot be used in science. Any hypothesis that includes personal opinions should not be used, as these opinions cannot be scientifically or fairly tested.

ACTIVITY 8.1.2: IDENTIFYING INDEPENDENT AND DEPENDENT VARIABLES

Read the following descriptions of experiments and identify the independent and dependent variables for each.

Experiment 1

Cows on four different farms were fed the same amount of hay each day, but with different amounts of a food additive to test the effect of the additive on milk production.

Experiment 2

Seatbelt locking positions and material stretch was altered to see the effect on impact damage in car crashes.

Experiment 3

The pH of reactant solutions was changed to see the effect on reaction rate.

ACTIVITY 8.1.3: SCIENTIFIC HYPOTHESES

Identify the following hypotheses as scientific and testable or not. Explain your reasoning if unscientific.

Hypothesis	Scientific and testable (yes/no)	Reason (if unscientific)
Tea is better than coffee.		
Brown hair is stronger than blonde hair.		
Heavy pendulums swing faster than lighter ones.		
Expensive jogging shoes last longer than cheap ones.		
Eating an apple each day will make you live longer.		
There are more stars in the sky now than there were 1000 years ago.		
Listening to heavy metal music is bad for you.		
Diet cola tastes better than regular cola.		

Writing a hypothesis

Scientifically, a hypothesis can be worded as follows:

> If (the independent variable) is (increased/decreased/changed), then (the dependent variable) will (increase/decrease/change).

In other words, the independent variable is the cause and the dependent variable is the effect, and a basic hypothesis would read:

> A (change) in the (cause) will cause a (change) in the (effect).

There are many different ways to word your hypothesis. For example, one hypothesis is:

> If the amount of sunlight is increased, then there is an increase in the height of bean sprouts.

However, it is still perfectly valid to say:

> As the amount of sunlight increases, the height of bean sprouts will also increase.

Or:

> When the amount of sunlight is increased, there will be an increase in the height of bean sprouts.

In the examples above, no matter how the hypothesis is written, the independent variable is the amount of sunlight and the dependent variable is the height of bean sprouts.

Table 8.2 gives some examples of experiments and some possible hypotheses.

Table 8.2 Experiments and related hypotheses.

Experiment	Hypothesis
Stain remover removes more of a beetroot stain than water alone.	As the amount of stain remover added to water is increased, more beetroot stain is removed.
Nails rust the most in salty water.	If the salt level in water is increased, then nails will rust more.
Garlic will prevent bacterial growth on bread.	When the amount of garlic on a piece of bread is increased, there will be a decrease in the amount of bacterial growth.

It is also important to note that your hypothesis may not necessarily be correct. It just needs to be able to be tested.

When the results of the experiment agree with the hypothesis, it is said to have been supported rather than proved. Due to the huge number of variables that may not necessarily have been controlled, it is extremely difficult to prove a hypothesis beyond all doubt. When the results disagree with the hypothesis, they disprove it. This does not mean the experiment was a failure, simply that the explanation of the cause-and-effect relationship and the experiments to test it need to be revised.

ACTIVITY 8.1.4: FORMULATING A HYPOTHESIS

In an experiment investigating which substances conduct electricity, the results shown in the table below were collected.

Material tested	Metal or non-metal	Conductor or non-conductor
Copper	Metal	Conductor
Sulfur	Non-metal	Non-conductor
Iodine	Non-metal	Non-conductor
Zinc	Metal	Conductor
Lead	Metal	Conductor
Phosphorus	Non-metal	Non-conductor

1 Peter made the following specific statement from these observations.
'The copper tested was a metal and it conducted electricity.'
Make a similar statement about sulfur.
2 Peter then went on to make a general statement about all metals tested.
'All the metals tested were conductors of electricity.'
Make a general statement about all the non-metals tested.
3 Peter was then able to make a hypothesis about metals, including those not tested.
'All metals are conductors of electricity.'
Write a hypothesis about all non-metals.
Some additional substances were tested for their electrical conductivity. The results are shown in the table below.

Material tested	Metal or non-metal	Conductor or non-conductor
Iron	Metal	Conductor
Carbon	Non-metal	Conductor
Tin	Metal	Conductor

4 Do these results support the hypothesis Peter made about metals?
5 Do these results support the hypothesis you made about non-metals?
6 If neither hypothesis is supported, write a new hypothesis.

QUESTIONS 8.1.4: MAKING A HYPOTHESIS

Remember

1 Define 'hypothesis' in a scientific context.
2 Identify the basic structure that a hypothesis needs to take.

Apply

3 Make a hypothesis for each of the following situations.
 a A student wants to see if the amount of sunlight affects the growth cycle of a flower.
 b Salt in the soil may affect plant growth.
 c Temperature changes may cause leaves to change colour.
 d What effect will stirring have on how fast a tablet dissolves in water?

Create

4 Write a hypothesis for your own investigation.

WRITING AN INTRODUCTION

Once you have completed your background research and written a hypothesis, you will need to write an introduction for your report. A draft of the introduction can be completed before you even start planning the rest of your experiment. This is because the introduction is based only on background information from secondary sources or prior research in the same area.

An introduction is one of the first things that someone reading your report will see, and therefore it will leave a lasting impression.

An introduction should provide the general context of your topic as well as the more specific context of your actual experiment. It should suggest an explanation for the interaction between the variables you are investigating, state the aim of the experiment and the hypothesis.

Figure 8.7 shows a sample introduction with all the key areas. Keep in mind that this introduction is only a very short one, and in reality, should be expanded upon.

Cut flowers are sold at many florists. Ranging in shape and size, flowers are often given to loved ones as gifts. However, the lifespans of cut flowers are often short; some flowers will last for up to three weeks, but most will only last a week or so, in a vase of water.

Provides the broad context (summary of previous research)

Flower additives are also often sold at florists. These are packets of chemicals designed to prolong the life of a cut flower when placed in a vase. Research shows that while flower additives work in prolonging the lifespan of a cut flower, the use of a combination of vinegar and sugar will also help prolong the flower's lifespan.

Provides more specific context to your investigation (summary of previous research)

The reason why adding sugar and vinegar works is that flowers are able to use the sugar to grow, while the vinegar is used to increase the acidity of the water, inhibiting bacterial growth.

Suggested mechanism based on research

By examining and varying the percentage of vinegar and sugar used in prolonging the lifespan of cut flowers, it is hoped that an optimum solution can be found which allows the cut flowers to remain vibrant for the longest period of time.

Aims of the research

It is hypothesised that a high level of vinegar and sugar will actually be detrimental to the cut flower, as the acidity of the vinegar may inhibit flower growth as well as bacterial growth. Therefore it is likely that moderate amounts of vinegar and sugar are required for the optimum lifespan of cut flowers.

Hypothesis

Figure 8.7 A sample introduction for a scientific report.

Example of poor introduction

The following is an example of a poor introduction.

> Roses and daisies are both cut flowers. However, their lifespan as cut flowers are very different; roses will last only a week or so, while daisies are able to last over three weeks. In this study, the length of both flowers surviving in vinegar and sugar are compared.

Although the aim of the investigation is outlined, there is little reasoning explained, i.e. no purpose or aim has really been outlined. There is no hypothesis. In addition, the information is not clearly related to previous research. It is important that any investigation undertaken tries to fill a gap in current knowledge.

QUESTIONS 8.1.5: WRITING AN INTRODUCTION

Remember

1 State the purpose of an introduction in a scientific report.

2 Identify the key sections of an introduction.

Apply

3 A student wanted to examine whether double-insulated glasses kept drinks warmer for longer than single-walled glasses.

- **a** Suggest the key words they would need to search for when conducting background research.
- **b** Identify the types of information they would need to research when writing an introduction.

Analyse

4 A student wrote the following introduction for their report.

> 'Tape is used to stick things together. There is many different types of tape. Some types of tape include scotch tape, duct tape, plastic electrical tape and masking or freezer tape. The portion of tape that causes it to be sticky is called the adhesive. The purpose of this experiment is to determine whether the adhesive from duct tape or freezer tape is stickier, or will hold weight for a longer time. I hypothesise that duct tape will be stickier than freezer tape. The independent variables in this experiment are how much weight is held and how long the weight is held. The dependent variables in this experiment are the type of adhesive used.'

- **a** Explain whether you would consider this to be a good introduction or a poor introduction.
- **b** Identify some grammatical and factual errors within this introduction.
- **c** Suggest some additional content that could be added to this introduction.

Create

5 Start your background research and draft an introduction for your experiment. You will continue to refine this introduction until you have finished your project.

HOW AND WHERE TO START

8.1 CHECKPOINT

Remember and understand

1 Identify the purpose of an introduction in a scientific report. [1 mark]

2 Explain why timelines are required for your independent research project. [2 marks]

3 Recall some scientific questions you have come across this year and outline how they were answered. [3 marks]

4 Recall what information is required when referencing a textbook. [1 mark]

5 State the purpose of a logbook. [1 mark]

Apply

6 Matthew completed a research project but lost his logbook. Explain why this is a problem. [2 marks]

7 Annabel wanted to complete her research project based on how much water can be absorbed by different brands of paper towels.

- **a** Is this experiment scientific or not? Justify your answer. [1 mark]
- **b** What measurements would Annabel collect? Are these quantitative or qualitative? [2 marks]
- **c** How could you alter Annabel's experiment so that it is more quantitative? You may need to consider a slightly different experiment. [2 marks]

8 Charlie wanted to determine the best fishing line to use for different sizes of fish when he went fishing.

- **a** Design an experimental question that could be done to help Charlie. [1 mark]
- **b** Identify some of the types of measurements that can be collected in such an experiment. Are they quantitative or qualitative? [2 marks]
- **c** Identify some pieces of equipment that will be needed to collect the data that you have suggested. Explain why they are the most appropriate pieces of equipment to use. [3 marks]

Analyse and evaluate

9 Explain how you would evaluate the trustworthiness of a source of information. [3 marks]

10 Should a website such as www.wikipedia.org be used? Explain your answer. [2 marks]

11 Should a website such as www.answers.com be used? Explain your answer. [2 marks]

12 A year 8 student said 'My teacher said that I can't use any references from the Internet because they aren't reliable.' Explain to them why this is not necessarily correct. [2 marks]

13 Surahbi wanted to investigate how detergent affected the corrosion of copper pipes. Suggest some background research that she can complete to help to write her introduction. [3 marks]

Ethical behaviour

14 Suggest reasons why you should not perform experiments on live animals. [2 marks]

TOTAL MARKS
[/35]

8.2 FAIR TESTS AND EXPERIMENTAL DESIGN

Once you have decided on the topic that you wish to investigate, you need to design an experiment that will help you find the answers to your questions. But how do you ensure that all the tests are appropriate? It is important to design an experiment that is fair and will give you valid results. It is also important to assess all potential safety risks and control them as much as possible before you conduct your experiment.

FAIR TESTS

A **fair test** is an experiment that is structured to ensure constant conditions in order to obtain valid and reliable results. In a fair test, all variables are controlled (kept the same) aside from the dependent and the independent variables. These other variables are called **controlled variables** and should be written into the method, and repeat trials or replications should be completed where possible to ensure the results are not just a 'one off' or due to chance.

Identifying variables

There are three different types of variables that need to be considered when planning an experiment. They are the:

1. independent variable (cause)
2. dependent variable (effect)
3. controlled variables (also known as constants).

A table can be used to help identify all the variables and to design a fair test. Table 8.3 shows a planning table used by a student researching how fertiliser affects the growth of seedlings.

Qualitative and quantitative tests

All three types of variable (independent, dependent and controlled) can be either **quantitative** or **qualitative**. A qualitative test compares different characteristics, such as the colours of fruit. A quantitative test gathers data based on measurements or numbers, such as temperature or speed.

While qualitative tests are important and give useful results, it is important to also complete a quantitative test to allow you to analyse your data more thoroughly. Qualitative tests can be quite easily transformed into quantitative tests by thinking about them slightly differently. Table 8.4 gives some examples.

Table 8.3 Fair test planning table.

What will be changed (cause)	What will be measured (effect)	What will be kept the same
Independent variable	*Dependent variable*	*Controlled variables*
The amount of fertiliser	The height of seedlings	Amount of water seedlings receive Amount of sunlight seedlings receive Type of seedlings Size of containers Number of seedlings per container Type of soil

Table 8.4 Converting qualitative tests into quantitative tests.

Qualitative test	Quantitative test
Which brand of paper towels is best to use in a kitchen?	Determining the volume of water that can be soaked up by different brands of paper towels.
What effect does antibacterial soap have on bacteria?	What percentage of bacteria are killed by antibacterial soap?
Which plastics are biodegradable?	How long does it takes for different plastics to biodegrade?

Qualitative experiments are generally carried out first to help identify the parameters required for a quantitative experiment. For example, you may want to test the amount of suds produced by different soaps. A qualitative test could first group the different soaps into no bubbles and some bubbles. A quantitative test could then be used to measure the differences in volume of bubbles produced under different conditions.

In the qualitative test, the independent variable is the type of soap, and the dependent variable is whether they produced bubbles. In the quantitative test, the independent variable is the specific conditions of the water (temperature, pH, hardness etc.), and the dependent variable is the volume of bubbles produced.

In both quantitative and qualitative tests, other variables that could affect the results still need to be controlled.

ACTIVITY 8.2.1: DESIGNING FAIR TESTS

You have been asked to test the effect of a new fuel mix on the top speed of a go-kart. In pairs, or small groups, discuss how you would run this experiment.

1 Would a qualitative or quantitative experiment be more appropriate for this test? Justify your decision.
2 Identify the independent and dependent variables in this experiment.
3 Identify at least five other variables that would need to be controlled.
4 Explain why these variables should be controlled.

Figure 8.8 The speed and handling of a go-kart relies on many different variables. How would you identify the best set-up for your go-kart?

QUESTIONS 8.2.1: FAIR TESTS

Remember

1 State the difference between a qualitative experiment and a quantitative experiment.

2 Identify the three different types of variables in an experiment.

Apply

3 For the following experiments, identify the:
- independent variable
- dependent variable
- controlled variables.

a Students watched a cartoon either alone or with others and then rated how funny they found the cartoon to be.

b The heights of bean plants depend on the amount of water they receive.

c Four groups of rats are first weighed and then fed identical diets except for the amount of vitamin A they receive. Each group gets a different amount. After 3 weeks on the diet, the rats' weights are measured again to see if there has been a decrease.

d A student wanted to test how the mass of a paper aeroplane affected the distance it would fly. Paperclips were added before each test flight. As each paperclip was added, the plane was tested to determine how far it would fly.

Analyse

4 For the experiments in question 3, outline whether each of the variables measured is qualitative or quantitative.

USING AN EXPERIMENTAL CONTROL

Being able to control variables allows your experiment to be more valid and reliable. But how do you determine whether the independent variable is actually the cause of the changes observed in the dependent variable? To do this, an **experimental control** is used. An experimental control is made up of the conditions of the experiment without the independent variable. An experimental control is very different to that of controlled variables.

For example, if students were to test the effect of fertiliser on plant growth, they also need to measure the plant growth without fertiliser (i.e. no independent variable). This gives a point of comparison, to show that adding fertiliser improves growth.

Most experiments require an experimental control to ensure the results are valid and that the experiment is actually testing the effect of the independent variable and not another, hidden, variable. Another example of an experimental control is shown below.

Example: Melting ice and rock salt

Aim: To determine whether ice melts faster when rock salt is placed onto it.

Hypothesis: That the more rock salt is placed onto the ice, the faster the ice will melt.

Independent variable: The mass of the rock salt used.

Dependent variable: The time taken for ice to melt.

Controls/constants: The size of the cubes of ice, the type of rock salt, the environmental conditions of the day.

Experimental control: The time taken for ice to melt without any rock salt.

QUESTIONS 8.2.2: USING AN EXPERIMENTAL CONTROL

Remember

1 Compare and contrast an experimental control with controlled variables.

2 Suggest why experimental controls are necessary to most experiments.

Apply

3 For the following questions, identify the:

- independent variable
- dependent variable
- controlled variables
- experimental control.

a An experiment was performed to determine how the amount of coffee grounds could affect the taste of coffee. The same kind of coffee, the same percolator, the same amount and type of water, and the same perking time.

b Steve notices that his shower is covered in a strange green slime. His friend Irene tells him that coconut juice will get rid of the green slime. Steve decides to check this out by spraying half of the shower with coconut juice. He sprays the other half of the shower with water.

Create

4 For your own investigation, start planning what you will require and what you will need to consider in terms of independent variables, dependent variables and controlled variables, as well as whether you will need to use an experimental control.

SELECTING APPROPRIATE MATERIALS

As part of your independent research project, you will need to determine and source the equipment and materials needed to complete the experiment.

First, you will need to consider what you are measuring.

If you are measuring length or distance, then there are many pieces of equipment you would likely choose to use (see Table 8.5). You will select your equipment based on the scale of your measurements. For example, you wouldn't use a ruler to measure the distance a car travels, but you might use the car's odometer.

Other aspects to consider include the most appropriate type of equipment to use. For example, if you need to heat something, a Bunsen burner is fast and easy to use. However, if your experiment calls for exact temperatures, a hot plate would be more practical.

How do you decide what glassware is most appropriate for an experiment? Table 8.6 gives some examples of laboratory glassware and the typical uses.

If you are not completing your research project in your science laboratories, you need to consider what equipment you can obtain. You may be able to borrow some pieces of equipment from school, or you may have family or friends who work at universities or other higher education institutes who allow you to use other pieces of equipment, such as agar plates or fume cupboards.

Consider whether you could substitute other pieces of equipment for the equipment needed. Does anyone in your family have a multimeter that can measure voltage, current and resistance? You may be familiar with beakers and measuring cylinders in a school science laboratory, but what can you substitute in their place?

Lastly, where can you purchase new equipment? pH testing kits are often available in gardening stores or pet shops; some chemicals such as copper sulfate are available at hardware stores.

Table 8.5 Some possible pieces of equipment for different measurements relating to length.

Measurement required	Measurement	Possible equipment
Length	km	Scaled maps, odometer, GPS, laser rangefinder
	m	Trundle wheel, metre rule/ruler
	cm	Metre rule/ruler, 30 cm rule/ruler
	mm	30 cm rule/ruler with mm markings, Vernier callipers
	μm	Vernier callipers, micro grid under a microscope

Table 8.6 Some laboratory glassware and their typical uses.

Laboratory equipment name	Main purpose
Beaker	Holding or containing solutions or liquids
Test tube	Holding or containing small amounts of substances
Conical flask	Used when solutions need mixing
Measuring cylinder	Measuring an accurate amount of solution or liquid
Crucible	Heating substances that require high temperatures, which cannot be done in glass
Watch glass	Used to evaporate a small amount of solution that does not require heating
Evaporating basin	Used to evaporate a large amount of solution, usually started off with a Bunsen burner

QUESTIONS 8.2.3: SELECTING APPROPRIATE MATERIALS

Remember

1 What is an appropriate piece of equipment to measure length in metres?

2 Explain why you would not use a trundle wheel to measure the size of a grain of rice.

Apply

3 For the measurement of time, construct a table similar to Table 8.5 and suggest some possible equipment that can help you measure time in different increments. Compare your answers to those of your classmates.

4 Would you use a beaker or a measuring cylinder to measure volume? Justify your answer.

5 Steven had a thermometer that could measure from -100°C to 110°C, whereas Sylvia's thermometer could only measure from 34°C to 42°C.

   a Determine which thermometer would be the most useful in a variety of situations. Explain your answer.

   b If Anna had a fever, would Steven's thermometer or Sylvia's thermometer be more useful? Justify your answer.

   c Whose thermometer would be more precise? Explain your answer.

6 Consider what data you need to measure in your own independent research project. Suggest different pieces of equipment that you may be able to use to obtain these measurements.

7 Make a list of the equipment you need and determine how you will access these pieces of equipment.

RISK ASSESSMENTS

No matter what type of experiment you plan to conduct, it is important that you carry out the experiment in a safe manner, not just for yourself but for others in your household or classroom, and for the environment. Before you start, you should carry out a risk assessment to determine how to conduct your experiment safely. Generally, for a risk assessment you will need to:

1 identify the hazards

2 assess the risk

3 control the risk.

Figure 8.9 Working with lasers has many associated hazards. What safety precautions should be taken?

Identifying the hazards

Hazardous or dangerous materials are anything that may injure or cause harm to someone or to the environment. These materials may range from glass equipment to hot plates used for heating, or any specific chemicals you may be using. While some hazards are obvious, chemical hazards are often not considered in enough detail. For in-depth information, a Safety Data Sheet should be used.

Safety Data Sheets

A Safety Data Sheet (SDS) is a small document that:

- describes the physical and chemical properties of a substance or a material
- provides advice on the safe handling and use of that material
- gives guidance in first aid.

SDS are available:

- from manufacturers and importers of chemicals
- from the point of sale, such as shops and retail outlets
- online.

There is an SDS for every chemical and mixture of chemicals sold in Australia, meaning that there are over 20 million SDS available to you! When locating an SDS online, ensure it is an Australian version; Australian regulations for handling or disposal may differ from other countries' regulations.

Every time you use a chemical substance, at school or at home, ensure that you are familiar with any hazards. For example:

- Do you need to use it in a well-ventilated area? How will it affect people with asthma?
- How do you clean up any spills?
- What should you do if you spill it on your skin?
- How do you store it safely until next time you need to use it?

Assessing the risk

Once a risk has been identified, you then need to determine:

1. what could happen
2. how likely it is to occur.

For example, if you are assessing the hazard of glassware, the risk is breakage when dropped and that broken glass may cut skin, causing bleeding. The risk of the glass being dropped is somewhat moderate, but may be higher if you are working with wet or slippery materials.

Controlling the risk

Once a risk has been assessed, you will need to control it. Controlling the risk may range from careful handling (such as chemicals or hot material), to wearing appropriate safety equipment (such as safety glasses, or heatproof gloves). For some chemicals, it may be important to control or prevent their release into the water supply. For example, if you are using paint, excess paint should not be poured down the drain.

When assessing risks, always consider the following.

Figure 8.10 Common warning symbols used on Safety Data Sheets.

- Is the experiment safe?
- What personal protective equipment will you need?
- What actions should you take to ensure your safety, as well as that of others?

Table 8.7 shows a typical risk assessment for the use of the chemical copper sulfate.

Table 8.7 A risk assessment of the use of copper sulfate.

Hazardous or dangerous material	Copper sulfate (solution), copper sulfate (solid)
Source(s) of safety information	Chemical label and SDS
Identify the hazards	Copper sulfate may be hazardous in case of skin contact (irritant), eye contact (irritant), ingestion or inhalation.
Assess the risk	Copper sulfate (solid) may get onto hands through handling, then accidently be ingested. Copper sulfate (solution) may splash when being used. Both of these are likely to occur.
Control the risk	• Use low concentrations of solution. • Use smaller volumes of the solution. • Follow good hygiene and experimental practices. • Wear personal protection equipment such as safety glasses, a lab coat and gloves, wherever the material will be directly handled. • Wash hands thoroughly after experimentation.
Disposal	Diluted concentrations of copper sulfate (solution) can be disposed down the sink.
Name/date	Lisa Luong, 14 February 2015

ACTIVITY 8.2.2: PERFORMING A RISK ASSESSMENT

Read the following method for an experiment.

Method

1 Place 10 mL of dilute hydrochloric acid into the test tube.
2 Add the magnesium ribbon into the test tube and immediately stopper the test tube.
3 When the reaction is complete, remove the rubber stopper and immediately place a lit match at the mouth of the test tube.

Questions

1 Access an SDS for each of the chemicals used in this experiment.
2 Identify all the safety issues that should be considered in this experiment.
3 Write a risk assessment for the whole experiment using the format of Table 8.7 on page 361.

QUESTIONS 8.2.4: RISK ASSESSMENTS

Remember

1 What are the main features of a risk assessment?
2 What does the abbreviation SDS stand for?
3 Suggest ways to access an SDS for most chemicals.

Apply

4 Explain why it is important to complete a risk assessment for your investigation.
5 Suggest a source of information about safety if you cannot find any specific information on the label.
6 Explain who you might need to consider in your risk assessment if you are doing your investigation at home.

Create

7 Write a risk assessment for your own investigation. Show this to your teacher when you are done.

OBSERVATIONS AND INFERENCES

When you carry out your experiment, you will need to make **observations** and **inferences** based on those observations. An observation is something that we detect with our senses, whereas an inference is something that can be assumed from an event. It's important that when you make observations, they are concise but detailed enough so that the main points can be determined. The best way to determine what information needs to be included in an observation is by recalling the purpose or reason for making the observation in the first place.

ACTIVITY 8.2.3: MAKING OBSERVATIONS AND INFERENCES

Read the following observations recorded by a student who was asked to observe the effect acid had on a piece of magnesium.

> The magnesium was 2 cm long and 1 cm wide. It was a silvery grey colour. It was easy to bend and it felt smooth. The acid looked like water. I poured 10 mL of the acid into a small test tube with a chip out of the top. The test tube of acid felt cold. As soon as I dropped the magnesium into the acid, bubbles appeared all over it. Pretty soon, bubbles were everywhere. Some bubbles clung to the inside of the test tube. Acid splashed up onto the sides of the test tube and then rolled back down. Some acid splattered onto the bench. I could hear a fizzing noise like a soft drink. The magnesium was jumping around in the acid and it was getting smaller and smaller. It was completely gone after a little while. The test tube felt a bit warmer at the end.

1 Which parts of the student's observation were unnecessary?
2 Write, in dot points, the changes that occur when magnesium was dropped into the acid.
3 What inferences can be made from these observations?

QUESTIONS 8.2.5: OBSERVATIONS AND INFERENCES

Remember

1 Define 'observation'.
2 Using an example, compare and contrast an observation with an inference.

Apply

3 Look carefully at Figure 8.11.
  a List three observations.
  b List three inferences based on your observations.

Figure 8.11 What observations can you make about this scene? What can you infer from your observations?

WRITING A METHOD

Methods for scientific reports should be written in past tense, just like the whole of your report, because you have already completed the practical and you are reporting back on what you have done.

The method needs to be detailed enough that another person could replicate your experiment without having to ask for clarification. You should also ensure that you include any measurements you have made, as well as any repetitions you have completed. You may find that using a flow chart will help with the planning.

Table 8.8 compares method-writing styles for an experiment about electrochemical cells. Examine the differences between the notes in the logbook and the formal method of the report. Note that both methods are written without personal pronouns such as 'I' or 'we', i.e. in the passive voice.

Table 8.8 Comparing method-writing styles of logbook notes and the final report.

Method in logbook	Method in scientific report
1 Roll the lemon and squeeze gently to soften the skin and make sure it is juicy on the inside.	1 The lemon was rolled and squeezed gently to soften the skin and to make sure that it was juicy on the inside.
2 Slit the lemons and insert a strip of copper foil. Mark the electrode with a positive sign.	2 The lemon was slit and a strip of copper foil was inserted. This electrode was marked with a positive sign.
3 At the opposite end insert the galvanised nail, making sure that the nail is not touching the copper. Mark the electrode with a negative sign.	3 A galvanised nail was inserted at the opposite end of the lemon. The nail was secured so that it was not touching the copper. The nail was marked with a negative sign.
4 Connect an alligator clip to the copper foil and another clip to the nail.	4 An alligator clip was attached to the copper foil and another was attached to the nail.
5 Connect the copper lead to the long arm of the LED and the zinc lead (from the galvanised nail) to the short arm of the LED. The LED will not work if connected incorrectly.	5 The lead from the copper sheet was attached to the long arm of the LED and the lead from the galvanised nail was attached to the short arm of the LED.
6 Darken the room and look carefully at the LED. It should have a faint glow.	6 The room was darkened and observations of the LED were made.

QUESTIONS 8.2.6: WRITING A METHOD

Remember

1 Identify the purpose of the method section in a scientific report.

2 Compare and contrast a method written in a logbook and one written in a scientific report.

3 State the reason why the method will differ between a logbook and a scientific report.

Apply

4 A student is interested in examining how crushing a Berocca tablet will affect the dissolving rate of that tablet.

a Identify the independent, dependent and some controlled variables.

b Identify the experimental control required for this experiment.

c Write a logbook method to show how she will investigate this. Rewrite the method as if for a scientific report.

5 Another student is interested in examining how temperature affects the dissolving rate of the Berocca tablet. Compare this experiment to the one you have written for question 4. What will require changing?

Create

6 Write the method for your own investigation in your logbook. Keep your variables in mind when you design your experiment. You will need to show this to your teacher for approval to continue.

FAIR TESTS AND EXPERIMENTAL DESIGN

8.2
CHECKPOINT

All questions refer to the following information.

Many people spray their clothes before ironing them. The spray contains substances that allow the iron to glide over the clothes more easily, reducing the time and effort required to iron. Chloe bought three different brands of ironing spray at the supermarket. She also bought four identical, empty, trigger-action spray containers. Each of the three brands was poured into an empty spray container and water was poured into the fourth container. Chloe then set up the equipment as shown in Figure 8.12.

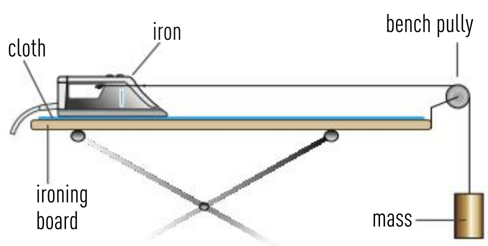


Figure 8.12 Ironing experimental set up.

Chloe used four different pieces of the same type of cloth. Each piece was sprayed with a different spray container. Each piece of cloth was sprayed by holding the container 30 cm from the cloth and giving the trigger three quick squeezes. After each piece of cloth was sprayed, it was placed on the ironing board, and Chloe timed how long it took for the iron to move 30 cm.

Remember and understand

1 Recall the purpose of an aim in an experiment. [1 mark]

2 Write an aim for the experiment above. [1 mark]

3 Identify where information about the chemicals in the ironing sprays are likely to be found. [1 mark]

4 Identify whether this experiment is qualitative or quantitative. Explain your answer. [2 marks]

5 Identify the dependent variable. [1 mark]

6 Identify the independent variable. [1 mark]

7 Identify some other variables that Chloe kept constant. [3 marks]

Apply

8 Describe a way Chloe could measure 30 cm in her experiment. Identify the appropriate piece of equipment to use for this measurement. [2 marks]

9 Write a possible hypothesis for this experiment. [2 marks]

10 Identify, assess and control *one* risk for this experiment. [2 marks]

11 Write a report method for Chloe's experiment. [5 marks]

12 Chloe's mother poured out one of her spray containers and took off the labels that Chloe had attached to it. Suggest how Chloe can fix this problem. [2 marks]

Analyse and evaluate

13 Analyse Chloe's experiment and explain how it is a fair test. [3 marks]

14 Explain the purpose of the mass. [2 marks]

15 Explain why Chloe used water for one of the tests. [2 marks]

Critical and creative thinking

16 Manufacturers often do not have a comprehensive ingredients list to identify what chemicals are in their products as they are industry secrets. Is this practice safe? Explain how you would go about finding more information about the products. [3 marks]

17 Do you think the type of material used affects the usefulness of the spray? Justify your answer with another possible experiment Chloe could perform. [2 marks]

TOTAL MARKS
[/35]

8.3 DEALING WITH DATA AND REPORT WRITING

Carrying out your experiment will produce data. But how should you collect the data and how do you deal with the data once you've collected it? How can you present your results so that they are easily read and meaningful for the general public? Analysing data and finalising your report will clearly show the research you have done and explain any discoveries you may have made over the course of your investigation.

COLLECTING DATA

Data collection depends largely on the type of investigation you are completing. The design of your investigation may require you to collect data throughout the experiment, or perhaps just at the end. The way you collect your data should be a part of your method.

So what will you do with all these data? It can get very confusing if you do not organise yourself early. All data needs to be collated (organised into an easy to read form) and then analysed for **trends** or patterns in the cause-and-effect relationship.

Figure 8.13 Data loggers can collect a variety of different types of information that can be graphed on screen, or sent to a computer for analysis.

Organising data into tables

Tabulation is one of the easiest ways to organise data. Tables show, at a glance, the crucial information that you have collected. They collate and group information together so that it is quicker and easier to read.

Imagine having collected the following information in your logbook.

> Every day, I measured the height of a pea plant and found that at day 0, it was 2.1 cm in height. At day 1, it was 3.0 cm in height. By day 2, it had grown another 1.1 cm. Day 3, it was 4.6 cm. Day 4, it was 5.8 cm, day 5 it was 6.0 cm and by day 6, it was 7.8 cm in height.

Rather than being written as a long paragraph, this information can be more clearly displayed through a table, such as Table 8.9.

All tables have the same basic structure as the example in Figure 8.14.

Table 8.9 Growth of a pea plant.

Time (days)	Height (cm)
0	2.1
1	3.0
2	4.1
3	4.6
4	5.8
5	6.0
6	7.8

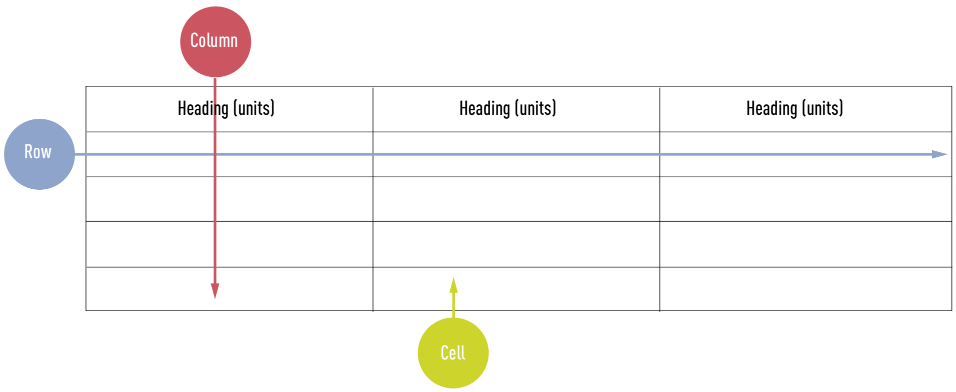


Figure 8.14 Key features of a table.

Figure 8.15 A sample table from a scientific report.

Checklist for constructing a good table

- Independent variable in the left column
- Dependent variable in following columns
- Calculated values in the far-right column (if applicable)
- Descriptive title mentioning independent and dependent variables
- Heading in every column
- Units in brackets within the column headings and not in the table itself
- A dash in cells where no data was available, or when data was not collected
- Every data cell filled in

You may wish to use a spreadsheet program to help you tabulate and manipulate your data, perform calculations or draw graphs. There are many spreadsheet programs available, and the 'Help' menu will explain how to perform statistical calculations and convert the data into different graphs.

QUESTIONS 8.3.1: COLLECTING DATA

Remember

1 State the name given to each individual box in a table.

2 Identify where the independent variable generally goes in a table.

Apply

3 Suggest a reason why units for results are given in the table headings and not in each individual box.

4 Tabulate the following information:

In a year 10 science class surveyed, there were 10 students with dogs as pets, 8 students with cats, 5 students with other animals as pets, 3 people with more than one type of pet, and 4 people with no pets.

Analyse

5 Suggest some improvements that can be made to the following table (assume all data to be correct). Redraw a better version of the table.

Trial 1: Length of plant	Trial 2	Trial 3	Amount of water used per day
10 cm	9 cm	8	2.00 mL
15 cm	14 cm	130 mm	5 mL
18 cm	18	160 mm	6 mL
10 cm	9 cm	10 cm	1 mL

STATISTICS

The types of statistics you perform in your investigation will depend largely on the data you have collected as part of your experiment. Some common statistics are described in the following paragraphs. If you have completed an experiment that is more physics-based, you may wish to run a few more statistical calculations on the data, including more in-depth error calculations. Check these with your teacher who will be able to help you.

Range

The **range** of the data you have collected is a measure of variation between your results.

Range = highest value – lowest value

Always make sure that you are using the correct data to calculate the range.

Mean

The **mean** of a set of data is the average of the scores. To calculate the mean, find the sum of the results and then divide the sum by the number of scores.

Standard deviation

The **standard deviation** is often used to measure the reliability of data. The larger the standard deviation, the greater the spread of the scores in the data set. The standard deviation can be calculated using a spreadsheet program on a computer, or with your calculator. Refer to a maths textbook for more information on calculating standard deviation.

Note that the mean, standard deviation and the range will have the same units as what you have calculated. The calculated data should be included in your results table.

QUESTIONS 8.3.2: STATISTICS

Remember

1 Expain how to calculate the:
  - a range
  - b mean
  - c standard deviation.

2 Identify some situations where statistics should be used in scientific reports. Should your report include some statistics? Why? Why not?

Apply

3 The following data is test scores from a Science test:

  72, 99, 89, 63, 57, 75, 100, 81, 62, 82

  Calculate the range, mean and standard deviation of this data.

4 A gardener grows strawberries in his greenhouse. The temperature of the greenhouse, in degrees Celsius, is recorded every day at noon for 1 week. The temperatures were:

  18, 21, 24, 17, 23, 14, 16
  - a Tabulate this data.
  - b Calculate the range, mean and standard deviation of this data.
  - c For best growth of strawberries, the mean temperature should be (20 ± 5)°C and the standard deviation should be less than 5°C. Are the conditions in the greenhouse likely to result in best growth? Justify your answer.

5 A scientist was studying the differences between crocodiles and alligators by comparing their lengths. He examined the length of six different crocodiles and collected the data below in metres.

5.5, 7, 5.3, 6.7, 6.3, 5.5

a Tabulate this data.

b Calculate the range, mean and standard deviation of this data.

c The lengths of six alligators were also recorded. The results gave an average of 5.1 metres and a standard deviation of 0.56 metres. Make two valid comparisons between the lengths of the crocodiles and the alligators. Justify your answer.

Figure 8.16 Statistics can be used to make the comparison of the lengths of crocodiles and alligators easier and more obvious.

GRAPHING

Graphing is another method of visually displaying data. The advantage that graphs have over data tables is that you can generally see trends straight away. The type of graph you draw will depend largely on the type of data you have collected: continuous or discrete.

Data that is counted is discrete. For example, the number of pets in families, the number of goals in each netball game in a season, the number of people who watch reality TV programs are discrete.

Data that is measured is continuous. For example, the times required to reach a particular level on a computer game, the lengths of sharks found in the bay, and the heights of plants are continuous. These measurements are continuous, even if rounded to a sensible level of accuracy (1, 2 or 0 decimal places). They can be represented on a continuous scale.

ACTIVITY 8.3.1: CLASSIFYING DATA

Classify the following data by using the terms qualitative or quantitative, and discrete or continuous. Each example of data should be classified using *two* terms.

1. The times required to wait for a bus in a week
2. The numbers of each of the different types of trees in your school garden
3. The heights of a tree over a period of time
4. A survey of people's favourite television programs
5. The heights of people in your class
6. The temperatures of an oven over time
7. The distances between any given two towns

Deciding which type of graph to use

If you have collected data for multiple trials in your experiment, you should use the average data to plot as data points. You can use the flow chart in Figure 8.17 to determine the type of graph you should use. This flow chart should only be used as a guide, it is not the rule, and the type of graph you use will depend on your own choice.

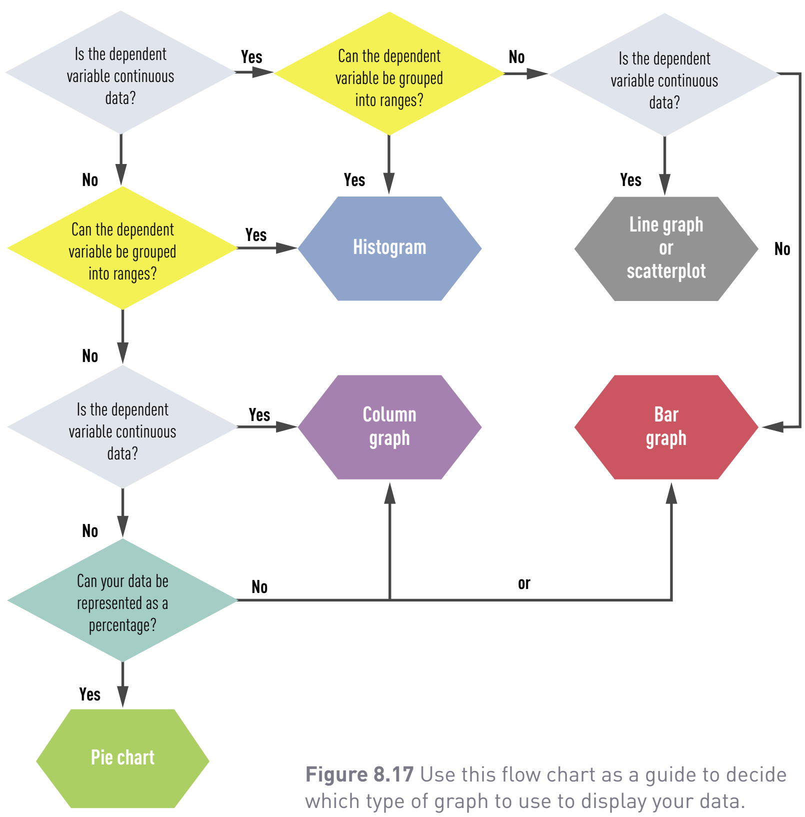


Figure 8.17 Use this flow chart as a guide to decide which type of graph to use to display your data.

Line graphs

Line graphs are one of the most commonly used graphs in science. You will have seen forms of lines graphs in chapter 5.

Line graphs give a direct relationship between the independent (horizontal axis) and dependent (vertical axis) variables, and so we can use them to predict unknown outcomes.

A line graph is best used when both the dependent and independent variables are continuous.

The data in a line graph should be plotted as points, then a general trend found through drawing a line (or curve) of best fit. A line of best fit should pass through as many points as possible, forming either a straight ruled line, or a smooth curve. Any points not directly on the line should be spaced roughly evenly on either side of the line of best fit. You will need to use your own judgement to determine how and where to draw the line of best fit.

Depending on the data you have collected, a straight line may describe the relationship between the variables very well, or perhaps a curve or a curve that plateaus would fit better. Some scatterplots show no relationship between the variables and have no line of best fit. Use your judgement to determine how and where to draw the line of best fit.

The shape of the graph, or the line of best fit, indicates the trend of the data and the relationship between the independent and dependent variables. Points that are nowhere near the line of best fit are called outliers and can indicate errors in the experiment. However, sometimes outliers are correct and can be a point of interest that may lead to further investigation. These trends and outliers are what are discussed in your scientific report.

On a line graph, you may **extrapolate** information by extending the line of best fit. Be aware the not all extrapolations are valid, as sometimes the curve will change shape or plateau (flatten out to horizontal). You can also **interpolate** information, which involves finding a point that lies on the line of best fit.

Checklist for drawing a line graph

- Did I include a title?
- Have I positioned the dependent variable (vertical axis) and the independent variable (horizontal axis) on the correct axes?
- Have I labelled both axes, including units where needed?
- Have I chosen an appropriate scale for each axis? The larger the graph, the easier it is to read and interpret.
- Did I plot the data correctly?
- Have I drawn the line of best fit through most of the points? It may be curved.
- Have I included an appropriate key (where more than one line is on the same set of axes)?
- Have I used ruled dotted lines to interpolate and extrapolate specific points?

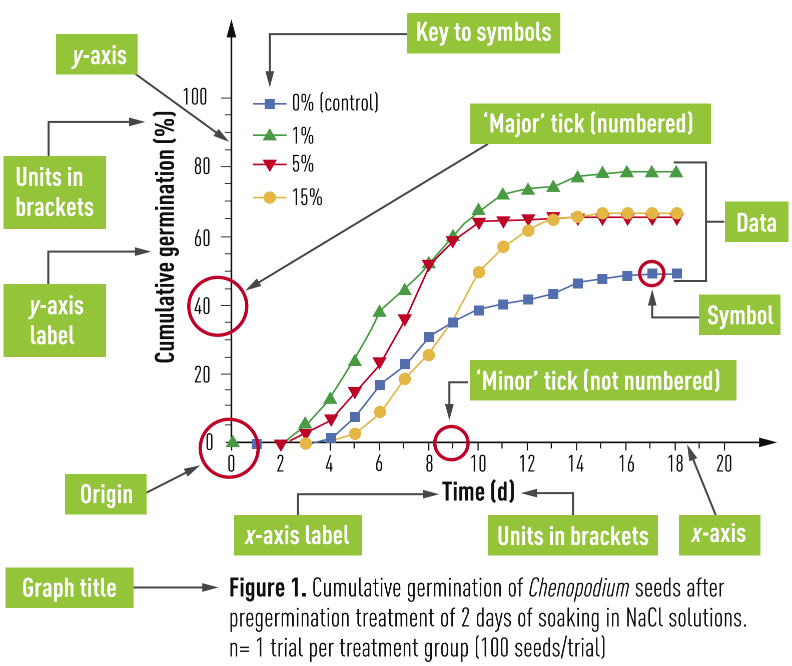


Figure 8.18 Key features of a line graph.

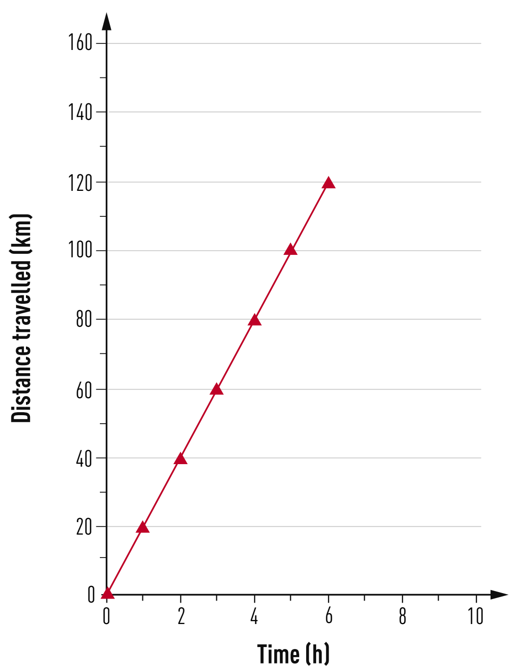


Figure 8.19 A line of best fit should go through most of the points, but not necessarily all. This graph shows the distance a cyclist has travelled every hour.

Histograms

Histograms are most useful when the independent variable has a very large range that can be easily grouped into 5–10 class intervals, rather than displayed as individual data points. The independent variable is always shown on the horizontal axis and the dependent variable on the vertical axis.

When dealing with class intervals it is always easiest to first complete a frequency table before drawing the histogram. If the independent variable is continuous, the class intervals are shown using the less than symbol (<), if the independent variable is discrete, the class intervals are labelled using whole numbers. Raw data collected during the experiment can be tallied in a frequency table directly, or a results table could be converted into a frequency table afterwards.

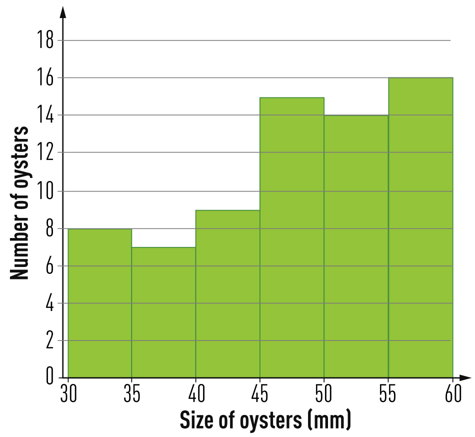


Figure 8.20 Histogram showing the number of different-sized oysters grown over a 10-year period.

Checklist for drawing a histogram

- Did I include a title?
- Have I positioned the dependent variable (vertical axis) and the independent variable (horizontal axis) on the correct axes?
- Did I draw the scales of the axes evenly?
- Have I labelled both axes, including units where needed?
- Did I plot the data correctly?
- Are the bars of the histogram touching, and did I leave a small space before the first column?
- Have I labelled the columns on the edges rather than in the middle?

ACTIVITY 8.3.2: PLOTTING A HISTOGRAM

All the students in year 10 of a small school were surveyed for their shoe size. The data collected is shown below.

Table 8.9 Survey of shoe sizes of students in year 10.

Shoe size of students (European sizing)	Number of students
35–36	4
37–38	8
39–40	15
41–42	24
43–44	20
44–45	13
46–47	3
48–49	1

1 Identify the independent and dependent variable of this survey. Justify your decision.

2 Classify shoe size as continuous or discrete data. Justify your decision.

3 Use the information in the section above to plot a histogram.

Column and bar graphs

Column and bar graphs are best used to display data where one variable is discrete or qualitative, and the other is numerical. Column graphs place the independent variable on the horizontal axis and the dependent on the vertical axis. Where the independent variable is discrete, draw a column graph. If the dependent variable is discrete, draw a bar graph. The columns or bars of the discrete variable should be labelled with their category name and should not touch. Unlike a histogram, the labels should be in the middle of each column or bar.

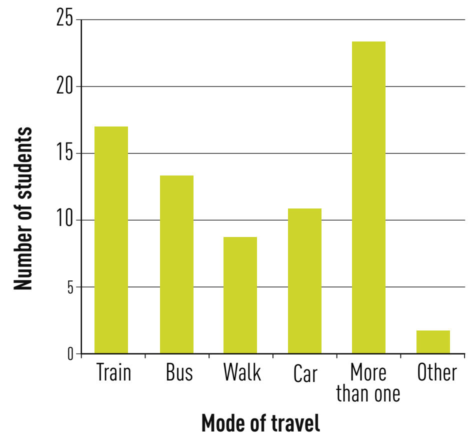


Figure 8.21 Column graph showing the results of a survey of 75 students about how they travelled to school in the morning.

Checklist for drawing a column or bar graph

- Did I include a title?
- Have I positioned the dependent variable (vertical axis) and the independent variable (horizontal axis) on the correct axes?
- Did I draw the scales of the axes evenly?
- Have I labelled both axes, including units where needed?
- Have I included an appropriate key (where more than one set of columns or bars are used)?
- Did I plot the data correctly?
- Did I leave small spaces between each column or bar?
- Have I labelled the columns or bars in the middle rather than on the edges?

ACTIVITY 8.3.3: DRAWING COLUMN AND BAR GRAPHS

200 students were surveyed about their favourite breakfast foods. Table 8.10 displays the results.

1 Identify the independent and dependent variable of this survey. Justify your decision.

2 Determine whether a column or bar graph is most suitable for this survey. Justify your decision.

3 Use the information in in the section above to draw either a column graph or a bar graph.

Table 8.10 Survey of 200 students about their favourite breakfast foods.

Favourite breakfast food	Number of students
Toast with spread	22
Bacon	61
Sausages	55
Egg	20
Cereal	5
Yoghurt	15
Zaatar	9
Congee	10
Others	3

Sector graphs

Sector graphs, or pie charts, are commonly used to display qualitative data or any data that can be expressed as a percentage of the whole data set. Each percentage is then converted into an angle as a percentage of 360°. Regardless of the number of data or categories, a sector graph should always form a whole circle.

Each segment of the sector graph is coloured or coded in some way, so a key is vital to explain what each sector represents.

Checklist for drawing a sector graph

- Did I include a title?
- Have I converted the data into percentages and then into angles correctly? Do all the angles add up to 360°?
- Have I included an appropriate key?

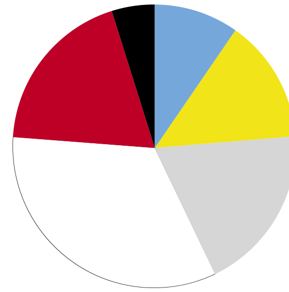


Figure 8.22 A sample sector graph.

QUESTIONS 8.3.3: GRAPHING

Remember

1. State the three most common types of graphs that are used in science.
2. Identify the axis on which the independent variable is always plotted.
3. On the graph shown in Figure 8.23, circle and label the:
   - **a** horizontal axis
   - **b** vertical axis
   - **c** data lines.
4. The graph in Figure 8.23 is missing many essential features. Identify them.

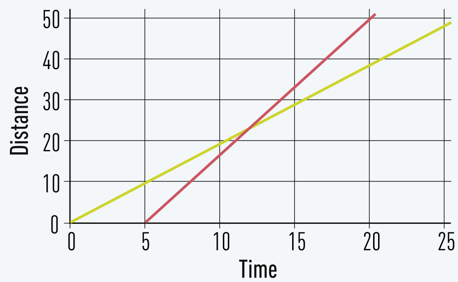


Figure 8.23 An incomplete line graph.

Apply

5. The following data table shows the number of hours students spend studying for a Science examination and their final examination mark.
   - **a** Identify which variable goes on each axis.

Student number	Number of hours studied	Final examination mark
1	3	78
2	2	73
3	5	92
4	1	65
5	0	55
6	4	85
7	3	80
8	5	55

   - **b** Draw a scatterplot of the data.
   - **c** Draw in a line of best fit, and identify the outlying data point.
   - **d** Suggest some reasons why there is an outlier to this data.
   - **e** Extrapolate a mark for a student who studied for 6 hours.
   - **f** Could this line on best fit go on forever? Justify your answer.

TRENDS AND EVALUATIONS

The trend in a data set is the pattern in which one variable changes in response to another. It is important to look for trends in your data so that you can clearly see whether your independent variable is linked to the dependent variable. A **correlation** (relationship between the independent and dependent variables) can be either strong or weak, depending on the spread of the data, or there may be no correlation at all. If there is a correlation, then the correlation may be positive, negative or exponential.

A positive correlation suggests that as your independent variable increases, your dependent variable will also increase. A negative correlation suggests that as your independent variable increases, your dependent variable will decrease. An exponential correlation suggests that as your independent variable increases, your dependent variable will increase or decrease at a rapid rate.

As with all graphs, the independent variable is always on the horizontal axis, while the dependent variable is on the vertical axis.

The key thing to remember is that correlation does not equal causation. A correlation is a measure of a mathematical link between the two variables. But mathematical links can exist for all sorts of other reasons. Causation is whether the independent variable actually has a direct effect on the dependent variable and is the reason why it changes during the experiment.

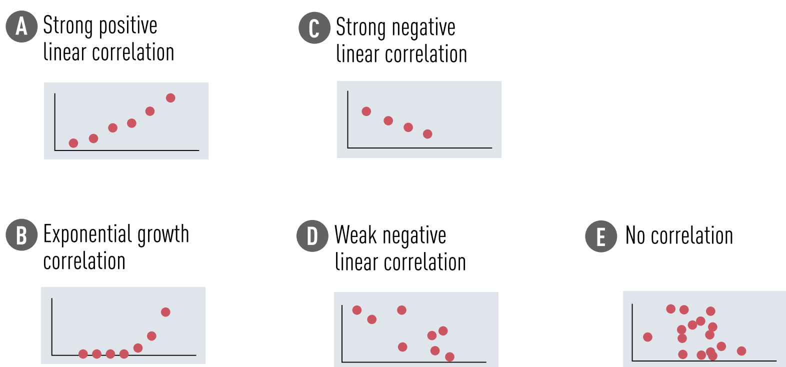


Figure 8.24 The common patterns of correlation.

SCIENCE SKILLS

Interpreting correlations

There is an age old saying that a baby is brought 'by the stork' to the new parents. In a scientific article published in *Paediatric and Perinatal Epidemiology* in 2004, three scientists, Höfer, Przyrembel and Verleger examined the data between the number of storks in Germany, as well as the number of births in the country and found an odd statistic. There was a negative correlation. The data (Figure 8.25) clearly showed that while the number of storks in Germany was increasing, the number of births was actually decreasing.

How could this possibly be? Everybody knows that storks bring babies!

The scientists decided to conduct further research. There must be some other

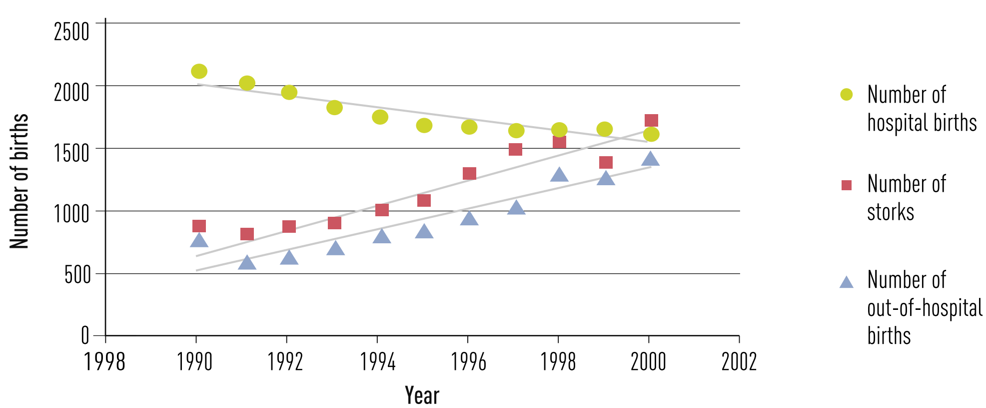


Figure 8.25 Sample data that shows the same correlation as the data in the paper.

reason for the decreasing number of births. And they found it! The number of out-of-hospital births has been rising and shows a clear positive correlation to the number of storks in the region. This follows with the observation that with the increase of air conditioner use, hospital windows have had to remain closed more often, therefore restricting access to the storks bringing babies.

So the scientists conclude by suggesting that if you would like a stork to bring your baby, you should consider an out-of-hospital birth rather than giving birth in hospital.

1 Describe the trends that you see in changes of stork numbers and number of births, both in and out of hospital.
2 Suggest why the 'scientific' article published was very light hearted.
3 Explain the difference between correlation and causation.
4 Explain why this article relating to storks and number of births is a good example of the difference between correlation and causation.

Evaluating your investigation

Your evaluation of the experimental design and the results make up most of the discussion component of your scientific report. The discussion has two main functions: the first to explain the results of your study, and the second to explore the significance of your investigation's results. When completing the discussion, you need to ensure that you attempt the following.

1 Interpret and explain the results of your investigation, including any inconsistent or unexpected results (use appropriate science here).
2 Determine how the questions raised in your original hypothesis have been answered. That is, have you fulfilled the aims of your experiment?
3 Relate your results to the background research you completed in the introduction. How do your results compare to previous research?
4 Determine the reliability and validity of your investigation. What problems arose and how could you overcome them in further investigations?
5 Discuss the significance of your results. What is something new or different you have discovered?
6 Outline any new research areas, which, if given time, you would investigate with your current results and understanding.

Accuracy

The accuracy of your experiment depends on several factors, such as the equipment you have used, as well as the expected results. For example, if you were trying to calculate the acceleration of gravity by using a pendulum, you might obtain the following results.

Trial	Value of acceleration of gravity calculated (m/s^2)
1	10.3
2	9.7
3	10.5
4	9.9
5	10.4
Average	10.16

The accepted value for acceleration due to gravity is 9.8 m/s^2. This means that your experiment would be relatively accurate, as you didn't get values of 30 m/s^2 or 1 m/s^2. Accuracy, as with validity and reliability, tends to be a qualitative measure at this stage. It is only valid for you to determine whether your experiment was very accurate, not very accurate, somewhat accurate and so on. You can improve accuracy by using different equipment. For example, rather than using a set of kitchen scales to determine the mass of an object, you may choose to use a balance that can determine the mass of an object to two decimal places. Using a measuring cylinder to measure volume rather than a beaker will also improve the accuracy of your experiment. Accuracy plays an important part in the validity of the experiment.

Reliability and validity

These two concepts are often confused. Reliability is a measure of consistency and repeatability of the investigation; that is, whether similar results can be achieved if the experiment is repeated. Validity is a measure of accuracy and appropriateness of the investigation; that is, whether the experiment actually tests the aim.

The best way to visualise the differences between the two concepts are with an analogy: imagine yourself at an archery competition. You have 15 shots to take. The distance between each of your shots depends on your consistency, so the closer together your shots, the more reliable you are. Hitting the centre of the bullseye is the aim of the test, so the closer and more evenly distributed your shots are to the bullseye the more valid you are.

So what does this look like in a scientific experiment?

The reliability is simply how similar your results are. As you can tell from the archery competition, you want clustered results, i.e. high reliability.

Validity in an experiment is perhaps the more difficult to understand. Validity is based on how you have completed your experiment. Does your experimental method actually test your aim? Have you used appropriate equipment and units to collect your data? Did you control all variables appropriately? Did you use an experimental control? If you can answer yes to all these questions, then your investigation is likely to be highly valid.

Writing a discussion

There is no rule about how to structure a discussion, as sometimes the explanation of the results will take you on different paths. However, the following should serve as a general structure.

- Relate your results to the hypothesis and aim of the experiment.
- Compare your results to those you have gathered from background research. Explain any differences found.
- Explain your results in terms of trends, and give scientific reasons to explain results you have found.
- Comment on the reliability and validity of the results of your investigation.
- Identify any problems in the method you have used and suggest improvements.
- Explain the significance of your experimental findings.
- Suggest areas of future research.

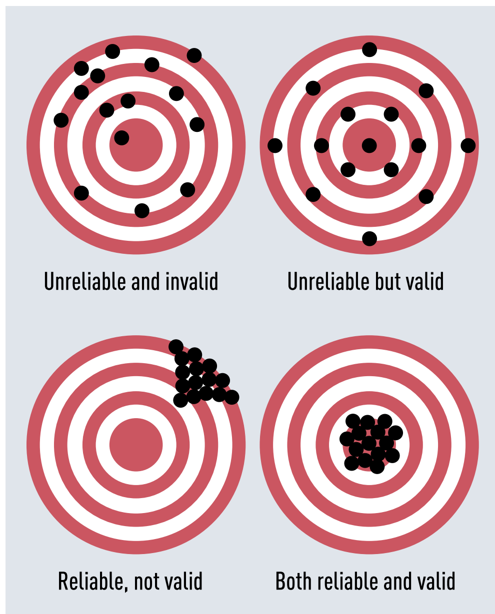


Figure 8.26 An archery analogy of validity and reliability.

QUESTIONS 8.3.4: TRENDS AND EVALUATIONS

Remember

1 Compare a strong negative correlation to a weak positive correlation.

2 Propose what you can infer from data that has no correlation.

3 Explain the difference between reliability, validity and accuracy.

Apply

4 The following data was compiled by scientists studying the number of kangaroos in an area compared the number of dingos.

Number of dingos	Number of kangaroos
9	450
10	380
11	390
12	320
12	340
12	350
13	410
14	350
15	200
15	230
16	190
16	250
20	200
22	140
22	150
23	100
24	90
24	110
25	90

a Draw a scatterplot to display the data.

b Draw a line of best fit through the data and describe any trends.

c Extrapolate the number of kangaroos that would be present if there were only four dingos in the area.

d Extrapolate the number of dingos in the area if there were no kangaroos.

e Using this example, explain why a correlation cannot be used as causality.

f Suggest another variable that may affect the population of both animals.

Analyse

5 In your own research project:

a analyse your data for trends and correlations

b evaluate the reliability, accuracy and validity of your results.

WRAPPING IT ALL UP

Once you have analysed and evaluated your data, you will need to write a conclusion for your scientific report. While you may have written conclusions before, no doubt they have been short (two, maybe three sentences), to reflect the aim.

Conclusions in a scientific report tend to be a full paragraph. They are designed to sum up all the key points of your research, in a short, concise way. There are a number of key points that should each be addressed by a sentence or two in your conclusion. Use Figure 8.26 as a guide.

Keep in mind that the conclusion is the last thing that readers will come across. It should be concise, because they have already read through the rest of your report. The concluding paragraph is needed to round out your report and to give you a final say in what it is that you have discovered.

Finalising the written report

Table 8.11 summarises the order of your report and what to include in each section. There are also references to the different pages in this chapter that explain the requirements of each section in more detail.

The purpose of the investigation was to determine the effect that fertiliser had on the speed of bean sprout growth. It was found that increased mass of fertiliser helped the speed of growth of bean sprouts up to 3 g per 100 g of soil. After this, there was no clear advantage to using fertiliser. This is in accordance to manufacturer's directions of using the correct amount of fertiliser. The maximum limit to the advantage of the fertiliser is likely due to the plant achieving maximum nutrients and growth at 3g per 100 g of soil. A longer period of study would help improve results to ascertain whether additional fertiliser will help long-term growth. Additional research on different plants may help determine whether the effect of the fertiliser is universal for all plants.

What was the aim of the experiment?

What improvements can you suggest to the experiment?

Briefly explain any anomalies in the results.

What were the main findings?

What further research could be completed?

How do your results compare to expected results?

Figure 8.27 A sample conclusion for a scientific report.

Table 8.11 The order and features of sections in a scientific report.

Section	Explanations	Reference
Logbook	Your logbook needs to be submitted separately to your scientific report to show evidence of your planning and long-term work.	Pages 345–346
Introduction	Include background information and hypotheses, or what scientific theories are being tested, or what question is being answered.	Pages 347–352
Materials and methods	Describe what was done so that someone else could repeat your experiment exactly as you did it. Include diagrams. Write in passive past tense.	Pages 354–364
Results	Include tables and graphs. If you did the experiment more than once, include averages of multiple trials as well as related statistics.	Pages 366–381

Section	Explanations	Reference
Discussion	The first paragraph should indicate whether or not your results supported the hypotheses. Note that in general, scientific experiments test hypotheses and the results either support or refute hypotheses. Later paragraphs should deal with other points of interest, such as the accuracy of your experimental data and the errors involved.	Page 378
Conclusion	A very short summary of your experiment, in particular, a statement about how your results supported or refuted the hypothesis you first presented.	Page 380
References	This should include any source material, including textbooks. Your reference section should only use books and articles you have used in writing your report and doing background research.	Page 347
Acknowledgements (optional)	Include a list of people who have helped you in your experiment and perhaps a small note of acknowledgment or thanks.	
Appendix	Include your risk assessment(s), as well as any other results you feel are needed (especially if you did not show your raw data in the results section of the report).	

Other things to consider

Organisation is the key to achieving a good report of a standard expected at a high school level. You need to ensure that you leave enough time to write up your report.

You should also write a draft version of your report. At least one draft is needed, although two or three are recommended. You may be able to submit a draft report to your teacher for feedback. If not, get a friend or family member to read your draft. Your report should be clear enough that someone with no prior knowledge of your topic can understand and follow it.

Remember:

- Keep referring back to the question (aim). Have you strayed from the topic?
- Have you supported your information with facts and references from reliable external sources?

Allow a few days between writing your final draft and starting the finished report. This will allow you time to critically read and edit it. If the report is too fresh in your mind, you will read what you think is there, rather than what you have actually written.

Your final draft should be read several times – once for fluency and clarity of ideas, once for punctuation and once for spelling.

Save your work regularly if working on a computer and back up to at least two different locations. Save your drafts as separate files, rather than overwriting a single document. That way you can revert back to an earlier version if necessary.

Once you have finished your report, ensure that you keep a copy for yourself! Be proud of the effort you have put into your investigation and research!

QUESTIONS 8.3.5: WRAPPING IT ALL UP

Remember

1 Outline at least three things that need to be stated in the conclusion.

2 Explain why conclusions in scientific reports tend to be longer than those in experimental plans.

3 List the order of the sections in your scientific report.

4 Explain why you would need to complete several draft copies before finalising your report.

Apply

5 A student forgot to include their method section in their scientific report. Explain why this is a problem.

6 Suggest reasons why risk assessments are not found in the main body of scientific reports. Where should they be found instead?

8.3 CHECKPOINT

DEALING WITH DATA AND REPORT WRITING

Remember and understand

1 Recall the two main ways you should display experimental data. [2 marks]

2 Suggest reasons why you need to perform statistical analysis on your data, such as mean, range and standard deviation. [3 marks]

3 Recall what the standard deviation of data measures. [1 mark]

4 Identify the best graph to use to plot a continuous independent variable against a continuous dependent variable. [1 mark]

5 Identify the four main trends that can be seen from a scatterplot. [4 marks]

6 If you repeated trials in your experiment, does that increase its reliability, validity or accuracy? Justify your answer. [2 marks]

Apply

7 A student wanted to test the idea that shallots grow better in soil that receives more than 4 hours of sunlight per day compared to soil that only receives 2 hours of sunlight per day. Design an investigation to test this idea. [5 marks]

Analyse and evaluate

8 The following table gives the height (cm) and weight (kg) of female and male university sports students.

Male height (cm)	Male weight (kg)	Female height (cm)	Female weight (kg)
165	57	152	46
157	59	154	47
158	64	156	49
172	69	159	52
177	75	163	56
182	83	168	62
186	90	172	68
189	97	175	71
190	100	176	75

a Use a computer program, graphics calculator or manually graph the two sets of data on a single set of axes. [4 marks]

b Describe any trends in the data. [2 marks]

c Compare the results for the females and the males. [2 marks]

d If a female student was 180 cm in height, extrapolate her weight. [1 mark]

e Interpolate the weight of a male student who is 175 cm in height. [1 mark]

f This survey takes into account 18 sports students in total. Would the results of this survey be valid to apply to all university students? Justify your answer [2 marks]

g Would the results of this survey be valid to apply to all students (primary, secondary and university)? Justify your answer. [2 marks]

h Suggest a way to make this survey more reliable and valid so that the results can be applied to the general population. [1 mark]

Ethical behaviour

9 Public health surveys are often completed by government agencies. Identify some ethical issues with making this type of data public and suggest some ways to avoid these issues. [3 marks]

Critical and creative thinking

10 Experimental design and scientific reporting is a very important part of a scientist's job.

a Suggest some ways that scientists can communicate with the general public about their findings. [2 marks]

b Do you think you would want to find out about every aspect of the topic that a scientist researches? Explain your answer. [2 marks]

TOTAL MARKS
[/40]

8 CHAPTER REVIEW

1 Fill in the gaps, using the words in the Word Bank below.

The ________________ method involves coming up with a ________________, then testing that hypothesis through first-hand ________________. When planning first-hand research, you need to examine secondary research for ________________ information. The ________________ of a first-hand investigation is planned so that a fair test can be completed, where the ________________ and dependent variables are the only two things that are ________________ within an experiment. Data can be gathered from experimentation. The results then need to be ________________. This analysis can take place through statistics and plotting a ________________ to determine the ________________. The investigation is then analysed and a conclusion reached. If the investigation shows results that back up the hypothesis, then the hypothesis is ________________. If not, a new hypothesis to explain the results is then made and re-tested.

WORD BANK

analysed	graph	method	trend
background	hypothesis	research	upheld
changed	independent	scientific	

Develop questions and hypotheses to be investigated

2 List some criteria regarding ethics and safety that will exclude some projects from being investigated safely. [2 marks]

3 A student set out to investigate whether ants are attracted to sweet substances or salty substances.

a Suggests some ethical issues with this. [2 marks]

b Predict the outcome of this experiment based on your background knowledge. [1 mark]

4 Patricia wanted to investigate whether wing length affects the distance a plane flies.

a Identify the independent and dependent variable in her investigation. [2 marks]

b Suggest a hypothesis for her experiment. [1 mark]

Apply scientific understanding and critical thinking to suggest solutions to problems

5 Jason was working on an experiment to determine the frictional force on a block of wood down a slope. He noticed that the block of wood would slide down too quickly for him to get any meaningful results. Suggest some ways he can alter his experiment to achieve his aim. [3 marks]

6 When you completed your independent research project, you would have encountered many problems, which may have ranged from obtaining materials, finding reliable information to interruptions to your data gathering.

a Identify a problem you had. [1 mark]

b Explain how you overcame that problem. [1 mark]

c Evaluate how successful your solution to the problem was. [1 mark]

7 Alexandro was working on an experiment to determine the optimum amount of fertiliser to use when growing wheat. In a small container, he used four stalks of wheat as his trials. In his introduction, Alexandro explained that his experiment was designed as a model of a large-scale farming operation.

a Justify Alexandro's statement about his model. [2 marks]

b Explain why models are used in science. [2 marks]

c Suggest how Alexandro's experiment may be useful in the scientific industry. [2 marks]

Produce a plan to investigate questions, hypotheses or problems

8 Indicate what is required in producing a risk assessment. [2 marks]

9 Explain what is meant by 'completing a fair test'. [3 marks]

10 Compare an independent variable and a dependent variable. [2 marks]

11 Compare and contrast controlled variables (constants) and experimental controls. [2 marks]

Undertake first-hand investigations and collect valid and reliable data and information

12 Identify the appropriate units required to measure: [3 marks]

- **a** mass
- **b** volume
- **c** speed
- **d** distance
- **e** time
- **f** density.

13 Peter planned an investigation to examine the salt content of an estuary environment. He and his parents went out on a row boat around a river and at every 10 metres, took a water sample. Peter then went back into the laboratory and used a conductivity meter to measure the salt levels at each place where he sampled.

- **a** Identify the piece of technology that Peter used to gather his data about salinity. [1 mark]
- **b** Estuary environments are where freshwater rivers meet the ocean. Predict what Peter's results may look like. [2 marks]
- **c** Evaluate the validity of Peter's experimental method. [4 marks]
- **d** Suggest improvements to make Peter's method more reliable. [2 marks]

Process, analyse and evaluate experimental and secondary data to develop evidence-based arguments and conclusions

14 Suggest reasons why data gathered from first-hand investigations should be represented in tables and graphs. [2 marks]

15 Sandra investigated how the amount of gas used to heat water affected the change in temperature of the water. She heated 100 mL of water in a beaker using a single small camping gas cylinder for 2 minutes. She then repeated her experiment, but used two, three, four and five gas cylinders instead to heat 100 mL of water for 2 minutes. At the start of each trial, the temperature of the water was noted. Sandra obtained the following results.

Number of gas cylinders	Starting water temperature (°C)	Finishing water temperature (°C)
1	18	24
2	17	30
3	19	35
4	18	40
5	19	48

- **a** Redraw the table in your books with the temperature change as another column. Calculate the temperature change for each data point. [2 marks]
- **b** On a piece of graph paper, draw an appropriate graph to display these results. [4 marks]
- **c** What would be the likely air temperature of the room where Sandra was completing the experiment? Justify your answer. [2 marks]
- **d** From your graph, determine how much gas would be required to raise the temperature by 40°C in 2 minutes. [1 mark]
- **e** From your graph, determine what temperature 3.5 gas cylinders will raise the temperature to, if you had a starting temperature of 19°C. [2 marks]

Present scientific evidence to support conclusions using appropriate scientific language, conventions and representations

16 Name the section in a scientific report where results are analysed in detail. [1 mark]

17 Scientists often prefer to use black and white pictures or black and white keys for graphs. Give a reason as to why these are often better than coloured diagrams. [1 mark]

18 Describe the key features of language you should use to present your information. [2 marks]

19 Suggest why scientists need to communicate their findings to different audiences. [2 marks]

8 CHAPTER REVIEW

TOTAL MARKS
[/60]

REFLECT

Me

1 How successful was my independent research project?

2 What did I find difficult with the independent research project?

3 What problems did I come across in my project and how did I solve them?

My world

4 How does my independent research project relate to how a scientist works in the laboratory?

5 What applications does my research have to my life? To the community?

My future

6 Was I interested in the research that I carried out? Can I see myself doing this type of research?

7 What new developments will come about because of scientific research?

KEY WORDS

controlled variable
correlation
dependent variable
experimental control
extrapolate
fair test
hypothesis
independent variable
inference
interpolate
logbook
mean
observation
qualitative
quantitative
range
reliable
standard deviation
trend
valid
verify

GLOSSARY

A

ABIOTIC non-living

ABSOLUTE DATING determining the age (in years) of a rock or object by using the radioactive decay of elements

ABSOLUTE MAGNITUDE scale for measuring the brightness of objects if they were placed at the same distance from Earth

ABSORPTION SPECTRUM spectrum with lines missing from the pattern; opposite of an emission spectrum because the element has absorbed its characteristic light wavelengths so they are removed from the spectrum

ACCELERATION rate of change of velocity; rate of change of speed if the motion is in a constant direction

ACCELERATION DUE TO GRAVITY (*g*) acceleration of an object due to a planet's gravitational field; on Earth, $g = 9.8\ \text{m/s}^2$ (to one decimal place) or $g = 10\ \text{m/s}^2$ (to the nearest whole number for ease of calculations)

ACID chemical compound with a $pH < 7$ that tastes sour and contains at least one hydrogen atom

ACIDIC OXIDE oxide that dissolves in water to make an acid

ACTIVATION ENERGY energy required to start a chemical reaction

ADSORB stick onto

AEROBIC reaction environment rich in oxygen

ALCOHOL name of an entire family of compounds that contain carbon, hydrogen and oxygen

ALKALI base that dissolves in water

ALKALINE solution formed by soluble bases

ALLELE different form of a gene

ALLOPATRIC SPECIATION process by which new species arise in isolated populations

AMINO ACID monomer unit that combines with others to form protein molecules

ANAEROBIC reaction environment without oxygen

ANALOGOUS STRUCTURE structure in an organism that performs the same function as another structurally different one in another organism

ANODE negatively charged electrode

APPARENT MAGNITUDE scale for measuring the brightness of an object when viewed from Earth

ARTIFICIAL SELECTION process by which humans intentionally breed organisms for specific traits

ATMOSPHERE layer of gases that surround the Earth

AUTOSOMAL any chromosome that is not a sex chromosome

B

BASE (CHEMISTRY) chemical compound with a $pH > 7$ that tastes bitter and is soapy to touch

BASE (DNA) nitrogen-containing section of a nucleotide that differentiates the monomers

BIG BANG THEORY theory that states that the universe began from a hot, dense state at some time in the past, from when it has continued to expand and will continue to do so into the future

BIOFUEL any fuel produced from organic (once living) matter

BIOGEOGRAPHY distribution of organisms over the Earth's surface

BIOSPHERE all the living things on the Earth

BIOTIC living

BLACK HOLE region in space of infinite density where gravity is so large that nothing can escape from it, including light

C

CARBON SINK any feature of the environment that absorbs and/or stores carbon

CARRIER individual who is heterozygous for a recessive condition; they do not show the phenotype, but may pass the allele to their offspring

CATALYST substance that increases the rate of a reaction but is not used up in the reaction

CATHODE positively charged electrode

CHARGE-COUPLED DEVICE (CCD) light-sensitive electronic device made from semiconductor material; used in digital imaging for converting light into electrical signals; pixels store electric charge proportional to the amount of light that falls on each pixel

CHEMICAL EQUATION shorthand way of showing what happens to the reactants and products in a chemical reaction

CHEMICAL FORMULA shorthand way of describing the ratio of elements in a compound or molecule

CHROMOSOME long strand of tightly wound DNA made up of many genes joined together

CLIMATE weather conditions at a particular place over a long period of time based on the collection and analysis of large amounts of data

CLIMATE CHANGE any long-term change in the Earth's weather; can be evident in changes to averages, extremes or other statistical measures

CLOUD visible collection of condensed water vapour particles floating in the atmosphere

CODON group of three bases within a gene that codes for a single specific amino acid

COLLISION THEORY theory that states that for a chemical reaction to occur, the atoms, ions or molecules must collide in the right orientation and with enough energy

COMBUSTION reaction that involves a substance rapidly combining with oxygen, usually accompanied by a flame; burning

COMMON DESCENT group of organisms sharing a common ancestor

CONSTELLATION grid-like segment of stars in the sky; older definition was a group of stars that appear to form a pattern

CONTROLLED VARIABLE factor kept constant during an experiment

CONVERGENT EVOLUTION process by which distantly related organisms develop similar structures

CORRELATION relationship between two variables where the cause and effect are not necessarily known

CORROSION reaction that involves the oxidation of a substance, usually a metal

COSMIC MICROWAVE BACKGROUND RADIATION (CMBR) form of electromagnetic radiation in the microwave spectrum left over from the formation of the universe; evidence for the Big Bang theory

CRUST outer layer of the Earth, 7–50 km thick

CRYOSPHERE part of the hydrosphere that is made up of frozen water

CYCLONE large weather system with high winds circling a low-pressure centre

D

DECELERATION slowing down; also known as negative acceleration

DECOMPOSITION reaction that involves the breakdown of a compound into simpler substances; energy in the form of heat or electricity is required to break the bonds in the reactants

DENITRIFYING BACTERIA bacteria that can return nitrogen to the atmosphere

DEOXYRIBONUCLEIC ACID (DNA) complex giant molecule that determines all the structures and functions in a cell; usually organised into chromosomes and contained in the cell nucleus

DEPENDENT VARIABLE variable that changes as a result of the independent variable; the variable that is measured during the experiment

DIPLOID cell containing two copies of each specific chromosome; somatic cells are diploid

DISPLACEMENT (PHYSICS) vector quantity that measures the change in position of an object and its direction

DISPLACEMENT (CHEMISTRY) swapping of ions between two salts in solution

DISTANCE scalar quantity that measures the total length of the path of an object

DIVERGENT EVOLUTION process by which related organisms become different from each other

DNA LIGASE enzyme that joins nucleotides together to form strands of DNA

DOMINANT allele that is always expressed when present in the genotype

DOUBLE HELIX shape of a DNA molecule consisting of two strands joined together at complementary bases, which twist around each other to form a 'twisted ladder'

E

EARTHQUAKE jolting of the Earth's surface caused by the release of built-up pressure in the Earth's plates

ECOLOGIST scientist who studies the interaction between living things and their environment

ECOLOGY study of the relationship of organisms to each other and the environment

EFFICIENT a measure of the transfer of energy in a system without loss

EL NIÑO weather pattern in which a warm current off South America leads to cooling and drought in eastern Australia

ELASTIC POTENTIAL ENERGY (EPE) energy possessed by stretched or compressed objects

ELECTROCHEMICAL CELL device that produces electricity from an exothermic chemical reaction or that uses electricity to drive an endothermic chemical reaction

ELECTRODE terminal by which electricity passes into or out of a conducting substance

ELECTROLYSIS use of electricity to provide energy for a chemical reaction

ELECTROLYTE solution or molten substance in which an electric current is made to flow by the movement of ions

ELECTROMAGNETIC RADIATION transverse wave that carries energy consisting of perpendicular oscillating electric and magnetic fields; includes visible light, radio waves, infrared light, gamma rays and X-rays

EMISSION SPECTRUM pattern of wavelengths (or frequencies) that appear as coloured lines in a spectroscope; unique to each element

ENDOTHERMIC requires input of energy

ENERGY the capacity to do work; derived from sources such as motion (kinetic), position (potential), heat (thermal), chemical and nuclear

ENHANCED GREENHOUSE EFFECT increased greenhouse gases in the atmosphere due to human activity

ENZYME biological catalyst produced in cells, capable of speeding up the chemical reactions needed for life

EUTROPHICATION process whereby high levels of phosphorus in waterways lead to the excessive growth of algae and bacteria and an increased consumption of oxygen, suffocating fish and other aquatic animals

EVOLUTION gradual change in the genetic material of a population of organisms over a period of time

EXOTHERMIC releases energy

EXPERIMENTAL CONTROL condition or trial within the experimental design that does not apply to the independent variable and is used to compare to experimental conditions

EXTINCTION dying out of a species

EXTRAPOLATE using a known trend in data, or line of best fit, to extend a graph and predict data points

F

FAIR TEST controlled experiment

FERTILISATION process of sperm DNA joining with ovum DNA to form a diploid zygote cell

FORCE push or pull

FORCE DIAGRAM a pictorial way of representing the forces involved in a situation; also known as a vector diagram

FOSSIL remains or imprints of animals or plants preserved in rock

FOSSIL FUEL fuel such as coal, oil and natural gas, produced from ancient organisms, mainly plants, that lived millions of years ago

FOSSILISATION process by which animal or plant remains become preserved in rock

FUEL substance that will undergo a chemical reaction to produce a large amount of useful energy at a fast but controllable rate

G

GALAXY collection of billions of stars held together by their own gravity

GAMETE sex cell; in humans, the sperm and egg

GENE section of a DNA molecule that contains information for one specific characteristic

GENE FLOW movement of genes from one population to another

GENE POOL all the genes or alleles in the entire population

GENETIC ENGINEERING process of modifying genes in some way

GENETIC SCREENING process of 'reading' the DNA of an individual to locate specific traits

GENOME full set of genes in a species

GENOTYPE allele combination for a particular trait of an individual

GEOGRAPHIC ISOLATION where a population is divided into smaller groups by a barrier

GEOLOGIST scientist who studies the origin, composition, structure and history of the Earth

GRAVITATIONAL POTENTIAL ENERGY (GPE) energy possessed by objects raised to a height in a gravitational field

GREEN CHEMISTRY study and development of new substances that have a low impact on the environment

GREENHOUSE EFFECT absorption of heat energy by gases in the atmosphere

GREENHOUSE GAS gas that traps some heat inside the Earth's atmosphere

H

HAPLOID cell containing one copy of each specific chromosome; gametes are haploid

HERITABLE any characteristic that is coded for within DNA and can be passed from parent to offspring

HERTZSPRUNG–RUSSELL DIAGRAM graph for plotting star brightness and temperature or colour; used to study the life cycle of stars and to relate the measured properties of stars to their other properties

HETEROZYGOUS when the alleles are different in a genotype (e.g. Bb)

HOMOLOGOUS PAIR corresponding pairs of chromosomes that contain the same genes, but not necessarily the same alleles

HOMOLOGOUS STRUCTURE structure found in different organisms that has a similar pattern but may have a different function

HOMOZYGOUS when both alleles are the same in a genotype; also known as pure breeding

HYDROCARBON compound of carbon and hydrogen

HYDROSPHERE collection of all the Earth's water

HYPOTHESIS testable explanation of a phenomenon

I

IGNEOUS ROCK rock formed from cooled lava or magma

INDEPENDENT VARIABLE variable that is deliberately altered during an experiment; the cause of changes in the dependent variable

INDICATOR substance that changes colour in the presence of an acid or base

INERTIA tendency of an object to resist changes in its motion while either at rest or in constant motion

INFERENCE likely explanation of an observation

INNER CORE Earth's innermost part, which is shaped like a ball and made mostly of iron and nickel

INTERPOLATE using a known trend in data, or line of best fit, to predict additional points within the data range of a graph

ISOLATING MECHANISM property that stops two populations interbreeding

K

KARYOTYPE number and appearance of the chromosomes in the cell nuclei of an organism or species

KINETIC ENERGY (KE) energy possessed by moving objects

L

LA NIÑA weather pattern that produces warming and wet weather in Australia

LAW OF CONSERVATION OF ENERGY scientific law that states the total energy in a system is always constant; energy cannot be created or destroyed, only transformed from one form to another

LAW OF CONSERVATION OF MASS scientific law that states the total mass of the reactants in a chemical reaction always equals the total mass of the products

LIGHT YEAR distance that light travels in 1 year

LITHOSPHERE outermost rocky layer of the Earth, consisting of the mantle and crust

LITMUS PAPER commonly used indicator that becomes red in an acid and blue in a base

LIVING FOSSIL existing species of ancient lineage that has remained unchanged in form for a very long time

LOCK-AND-KEY MODEL model that explains the action of enzymes, which contain a lock (active site) into which the reactants fit in order to form the products of a reaction

LOGBOOK place to keep all notes and ideas, research information, experimental data and conclusions about the research topic

M

MAGNITUDE often refers to a number and the relative size of that number; the size or length of the arrow that represents a vector quantity

MANTLE layer of the Earth beneath the crust 2800 km thick

MEAN mathematical average of data scores

MEIOSIS process of cell division in which the number of chromosomes in the cell is halved; its primary purpose is to produce gametes

METAMORPHIC ROCK rock changed by heat and pressure

MONOHYBRID CROSS genetic cross between two heterozygous (hybrid) individuals when one (mono) characteristic is being studied

MONOMER small molecule from which polymers are made

MUTATION change that occurs at the DNA level that may add, delete or rearrange genetic material

N

NATURAL SELECTION process whereby the occurrence of a particular trait in a population changes as a result of certain individuals producing more offspring than others because they are better suited to survive and reproduce in that environment

NEBULA cloud of gas and dust in space

NET FORCE vector sum of all the forces acting on an object; also known as resultant force

NEUTRAL substance that is neither an acid nor a base; pH = 7

NEUTRALISATION when an acid and a base react to neutralise each other and form a salt and water

NEUTRON STAR small, highly dense star, made mostly of neutrons

NICHE small area within a habitat with highly specific conditions

NITROGEN-FIXING BACTERIA bacteria that can convert nitrogen from the atmosphere into various nitrogen compounds

NUCLEIC ACID chemical compound that makes up all genetic material; DNA and RNA

O

OBSERVATION use of all of your senses to notice things around you

OVARY sex organ responsible for the production of female gametes (ova)

OVUM female gametes

OXIDANT substance that can supply oxygen or take the place of oxygen in an oxidation reaction

OXIDATION reaction that involves the combination of oxygen with a fuel or metal

OZONE form of oxygen consisting of three oxygen atoms; absorbs ultraviolet light in the atmosphere that would otherwise be harmful to humans

P

PALAEONTOLOGIST scientist who studies fossil records and determines their relationships with different geological time periods

PEDIGREE recorded ancestry of an individual

PENTADACTYL LIMB limb with five digits

***p*H SCALE** scale that indicates the relative acidity or alkalinity of a solution; ranges from 0 to 14

PHENOTYPE physical presentation of a characteristic (e.g. black hair)

PHOTOLYSIS breakdown of a chemical substance by light; e.g. the breakdown of water into oxygen and hydrogen

PHOTOSYNTHESIS process in plants in which glucose is made from water and carbon dioxide

PLANETARY NEBULA glowing shell of gas formed when a star dies

PLATE TECTONICS theory that states that large plates of the Earth's crust gradually move and interact

POLLUTANT chemical substance that is in the wrong place or is present in the wrong amount

POLYMER giant molecule formed by joining many smaller repeating molecules (monomers) together

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

POPULATION group of interacting individuals of a species living in a particular area

PRECIPITATE insoluble compound formed in a precipitation reaction

PRECIPITATION (CHEMISTRY) when solid products 'fall out' of solution of ionic substances

PRECIPITATION (CLIMATE) droplets of falling rain, hail or snow

Q

QUALITATIVE descriptive data, using words; not based on measurement or numerical data

QUANTITATIVE numerical data, such as a measurement or a tally

R

RANGE measure of variation between quantitative results; the difference between the highest and lowest scores

REACTION RATE speed at which a chemical reaction proceeds

RECESSIVE allele that is only expressed in the absence of the dominant allele

RED GIANT large, bright star with a cool surface that forms when a star like our Sun runs out of hydrogen fuel

RED SHIFT apparent decrease in frequency (towards the red end of the spectrum) of light from galaxies that are moving away from the Earth

REDUCTANT substance able to remove and combine with oxygen taken from other substances

REDUCTION reaction that involves the removal of oxygen

RELATIVE DATING process of working out the age of rocks as being younger or older than existing rocks

RELIABLE describes data that can be consistently obtained through repeating the experimental method

REPLICATION process of copying DNA

RESPIRATION combination of an organic molecule with oxygen in cell that provides energy

RESTRICTION ENZYME enzymes responsible for 'cutting' DNA at specific points within a sequence

REVERSIBLE chemical reaction that can also occur in reverse

S

SALT chemical substance formed in a reaction between an acid and a base, usually a metal and non-metal combination; common or table salt, NaCl, is one type of salt

SCALAR quantity that has size but not direction (e.g. speed, distance)

SCIENTIFIC THEORY comprehensive explanation of some aspect of nature supported by a vast body of evidence

SEDIMENTARY ROCK rock made of pre-existing material such as sediments

SEX CHROMOSOME chromosome that differs between the sexes and determines the gender of the individual; human females have two X chromosomes and human males have an X and a Y chromosome

SEXUAL DIMORPHISM difference in appearance of males and females of the same species

SEXUAL SELECTION selection for traits that provide an advantage with regard to mating

SOMATIC refers to body cells rather than gametes

SPECIATION process that results in the formation of a new species

SPECIES group of organisms that look similar, and can breed and produce fertile offspring

SPEED quantity that conveys how fast an object travels a certain distance; the rate of change of distance over time

SPERM male gametes

STANDARD DEVIATION measure of variation between quantitative results that also indicates reliability

STAR object in space made of mostly hydrogen and helium, sustaining nuclear fusion reactions in and around its core

STEADY STATE THEORY theory that states that the universe has always existed and that matter is constantly being created at an enormous rate, causing the universe to expand

STELLAR PARALLAX change in apparent position of a star against its background when viewed from two different positions

STRATA layers of rock laid down at different times

SUGAR–PHOSPHATE BACKBONE structure of the side chains of DNA

SUN closest star to the Earth at the centre of our solar system

SUPERNOVA explosive death of a star

SURVIVAL OF THE FITTEST individuals in a population that are 'fitter' or better suited to survive and reproduce in their environment contribute more to the next generation than those that are less 'fit'

SYMPATRIC SPECIATION process by which new species arise in the same location

SYNTHESIS reaction that involves the building up of compounds by combining simpler substances, normally elements

T

TECTONIC PLATE large area of the Earth's crust that may include continents and/or sea floor

TELESCOPE device that can collect and focus electromagnetic radiation

TEST CROSS genetic cross between an individual with the dominant phenotype and one with the recessive phenotype; used to determine the genotype of the dominant phenotype

TESTIS sex organ responsible for the production of male gametes (sperm)

TICKER TIMER laboratory device commonly used to measure the speed of objects

TRACE FOSSIL moulds, casts or imprints of the activity of previous organisms

TRANSFER move from one place to another; energy is transferred when it is passed from one object to another

TRANSFORM convert from one form to another; energy is transformed when it is converted from one form to another

TRANSGENIC any individual or cell with altered DNA

TRANSITIONAL FOSSIL fossil or organism that shows the intermediate state between an ancestral form and that of its descendants; also known as a 'missing link'

TREND pattern or predictable relationship between two variables

U

UNIVERSAL INDICATOR accurate indicator that indicates the strength of an acidic or a basic solution

V

VALID describes results that accurately reflect the aim of the experiment

VECTOR quantity that has size and direction (e.g. velocity, displacement)

VECTOR DIAGRAM diagram in which individual vectors (e.g. forces) are joined head-to-tail in order to determine the overall effect

VELOCITY vector quantity that measures speed in a particular direction

VENT opening in the Earth's surface through which lava, gas and ash are ejected

VERIFY checking the accuracy of information with multiple, different sources

VESTIGIAL STRUCTURE structure that once performed a function in an ancestor but in the course of evolution has become functionless

VOLCANIC ERUPTION sudden discharge of lava, gas and/or ash from a volcanic vent

W

WATER VAPOUR gaseous water

WATSON–CRICK MODEL double helix structure of DNA in which two sugar–phosphate backbone chains are joined together with pairs of complementary bases

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

WEATHERING breakdown of rock

WEIGHT force of gravity acting on an object

WHITE DWARF small, hot star that forms when a star like our Sun runs out of fuel and slowly fades and cools

WORD EQUATION shorthand way of describing a chemical reaction in words; reactants are on one side of the equation and products on the other

WORK product of the force acting on an object by the distance caused by that force; measured in joules; work involves energy transformations

INDEX

D

E

F

G

O

P

Q

R

S

T

U

V

W

X

Y

Z

ACKNOWLEDGEMENTS

The research and development of Insight Science series was a process that involved many people. We would like to acknowledge them here:

Kristin Alford, Erin Bruns, Francesca Calati, Debbie Calder, Sally Cash, Amanda Clarke, Craig Cleeland, Leanne Compton, Gillian Coyle, Emma Craven, John Denmead, Ellaine Downie, Karen Drought, Teresa Eva, Anita Giddings, Eileen Kennedy, Christina Hart, Rosemary Koina, Greg Laidler, David McGowan, Karen Marangio, Daniela Nardelli, Rebecca Paton, Geoff Quinton, Peter Razos, Pam Robertson, Duncan Sadler, Maggy Saldais, Lynda Schulz, Nola Shoring, Helen Silvester, Jonathan Smith, Angela Stubbs, Mary Vail, Richard Walding, David Wilson.

Students and staff at: Koonung Secondary College, Mentone Girls' Grammar School, Rosehill Secondary College and Wantirna Secondary College for participating in location photography.

The author and the publisher wish to thank the following copyright holders for reproduction of their material.

AAP Image/Department of Primary Industries, 7.56 /Kyodo News, 7.14 /Native Fish Australia/ Michael Hammer, 7.61/Roderick Eime, 2.23 (b) /Supplied, 2.73; Article, 'Cold-blooded climate change surprise,' by Stephen Pincock. Reproduced by permission of the Australian Broadcasting Corporation and **ABC Online**. © 2012 ABC. All rights reserved, p.319; **Alamy**/Arcangelo Manoni , 2.43 (a) /Auscape International, 2.63 (a) /Blend Images, 8.4 /BSIP, 1.65 /Cultura RM, Chapter 5, chapter review, p.234 (watermelon, bottom) /David Fleetham, 2.55 /David R. Frazier, 3.27 /Dorset Media Service, The Origin of Species, p.97 /Heritage Image Partnership Ltd, 1.1 (a) /Interfoto, 4.61 /Joe Fox, 5.28 /Jonathan Day, 5.55 /Juniors Bildarchiv GmbH, 2.1, 2.16 /Justin Kase ztwoz, 5.33 /Karlmarx Rajangam , 2.39 /Michael Willis, 3.33 /petpics, 7.53 /Phototake, 1.71 /Phototake Inc., 1.21 /redbrickstock.com, Chapter 5, chapter review, p.233 (freeway) / Science Photo Library, 4.3 /studiomode, 3.18 /Tony Cordoza, 4.41; © **Australian Museum**/ Carl Bento, 2.51; **Burrup Fertilisers Pty Ltd** 2011, 4.63; Courtesy of The Archives, **California Institute of Technology**, 1.49; **Corbis**/Alberto Garcia, 7.16 /Bettmann, 4.62 /Bettmann, 2.3 /Caroline, 3.43 /Darrell Gulin, 2.62 (b) /David Scharf/Science Faction, 7.12 /David Scharf/ Science Faction, 1.67 /David Watts/Visuals Unlimited, 2.27 /Dean Conger, 4.8 (a) /DLILLC, 2.1, 2.3, 2.8 (left) /Dr. David Phillips/Visuals Unlimited, 1.5 /Frank Krahmer, 7.48 (a) /Fridrik Orn Hjaltested/Nordicphotos, 1.35 /Hulton-Deutsch Collection, 2.11 /Jamal Nasrallah /epa, 6.4 /Joe McDonald, 2.62 (a) /John Lee/Aurora Photos, 4.54 /Karen Hunt, 2.66 /Karen Kasmauski, 1.55 / Karen Kasmauski/, 1.69 /Leo Mason, 5.24 /Mike Kemp/Tetra Images, 4.33 /Ocean, 4.49 /Roger Ressmeyer, 6.48 /Science Photo Library, 3.37 /Scott Andrews/Science Faction, 4.16 (c) /Stocktrek Images, 6.32 /Tim Davis, 7.48 (b) /Tim Hauf/ Visuals Unlimited, 2.71 /Tim Pannell, 5.44 /Tim Wright, 5.50, 5.51 /Tom Van Sant, 6.30 /Udo Richter/epa, 2.23 (a) /Visuals Unlimited, 5.54 /W. Wisniewski, 2.24 /Wolfgang Flamisch, 1.7 /Zhang Jiansong/Xinhua Press, 7.5; **darwin-online.org.uk**/converted/published/1859_Origin_F373/1859_Origin_F373_fig02.jpg, 2.15 (b) **EFBrazil** via Wikimedia Commons, 6.53; **ESA**/Image by AOES Medialab, 6.50; **Fairfax Syndication**/ Glen McCurtAyne, 6.28 (bottom) /Paul Harris, 6.28(top) /Peter Mathew, 7.40; **Getty Images**, 3.21, 4.44, Chapter 5, chapter review, p.234 (train, top), Cover, contents page, crash test dummy, p.228 /AFP, 2.4 /Andew Syred, 1.34 /Auscape, 7.41 /Ben Cranke , 7.43 /Biophoto Associates, 1.1 /Bloomberg, 1.59 /Cultura/Richard Robinson, 2.28 /Dan Kitwood, 7.17 /Dave Einsel/ Stringer, 2.72 /David Greedy/ Stringer, 1.6 /David Hannah, 7.58/Detlev van Ravenswaay, 6.40 /Doug Cheeseman, 2.4 /E.R. Degginger, 3.3 /Ed Reschke, 2.37 /Eve Parry, 2.46 /Francis Leroy, Biocosmos, 2.33 /fStop Images - Caspar Benson, 5.53/Gallo Images, 2.63 (b) /Hulton Archive, 3.26 /Jesse Swallow, 4.46 /Jon Hicks, 4.48 /Kim Heacox, 7.6 /Kristian Bell, 7.50 /Lambert, 4.31 / Mark Jones, 2.8 (right) /Mark Kolbe, 5.58 /MedicalRF.com, 1.24 /Medioimages/Photodisc, 5.43 /Michael Rosenfeld, 4.35 /Nigel Cattlin, 7.28 /NLM/Science Source, 1.3 /Norbert Wu, 2.13 / Pascal Le Segretain, 1.42 (bottom) /Pascal Le Segretain, 1.42 (top) /Paul & Paveena Mckenzie, 7.51 /Peter Walton Photography, 7.26 /photo researchers, 2.35 /Power and Syred, 1.26 /Radius Images, 4.8 (b) /Regi Varghese, 5.59 /Robin Bush, 2.38 /Romilly Lockyer, 5.29 /Science Photo Library, 4.30 /Science Photo Library/Pasieka, Chapter 1 opening image /Simon D Pollard, 2.6 /

SM/ Aiueo, 5.34 /SPL, 1.1, 1.1 (b), 1.15, 1.57, 1.58, 1.66, 1.72, 1.74, 2.34, 7.22, 7.33, 7.39, 7.7 / SPL Creative, 5.56, 2.36, 2.7 /SSPL, 7.54 /Steve Allen, 2.14 /Stocktreck Images, 7.18 /Sven Zacek, Back cover, contents page /syagci, 2.41 /Tim Flach , 2.32 /Time and Life Pictures, 1.22 /Tom Brakefield - The Stock Connection, 5.8 (a) /Tui De Roy, 2.44 /UIG, 7.32; **IPCC**, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Figure SPM.3. [Stocker,T.F., D.Qin, G.-K. Plattner, M.Tignor, S.K.Allen, J.Boschung, A.Nauels, Y.Xia, V.Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK and New York, USA., Table 7.2; **iStockPhoto**/Brandon Laufenberg, 5.31 /Christian Uhrig, 3.42 /Christopher Steer, 50 /Dean Turner, 1.40 (a) /elkor, 5.45 /idizimage, 6.1 /Igor Shootov, 5.23 /Jessica Morelli, 5.27 /Marek Mnich, 4.47 /Peter Lora, 2.42 /Petre Milevski, 4.58 /pixhook, 4.57 /Sergii Tsololo, 6.23b /ShyMan, 5.15 /Thepalmer, 1.37 /Yahya Idiz, 6.2 /Zeffss1, 6.23a /Jenny Zhang, 8.3, 8.5; **K.T Grant**. Reproduced by permission of Peter Grant, 2.68; **Lochman Transparancies**, 7.63; **Luna Park**, Chapter 5, Chapter Review, p.235 (G-Force ride at Luna Park); **Michael Hammer**, 7.62; **Museum of New Zealand Te Papa Tongarewa**, OR.005098, 7.49; **Museum of Victoria**/ Peter Swinkels, 2.5; **NASA**, 6.33, Table 7.3 /ESA, and the Hubble SM4 ERO Team, Table 6.1 (Galaxies) /Apollo, 6.35 /Goddard Scientific Visualization Studio, 7.44 / X-ray: /CXC/SAO, Infrared: /JPL-Caltech; Optical: MPIA, Calar Alto, O.Krause *et al*., 6.8 **Newspix**/Collen Petch, 4.50 /Justin Lloyd, 5.1 checkpoint image, p.210; **Peter Batson**/DeepSeaPhotography.Com, 7.11; **Picture Media**/Reuters/Ho New, 7.59 /Reuters/Kyodo Kyodo, 7.13; **Rogier Windhorst and Sam Pascarelle (Arizona State University)** and NASA, 6.47; **Samantha Hopley**, 2.26; **Science Photo Library**, 2.6 (a, b & c), 3.39, 4.14, 4.60, 6.25, 6.39, 7.37, 8.13, 3.11 (third down), 3.11 (top), lemon cell battery, p.364 /Adam Hart-Davis, 3.25 /Adam Hart-Davis, 3.38 / Alex Cherney, Terrastro.com, 6.12, opposite imprint page /Andrew Lambert Photography, 3.14, 4.12, Chapter 3 opening image /Annie Haycock, 5.8 (b) /Ben Johnson, 4.37 /CNIR, 1.73 (a) / David Nunuk, Chapter 6 Review (Parkes Telescope) /David Taylor, 3.30 /Detlev Van Ravenswaay, Chapter 6 opening image /Dr Jeremy Burgess, 1.51 /Dr Philippe Vago, 1.33 (b), 1.33 (a), 1.8 / Dr Tim Evans, 6.52 /European Space Agency, the Planck Collaboration, 6.49 /Frans Liting/Mint Images, 2.43 (b) /Garry Hincks, 7.8, 7.25 /Goddard Space Flight Center, 7.47 /GustoImages, 3.15 /Harald Ritsch, 6.51 /Henning Dalhoff, 6.27 /Joe Tucciarone, 6.21 /John Durham, 2.48 /John Sanford, 6.22 /Laguna Design, 55 /Luke Dodd, 6.11, Table 6.1 (Stars) /Mark Garlick, 6.17, 6.37 /Martyn F. Chillmaid, 3.23, 4.23, 4.25 /Matteis/Look At Sciences, 4.53 /Matthew Russell, Visuals Unlimited, 6.6 /Maximilian Stock Ltd, 36 /Mikkel Juul Jensen, Table 6.1 (Solar System) /NASA, 6.31, Chapter 4 opening image, Table 6.1 (Nebulae) /ESA/STSCI/B. BALICK, University Washington, Table 6.1 (Others) /National Library of Medicine, 2.45 / National Physical Laboratory © Crown Copyright, 3.22 /NOAA, 7.42 /Peter Tuffy, University of Edinburgh, 3.1 /Photostock Israel, 1.73 (b) /Planetary Visions Ltd Table 6.1 (Planets) /Pr Philippe Vago, ISM, 1.47 /Professors P. Motta & T. Naguro, 4.19 /Ria Novosti, 3.31, 4.10, 4.38 /Russ Munn/ AgstockUSA, 4.64 /Science VU, Visuals Unlimited, 3.12 /Simon Fraser, 6.24 (a) /STScI/ESA/ NASA/IAA, J. Maiz Apellaniz, 6.14 /DETLEV VAN RAVENSWAAY, 6.45; **SDPMedia.com.au**, 7.57; **Steven Bourne**/ SA Department of Environment and Natural Resources, 7.64; **Superstock**, 7.60; Background: **William K. Hartmann**, Courtesy of UCLA; image: NASA/MCREL, 6.36; **Yuri Beletsky**/NASA, 6.19

All other photographs: **shutterstock.com, Oxford University Press**

OXFORD
UNIVERSITY PRESS
AUSTRALIA & NEW ZEALAND

ISBN 978-0-19-557757-0

visit us at: **oup.com.au** or
contact customer service: **cs.au@oup.com**