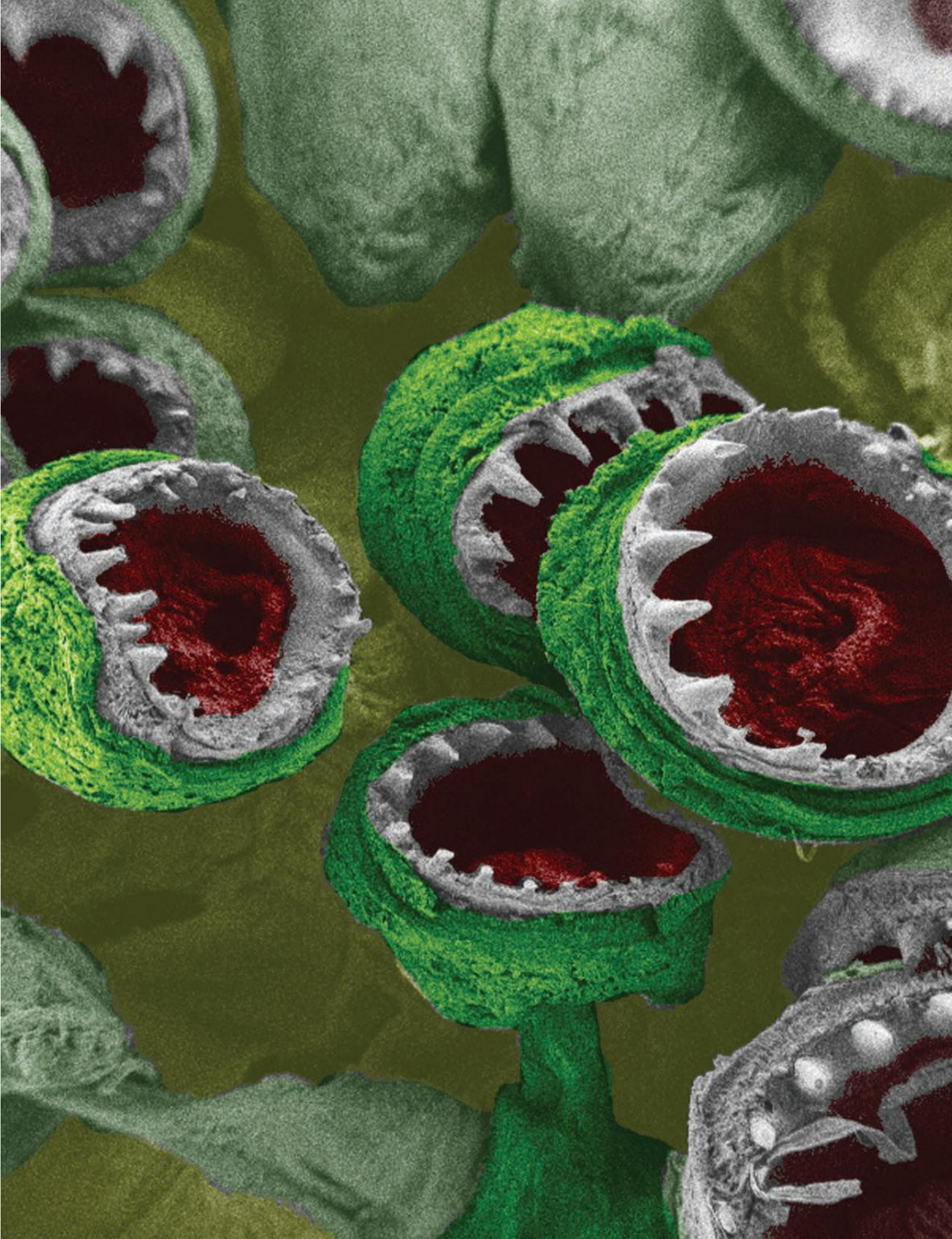
PEARSON science
S.B.
10

AUSTRALIAN CURRICULUM



Pearson Australia
(a division of Pearson Australia Group Pty Ltd)
20 Thackray Road, Port Melbourne, Victoria 3207
PO Box 460, Port Melbourne, Victoria 3207
www.pearson.com.au

First published 2012 by Pearson Australia
2015 2014 2013
10 9 8 7 6 5 4 3 2 1

Publisher: Malcolm Parsons
Commissioning Editor: Ross Laman
Project Editor: Michelle Hessels
Editor: Catherine Greenwood
Series Cover Designers: Miranda Costa, Kim Ferguson, Jo Groud and Glen McClay
Text Designer: Kim Ferguson
Copyright & Pictures Editor: Michelle Jellett
Typeset by: Cam McPhail
Production Controller: Julie Macarthur
Cover art: Jessica D. Schiffman and Caroline L. Schauer
Illustrator/s: Guy Holt, Wendy Gorton & Fiona Lee
Printed in China

National Library of Australia Cataloguing-in-Publication entry

Pearson science 10 student book / Greg Linstead … (et al.)
1st ed.
ISBN 978 1 4425 2362 3 (pbk.)
For secondary school age
Science—study and teaching (Secondary)
Linstead, Greg.
500

Pearson Australia Group Pty Ltd ABN 40 004 245 943

Acknowledgements

We would like to thank the following for permission to reproduce copyright material.
The following abbreviations are used in this list: t = top, b = bottom, l = left, r = right, c = centre.

We thank the following for their contributions to our text book:

AAP: p. 349r; Amel Emric, pp. 319, 334; Luca Brunoi, pp. 338t, 357 (identikit); Alan Porritt, p. 253tr; Alastair Fuller, p. 342t; John Mokrzycki, p. 40.

Alamy Ltd: pp. 7, 21, 48c, 85b, 132r, 204bl, 266, 304tl, 305br, 340; Larry Lilac, p. 347; Zute Lightfoot, p. 68; Bruce Benedict, p. 262; Oliver Furrer, p. 263l; Ron Yue, p. 269; E.R. Degginger, p. 62t; Jim West, pp. 41b, 67 (replacement fossil); Erick Nguyen, p. 56; Kike Calvo, p. 41l; Chris Howes, p. 48r; John Cancalosi, p. 48l; Bill Bachman, p. 206b; David Noton, p. 194; David Moore, p. 314; Carolyn Clarke, p. 304bl.

Auscape International Photo Library: Nicholas Birks, p. 78t; Davo Blair, p. 205l.

Australia Post: Peter Trusler & Belinda Marshall/National Philatelic Collection. Reproduced with permission of the Australian Postal Corporation., p. 45bl.

Australian Antarctic Division: NASA and courtesy Australian Antarctic Division, p. 198.

Australian Customs and Border Protection Service: p. 348tr.

Bloodhound SCC: Curventa and Siemens, p. 253bl.

Corbis Australia Pty Ltd: pp. 50, 107br, 120; Jebb Harris, p. 28r; Nigel Cattlin, p. 81c; Guy Motil, p. 157; Jonathan Blair, pp. 38, 39; James L. Amos, pp. 42bl, 67 (fossils); Tkachev Andrei, p. 43tl; Frans Lanting, pp. 58b, 67(stromatolite); Franck Robichon, p. 59tr; Francesc Muntada, p. 62b; George Steinmetz, p. 190tl; Gianni Dagli Orti, p. 313tr, Roger Ressmeyer, p. 242.

CSIRO Publishing: Carl Davies, p. 74t.

Department of Foreign Affairs and Trade (DFAT): p. 348tl.

DK Images: pp., 43bl, 52, 67 (tree ring dating), 72br, 102 (artificial selection).

Dreamstime: pp. 296t, 294, 304br, 315, 337t, 349l.

Fairfax Images: Kate Geraghty, p. 328t.

Flickr: Kristin Jones, p. 70b; Geoff Pyne, p. 228.

Getty Images: pp. 31, 89b, 102 (embryology), 104, 115t, 116r, 275, 283t, 292, 295t; Sean Gallup, p. 325; Natasja Weitsz, p. 342b; George Bridges, p. 341t; Koichi Kamoshida, p. 341c; Anup Shah, p. 10; Adrian Neal, p. 25t; Bellurget Jean Louis, p. 79br; Gary S. Chapman, pp. 214, 230, 247 (Big Bang); Alain Grosclaude, p.253br; Tim Hall, p. 271b; Ben Cooper, pp. 144, 273; Andre Kudyusov, p. 280; Mark Garlick, p. 106tr; Carol & Mike Werner, p. 129; Raphael Gaillarde, p. 130; Mark Garlick, p. 140 (electron shells); Casper Benson, p. 150l; Oliver Strewe, p. 163b; Jason Edwards, p. 59br; Dan Kitwood, p. 61; Scott Markewitz, p. 168; Ashley Cooper, p. 195b; Reinhard Dirscherl, p. 204br; David Goddard, p. 296b; Guy Vandereist, p. 305tl; Stuart Westmorland, p. 313br; David Paul Morris, p. 167bl.

Greg Linstead: p. 177l.

Greg Rickard: p. 316.

Harvard University: Hopi Hoekstra, p. 79tl.

International Rice Research Institute: p. 26.

IBM: Professor Don Eigler, pp. 146b, 146c.

iStockphoto: p. 82b, 177r.

Jeff Kubina: p. 70t.

Lonely Planet Images: Sally Dillon, p. 188; David Wall, p. 205r.

Lorraine Edmunds: p. 45br.

Mila Zinkova: p. 212 (permafrost).

Molymod: Molymod™ Organic Student Set, MMS-008 Spiring Enterprises Limited, England, p. 128.

NASA: pp. 184tl, 231t, 248 (Milky Way), 221 (all), 231c, 247(planetary nebula), 256.

National Geographic Society: p. 87.

News Limited Images (Newspix): James Croucher, p. 254; Andrew Tauber, p. 270br.

Photolibrary Pty Ltd: p.6t, 6c, 14t, 18b , 27, 29, 42t, 43br, 45t, 67 (carbon film fossil), 72l(both), 79tr, 80b, 82tl, 94tr, 102 (sexual selection), 102 (Australopithecus), 105 , 107tr, 115b, 121, 133, 141, 146t, 151tl, 152, 155, 167br, 169, 199t, 202b, 215t, 217, 218, 222(all), 225, 234t, 233, 232, 238, 247 (supernova), 248 (terrestrial planet), 249, 253tl, 263r; 270tr, 271t, 279t, 291(inertia), 293, 326, 327l, 329t, 329(wool), 329(cotton), 329 (synthetic), 336br, 336bl, 348bl, 350br, 357 (fibres); Philippe Psaila, pp. 8, 328bl; Steve Horrell, p. 348tc; Mauro Fermariello, pp. 327br, 336tr, 339, 357 (impressions), 357 (fluoresce); Volker Steger, p. 337r; Cheryl Power, p. 329 (human hair); Jan Hinsch, p. 337bl; Jim Varney, p. 324; Geoff Tompkinson, p. 351; Volker Stefer, p. 338b; James King-Holmes, p. 348br (both); Manfred Kage, pp. 12, 16l, 267; Patrick Landmann, p. 5; A. Barrington Brown, p. 6b; Adrian T. Sumner, pp. 11, 37; David Fox, p. 80t; Mark Pedlar, p. 81t; Robin Smith, p. 89tl; Julian Baum, pp. 223, 248 (binary star system); Adam Hart-Davis, p. 234b; John R. Foster, p. 215b; NASA, pp. 231b, 240b; Dr David Patterson, p. 240t; Claire Ting, pp. 241t, 248 (cyanobacteria); Tom Brakefield, p. 261; Jim Zipp, p. 264; Philippe Plailly, p. 106tl; David Guyon, p. 127; Charles D. Winters, pp. 122b, 145; Dr. E. Walker, p. 151bl; Martyn F. Chillmaid, pp. 143, 151br; Sylvain Grandadam, p.163tl; Paul Nevin, p. 150r; David Nanuk, p. 162t; Matt Meadows, p. 175 (agitation); Dirk Wiersma, p. 58t; Earl Scott, p. 43tr; John Reader, pp. 42r, 94tl; Richard Bizley, p. 44r; Goetgheluck Pascal, p. 60; Tom McHugh, p. 59tl; Sinclair Stammers, p. 53; Russell Kightley, p. 167t; Jim Reed, p. 183t; Nigel Cattlin, p. 180cr; Mark Hallett, p. 203l (all); Marko König, p. 197r; Yoshio Tomii, p. 305bl; Kim Steele, pp. 306, 323 (superstructure); Scott Camazine, p. 82c; Professor Miodrag Stojkovic, p. 30; Martin Shields, p. 90; Steve Gschmeissner, p. 17; Laurent Orluc, p. 97bl; Dung Vo Trung, p. 108b; Paul Mayall, p. 241b.

Shutterstock: pp. 16r, 25b, 69t (all), 73 (labradoodle), 74b, 76, 79bl, 93b, 89tr, 116l, 114, 113, 131t (all),132l, 142, 149, 153 (all), 154, 156, 175 (precipitation), 162b, 163tr, 164, 165, 166, 175 (aqueous solution), 181, 175 (combustion), 176, 180tr, 180l, 197l, 195t, 189, m183b, 202t, 204tl, 204tr, 206t, 212 (leguminous plants), 243, 245, 248 (moon), 251, 276, 281t, 283br, 283bl, 291 (acceleration), 297, 303, 305tr, 307, 311, 321, 313tl, 332, 344, 354.

South Australian Museum: p. 41t.

Smithsonian Institute, Human Origins Program: pp. 93t, 95, 96.

Thinkstock: pp.1, 2, 14b, 18t, 28l, 73t (all), 72tr, 73 (labrador), 73 (poodle), 100, , 107l, 122t (all), 131b (all), 140 (noble gases), 108t (all), 131 (amethyst), 140 (allotropes), 190br, 199br, 203r, 237, 250, 252, 279b(all), 282, 291 (elastic potential), 295b, 304tr, 308, 312, 327tr, 357 (iris).

University of Western Australia, The: Dr Jon Clements, p. 75.

Western Australia Police Forensic Division: p. 328br (all).

Wildlight Photo Agency: Penny Tweedie, p. 274.

Yale University: Jakob Vinther, p. 69b.

Cover © Jessica D. Schiffman and Caroline L. Schauer, Drexel University, p. Cover.

Safety "dummy" icon © Getty Images/Steve Hathaway

Thinking Scientifically banner © Getty Images/Don Carstens

Curriculum extracts from the Science Australian Curriculum (Sydney, 2010: Australian Curriculum, Assessment and Reporting Authority [ACARA]). ACARA does not endorse Pearson Group Australia or this product.

Every effort has been made to trace and acknowledge copyright. However, if any infringement has occurred, the publishers tender their apologies and invite the copyright holders to contact them.

PEARSON Australian Curriculum
Writing and Development Team

Greg Rickard
Teacher, Former Head of Department
Coordinating Author, Victoria

Misal Belvedere
Commissioning Editor, Pearson Australia

Mark Bradley
Teacher
Reviewer, Victoria

Alicia Brown
Publisher, Pearson Australia

Nici Burger
Lecturer, Southern Cross University, New South Wales
Reviewer, New South Wales

Mark Byrne
Teacher
Reviewer, Victoria

Dr Warrick Clarke
Research Fellow, University of New South Wales
Author, New South Wales

Penny Commons
Transition Fellow and Tutor, School of Chemistry, University of Melbourne
Project Officer for Chemistry Education Association
Reviewer, Victoria

Jacinta Devlin
Teacher
Coordinating Author, Victoria

Laura Ferry
Teacher
Author, Victoria

Trent Foster
Teacher
Reviewer, New South Wales

Ben Freeman
Teacher
Reviewer, Victoria

Dr David Geelan
University of Queensland
Author, Queensland

Owen Goyder
Teacher, Head of Department
Reviewer, Western Australia

Elissa Huddart
Teacher
Reviewer, Victoria

Greg Linstead
Teacher, Former Head of Department
Former Education Department of WA Curriculum Writer and Advisory Teacher,
Coordinating Author, Western Australia

Associate Professor Kristina Love
Head of School of Education
Australian Catholic University
Literacy Consultant, Victoria

David Madden
Teacher, Head of Department
Author, Queensland

Rochelle Manners
Teacher
Reviewer, Queensland

Greg Moran
Teacher, Head of Department
Former President, STAWA
Former Councillor, ASTA
Reviewer, Western Australia

Lana Salfinger
Teacher, Head of Department
IB Workshop Leader in MYP Sciences
Reviewer, Western Australia

Maggie Spenceley
Teacher
Former Curriculum Writer
Queensland Studies Authority
Author, Queensland

Jeff Stanger
Councillor, Science Teachers Association of NSW
Teacher
Reviewer, New South Wales

Jim Sturgiss
Senior Assessment Officer
Essential Secondary Science Assessment
Educational Measurement and School Accountability Directorate
Reviewer, New South Wales

Alisha Ward
Teacher
Author, Victoria

Contents

Contents

5 Chemical reactions

6 Global systems

7 The universe

8 Motion and energy

9 Structures

10 Forensic science

PEARSON science

Student Book

Written specifically to meet the requirements of the Australian Curriculum, the student book acts as a guide for both student and teacher.

- Written specifically for the Australian Curriculum Science course
- Utilises an inquiry approach throughout
- Offers content and activities that enhance the development of Achievement Standards. The content is presented in a range of contexts within the three interrelated strands of Science Inquiry Skills, Science as a Human Endeavour and Science Understanding.

Activity Book

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

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

Teacher Companion

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

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

AUSTRALIAN CURRICULUM

ALWAYS LEARNING

Pearson Reader

Much more than an e-book, **Pearson Reader** is an interactive online version of your student book linked to rich media resources. Not only does it support you with activities and teaching tools, it allows you to personalise your class version of the student book by adding your own links and content. **Pearson Reader** also enables you to harness the collective intelligence of education professionals by connecting you to other **Pearson Reader** users, building a powerful and continually evolving web book for your students.

Don't miss out on your Pearson Reader Starter Pack. When you choose to use **Pearson Science**, you will have free access to one chapter of the student book on **Pearson Reader** along with full access to the teacher and student interactive resources.

If you like what you see, you can add on more chapters or upgrade to the full course content. Visit the Pearson Reader home page at **www.pearsonplaces.com.au/pearsonreader**.

Pearson Places is the gateway to digital learning material for teachers and students across Australia. Sample the range of resources for Science and register for free at **www.pearsonplaces.com.au**.

Pearson Places

Professional Learning, Training and Development

Did you know that Pearson also offer teachers a diverse range of training and development programs? We are dedicated to supporting your implementation of **Pearson Science**, but it doesn't stop there. We offer specific training for the Australian Curriculum and beyond, such as our session titled 'Skilling Up in Science'.

Find out more about this session and others at Pearson Professional Learning Place at **www.pearsonplaces.com.au/professionallearning**.

Customised Content

We believe in learning for all kinds of people, delivered in a personal style. **Pearson Custom** is an exciting initiative that allows you to customise the content that you teach. Schools can be involved in choosing resources specifically tailored to their school or year level.

Speak to your Pearson Sales Consultant to find out more.

We believe in learning.
All kinds of learning for all kinds of people, delivered in a personal style.
Because wherever learning flourishes, so do people.

PEARSON

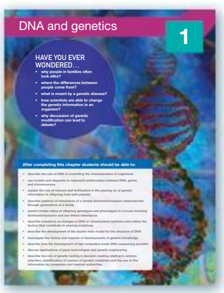
How to use this book

PEARSON science 10 Student Book

PEARSON science 10 has been designed for the Australian Curriculum: Science course. It includes content and activities that enhance the development of the Year 10 Achievement Standards within the three interrelated strands of Science Inquiry Skills, Science as a Human Endeavour, and Science Understanding. The content is presented through a range of contexts to engage students and assist them to make connections between science and their lives.

The Cross-curriculum priorities and General Capabilities are addressed throughout the series.

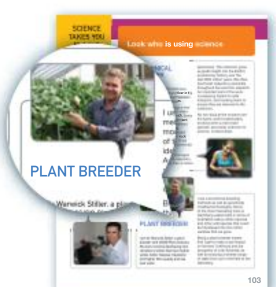
PEARSON science 10 is designed for an inquiry approach to science learning. Its engaging design, unambiguous features and clear easy-to-understand language make this a valuable resource for students of all interests and abilities.



Chapter opening page

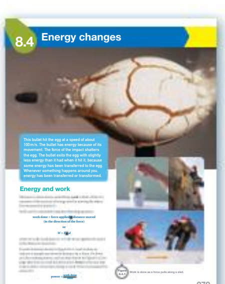
The chapter opener engages students through questions that get them thinking about the content and concepts to come.

The key ideas reflect the elaborations and standards relevant to the chapter.



Look who is using science

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



Unit opening

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

Photos and illustrations

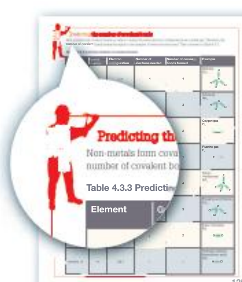
Stunning and relevant photos and illustrations are clearly referenced from within the text to assist students to understand the idea being developed.

science 4 fun

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

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

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



Skill builder

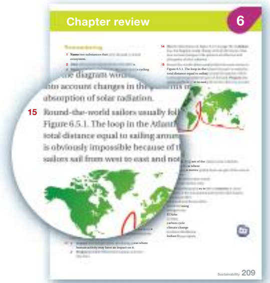
Key skills are outlined in clear steps to support science learning.

Worked example

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

SciFile

SciFiles include quirky information to engage students.



Chapter review

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

Unit review

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

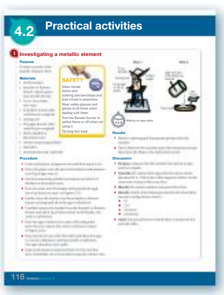
The final heading is 'Inquiring'. These questions challenge students to use their inquiry skills to go further with the unit content.

Thinking scientifically

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

Glossary

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



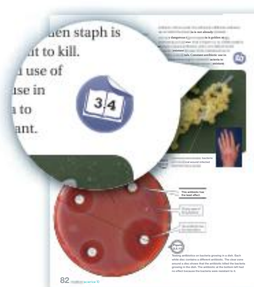
Practical activities

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

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

Safety boxes highlight significant hazards.

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



Activity Book icon

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

Science as a Human Endeavour

The Science as a Human Endeavour strand is addressed throughout the units and in Science as a Human Endeavour spreads. Many of these are developed and extended in the Activity Book.

The PEARSON science 10 package

Don't forget the other PEARSON science 10 package components that will help engage and excite students in science:

PEARSON science 10 Activity Book

PEARSON science 10 Teacher Companion

PEARSON science 10 Pearson Reader

Verbs

The verbs below, based on Bloom's Taxonomy, appear in **bold** text throughout this book. The verbs help students know the level of response required for a question and provide a common language and consistent meaning in the Australian Curriculum documents.

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

Analysing	
analyse	Identify components and the relationship between them; draw out and relate implications
calculate	Ascertain/determine from given facts, figures or information (requiring more manipulation than simply applying the maths)
classify	Arrange or include in classes/categories
compare	Show how things are similar or different
contrast	Show how things are different or opposite
critically (analyse/ evaluate)	Add a degree or level of accuracy, depth, knowledge and understanding, logic, questioning, reflection and quality to (analyse/evaluate)
discuss	Identify issues and provide points for and/or against
distinguish	Recognise or note/indicate as being distinct or different from; to note differences between
infer	Recognise and explain patterns and meaning and relationships
interpret	Draw meaning from
research	Investigate through literature or practical investigation
Evaluating	
appreciate	Make a judgement about the value of
assess	Make a judgement of value, quality, outcomes, results or size
conclude	Come to a judgement or result based on the reasoning or arguments that you present
critically (analyse/ evaluate)	Add a degree or level of accuracy, depth, knowledge and understanding, logic, questioning, reflection and quality to (analyse/evaluate)
deduce	Draw conclusions
evaluate	Make a judgement based on criteria; determine the value of
extrapolate	Infer from what is known
justify	Support using an argument or conclusion
propose	Put forward (for example a point of view, idea, argument, suggestion) for consideration or action
recommend	Provide reasons in favour
select	Choose one or more items, features, objects
Creating	
construct	Make; build; put together items or arguments
design	Provide steps for an experiment or procedure
investigate	Plan, inquire into and draw conclusions about
synthesise	Put together various elements to make a whole

SCIENCE TAKES YOU PLACES

Look who is using science

PALAEONTOLOGIST

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

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

GENETICIST

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

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

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

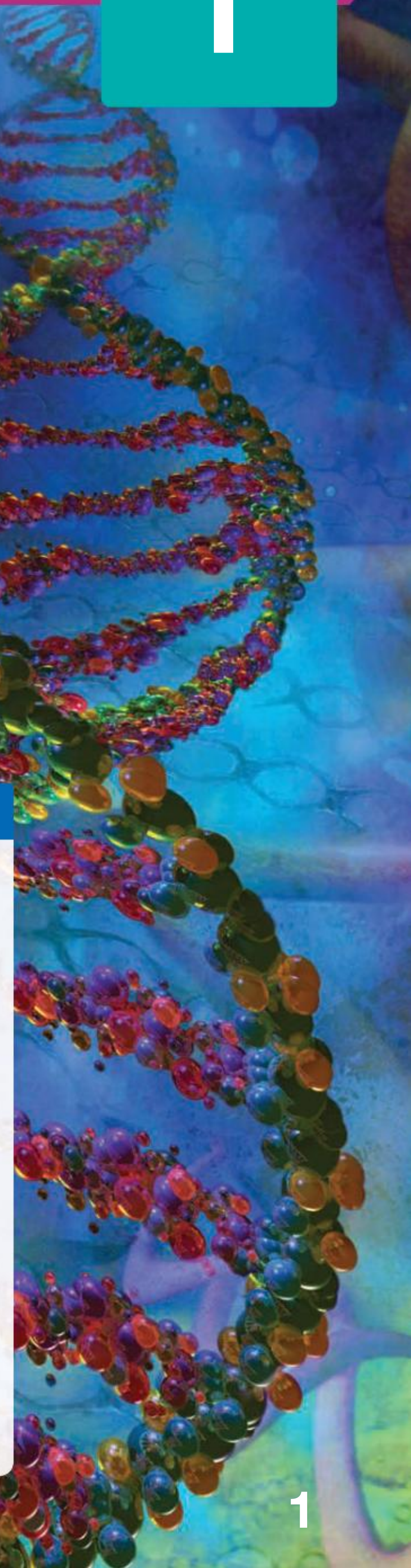
INSECTICIDE TOXICOLOGIST

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

First I 'milk' my spiders to get the venom. I test the venom for insecticidal activity and once I have a hit, I isolate the toxin of interest. I search for the matching DNA sequence in a library of known DNA sequences from the venom gland of the spider. Once found, the DNA sequence can be inserted into bacteria, which then make large quantities of the toxin. The toxin is then tested to ensure that it is not dangerous to non-target organisms, such as beneficial insects, pets or people. If the toxin passes these tests, only then can it be used in farming.

DNA and genetics

1



HAVE YOU EVER WONDERED…

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

After completing this chapter students should be able to:

- describe the role of DNA in controlling the characteristics of organisms
- use models and diagrams to represent relationships between DNA, genes and chromosomes
- explain the role of meiosis and fertilisation in the passing on of genetic information to offspring from both parents
- describe patterns of inheritance of a simple dominant/recessive characteristic through generations of a family
- predict simple ratios of offspring genotypes and phenotypes in crosses involving dominant/recessive and sex-linked inheritance
- describe mutations as changes in DNA or chromosome numbers and outline the factors that contribute to mutations
- describe the development of the double helix model for the structure of DNA
- investigate the history and impacts of developments of genetic knowledge
- describe how the development of fast computers made DNA sequencing possible
- discuss applications of gene technologies and genetic engineering
- describe the role of genetic testing in decision-making relating to embryo selection, identification of carriers of genetic mutations and the use of this information by companies and medical authorities.

1.1 DNA the molecule

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

INQUIRY science 4 fun

What do you know?

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

Collect this …

- notebook
- pen

Do this …

1. Make a list of the friends and family you are going to talk to.
2. Ask these people what they know about DNA.

Record this …

Describe what your family and friends know about DNA.

Explain why there may be differences in their understanding.

Deoxyribonucleic acid

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

DNA is a complex chemical compound that has a similar structure in all organisms. DNA is made up of molecules called **nucleotides**. The basic structure of a nucleotide is shown in Figure 1.1.1. Nucleotide molecules have three main parts:

- **phosphate group**
- **deoxyribose sugar**
- one of four **nitrogen-rich bases**.

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

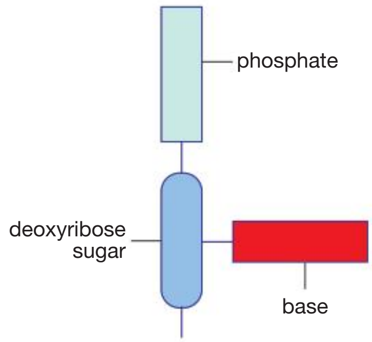


Figure 1.1.1 All the nucleotides of DNA have the same basic structure. It is the type of base that is different.

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

Therefore there are two types of 'rungs' on the 'ladder': A–T rungs and C–G rungs. This can be seen in Figure 1.1.2.

1 p8

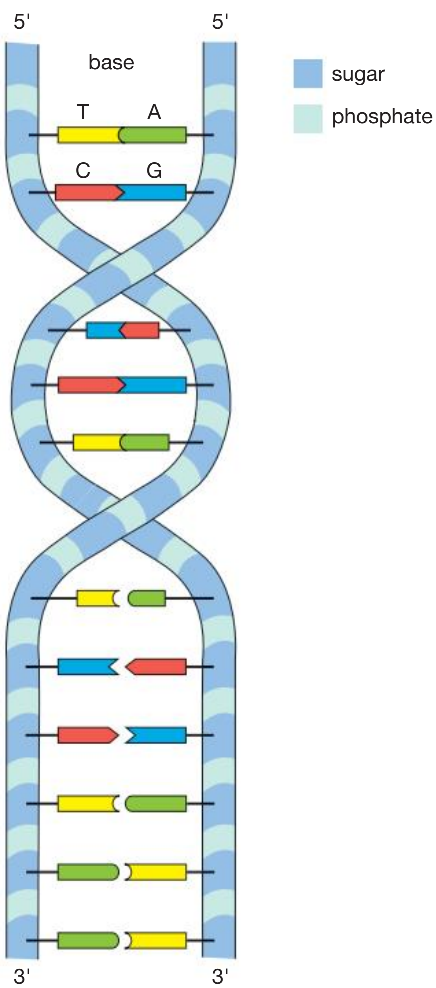


Figure 1.1.2 DNA structure—the lower section is shown uncoiled to illustrate the pairing of the bases.

SKILL BUILDER

Complementary base pairing

The chemical structure of the nitrogen-rich bases means that they can only form chemical bonds with one of the other bases.

- Adenine (A) only pairs with thymine (T)
- Cytosine (C) only pairs with guanine (G).

One side of the DNA ladder could be like Figure 1.1.3 with the sugar–phosphate backbone and the attached bases.

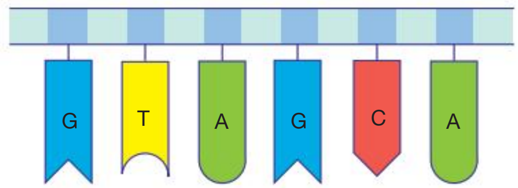


Figure 1.1.3 One side of the DNA ladder

Using complementary base pairing, the other side of the molecule would look like Figure 1.1.4.

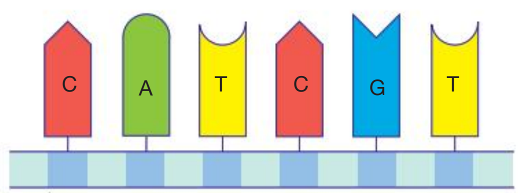


Figure 1.1.4 The other side of the DNA ladder

When the two sides are put together, the DNA molecule in Figure 1.1.5 would be the result.

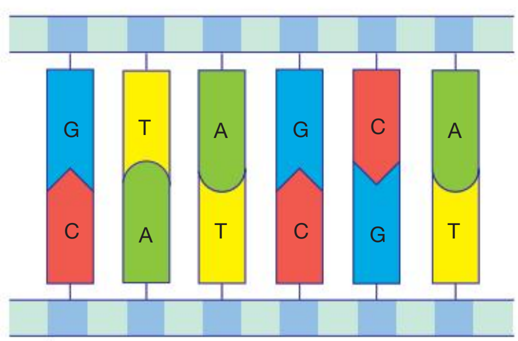


Figure 1.1.5 The resulting DNA molecule

1.1
2 p9
3 p9

Genes and chromosomes

Chromosomes are long, thin, threadlike structures found in the nucleus of cells. Chromosomes are made of DNA and protein. The cells in the human body each contain 46 chromosomes (in 23 pairs). The only exceptions are the sperm and egg cells, which only contain 23 chromosomes (one of each pair) and red blood cells, which have no nucleus. Other organisms have different numbers of chromosome pairs in their cells.

Genes are sections of DNA. A single gene is marked in Figure 1.1.6. Each chromosome can have over 1000 genes. The difference between one gene and the next is the:

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

The order of the bases along the DNA strand is the genetic code. Each gene codes (contains instructions) for a specific protein. Proteins control many characteristics or functions in the body. Proteins include the structural materials that build up your cells and tissues, most hormones and all enzymes.

SciFile

That much!

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

SciFile

No nucleus

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

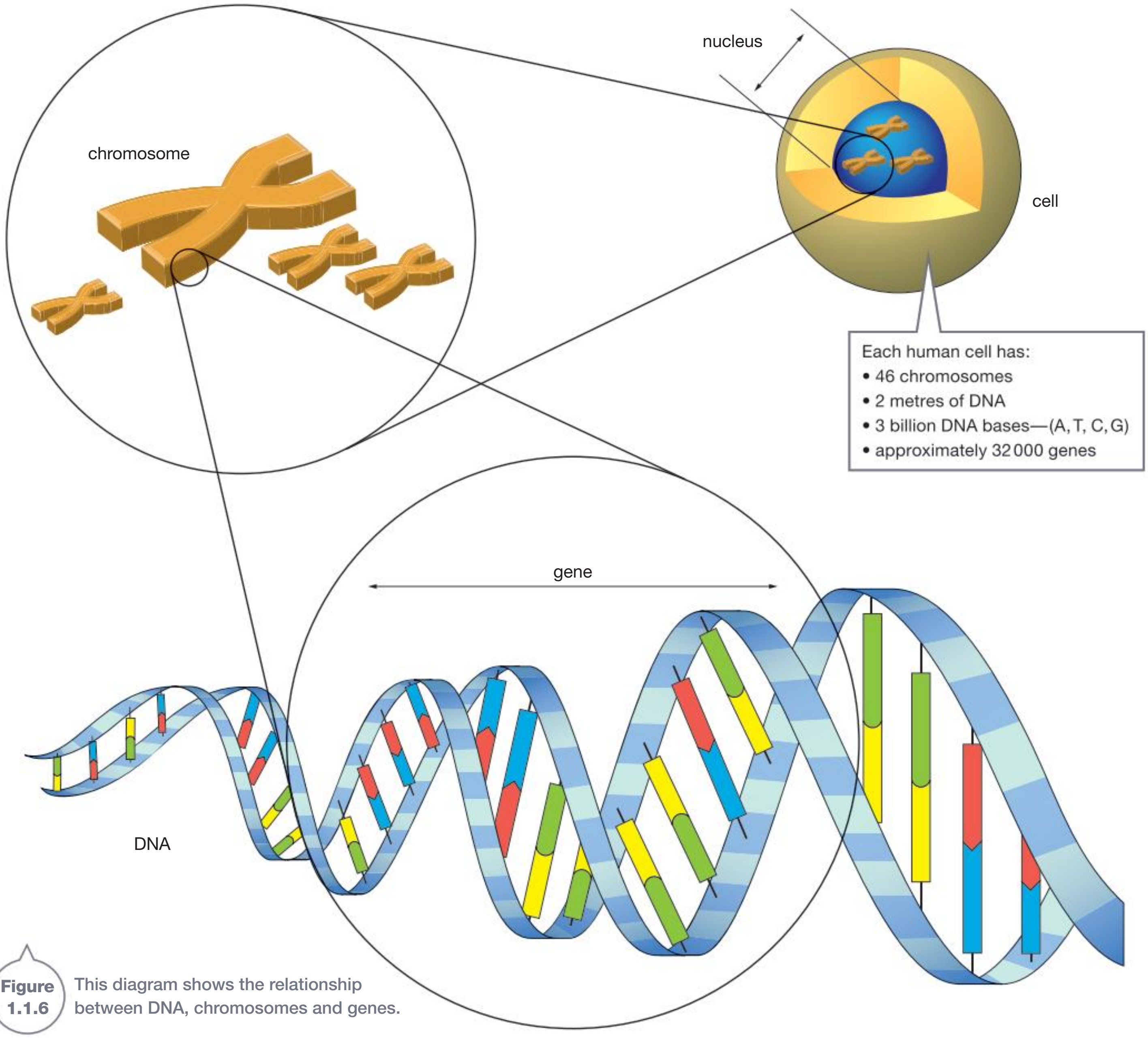


Figure 1.1.6 This diagram shows the relationship between DNA, chromosomes and genes.

SCIENCE AS A HUMAN ENDEAVOUR

Nature and development of science

Discovery of DNA

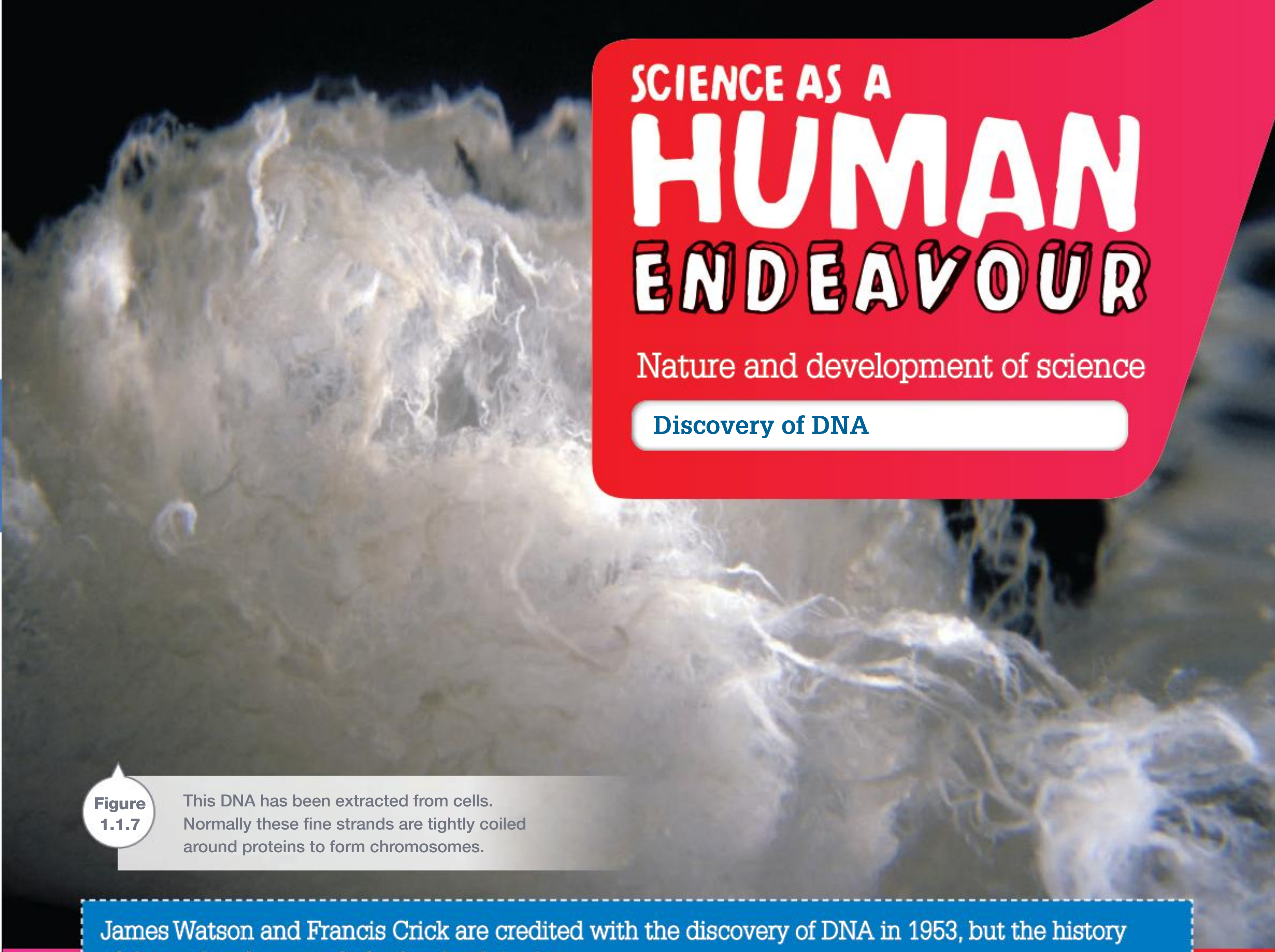


Figure 1.1.7 This DNA has been extracted from cells. Normally these fine strands are tightly coiled around proteins to form chromosomes.

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

In 1869, Johannes Friedrich Miescher (1844–95), a Swiss physician and biologist, isolated a previously unknown chemical from the nuclei of dead white blood cells. Miescher was looking for proteins when he identified a substance that was chemically very different. He called this new chemical *nuclein* because it was found in the cell nucleus. The name was changed to nucleic acid and eventually to deoxyribonucleic acid (DNA). DNA is shown in Figure 1.1.7. Miescher did not know that he had discovered the substance that is the genetic code.

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

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

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

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

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

In the early 1950s, Rosalind Franklin (1920–58), a British scientist, used her skills as an X-ray crystallographer to investigate DNA. She and fellow worker Maurice Wilkins (1916–2004), a New Zealander working in England, created an X-ray crystallograph of DNA. From the pattern seen in Figure 1.1.8 on page 6, they deduced that DNA contained rungs like a ladder and had an X-shape—a pattern consistent with it being a helix.

In 1951, American molecular biologist James Watson (1928–) attended a lecture in which Franklin presented her research. Using this new information about DNA, Watson and his associate, Francis Crick (1916–2004), a British molecular biologist, refined the 3D models they had been building in attempts at discovering DNA structure. They used Franklin's image to fit all the parts together. Later that year they published their research with diagrams of the double helix structure of DNA (Figure 1.1.9).

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

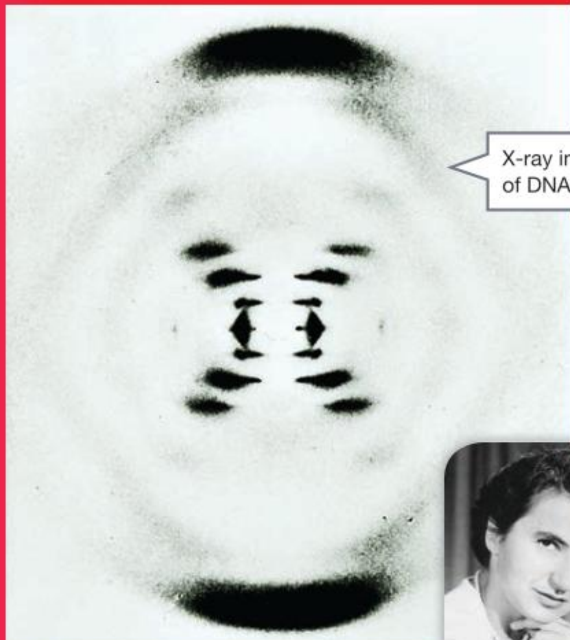


Figure 1.1.8 Rosalind Franklin obtained this image of DNA in 1953. James Watson and Francis Crick used it to work out the structure of the molecule.

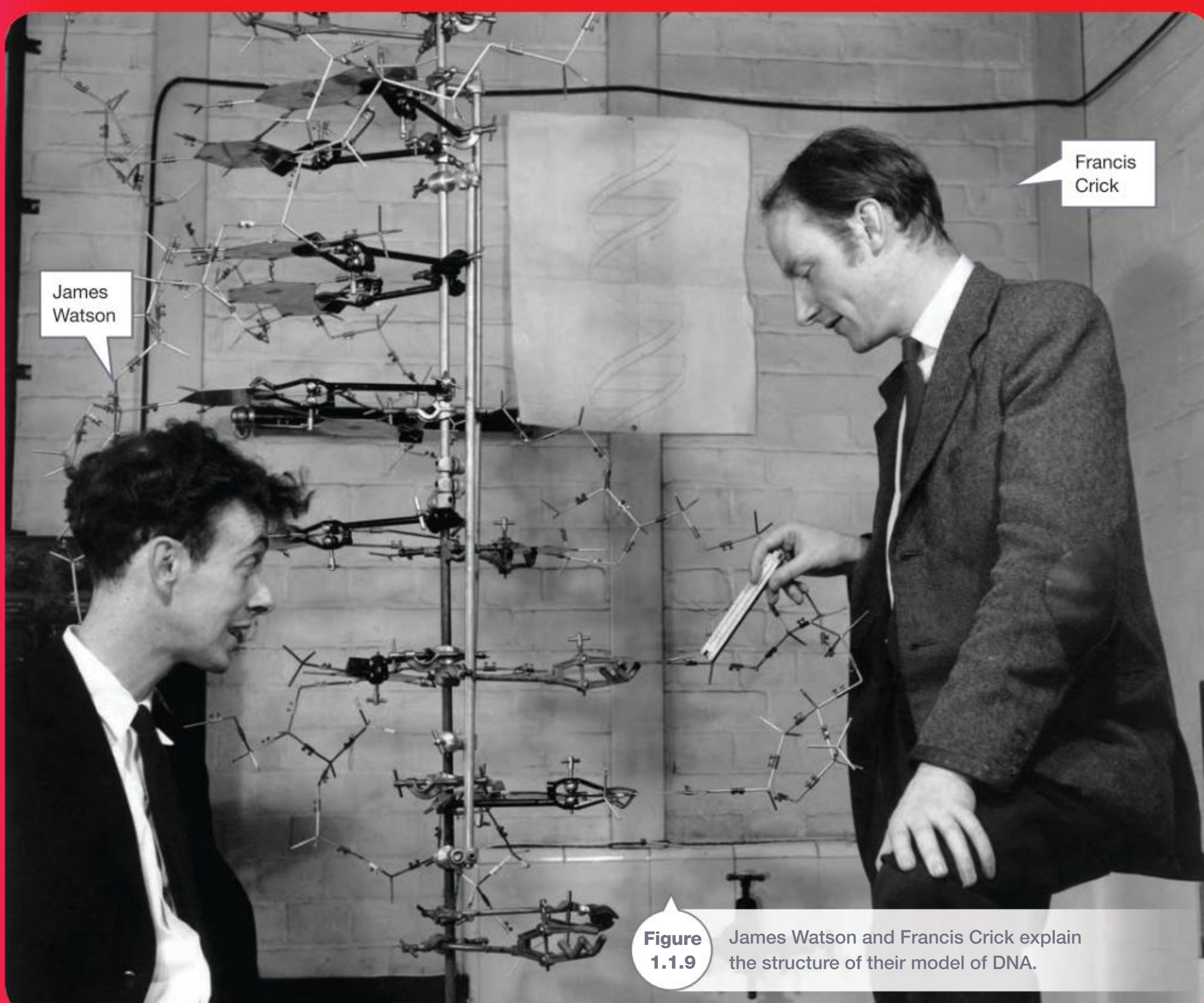


Figure 1.1.9 James Watson and Francis Crick explain the structure of their model of DNA.

1.1 Unit review

Remembering

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

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

3 **State** how long scientists have known of the existence of DNA.

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

5 In the DNA molecule:
- a **recall** what makes the 'rungs' of the ladder
- b **name** the molecules that make the 'uprights' of the ladder
- c **recall** the molecule of the 'upright' to which the 'rungs' are joined.

Understanding

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

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

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

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

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

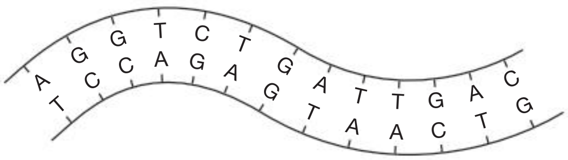
11
- a **Name** four scientists who contributed to our understanding of DNA.
- b **Outline** what each scientist did.

Applying

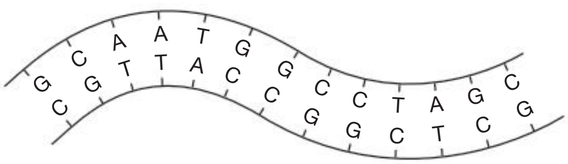
12 **Use** coloured pencils to draw and label a simple diagram representing a:
- a DNA molecule
- b nucleotide.

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

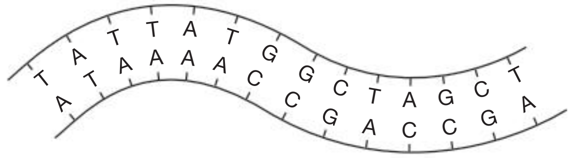
a



b



c



Analysing

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

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

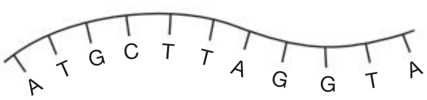
Evaluating

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

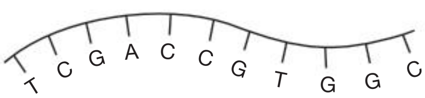
Creating

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

a



b



Inquiring

1 Find out what the Human Genome Project is and what scientists hope to learn from it.

2 Find out what mutations are and how certain agents can cause mutations. Agents you could research include UV radiation, nuclear radiation and certain chemicals.

Figure 1.1.10 Melanoma is a skin cancer caused by a mutation, which in turn was caused by UV radiation from sunlight.

1.1 Practical activities

1 Investigating DNA

Purpose

To extract and examine DNA.

Materials

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

SAFETY

Take care when using the blender.

Methylene blue stains clothes and hands. Avoid contact.

Procedure

Part A: Extracting the DNA

1 Process the peas and water in the blender for about 20 seconds. The mixture should be a thin, soupy consistency.

2 Pour the mixture through the strainer into the large beaker.

3 Add about 80 mL of dishwashing detergent to the strained mixture. This will help break down the cell membranes. Stir thoroughly with the glass rod.

4 Add a spatula-full of meat tenderiser (to destroy any proteins). Continue stirring for about 5 minutes.

5 Quarter-fill the large test-tube with the pea mixture.

6 Holding the test-tube at an angle, gently pour about the same quantity of alcohol (about a quarter of a test-tube) down the side of the test-tube. The test-tube should now be about half full. The alcohol should form a layer on top of the pea mixture. Alcohol causes the DNA to come out of solution.

7 Observe the mixture for a few minutes. A white, threadlike substance should rise from the pea mixture to lie above the alcohol layer (see Figure 1.1.11). This is the DNA that you have extracted from the cells of the peas.

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

Figure 1.1.11

Part B: A closer look

9 Use a pipette to carefully remove some of the DNA from the top of your preparation.

10 Place one or two drops onto a microscope slide.

11 Add 2 drops of methylene blue. Wait 3–4 minutes to allow the methylene blue to be absorbed by the DNA.

12 Place a coverslip on the slide. Soak up any excess liquid with a piece of paper towel.

13 Observe the DNA under low power, and then high power.

Results

Describe the appearance of the DNA under high power of the microscope. Use words and diagrams.

Discussion

1 **Describe** the material floating at the top of the test-tube after the alcohol was added.

2 **Explain** why each of the following chemicals was used in the extraction process:
   - detergent
   - meat tenderiser
   - alcohol.

3 **Explain** why methylene blue was used when observing the DNA under the microscope.

4 **Deduce** what factors affected your success in extracting and examining the DNA.

2 Modelling DNA

Purpose

To construct a model of DNA.

Materials

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

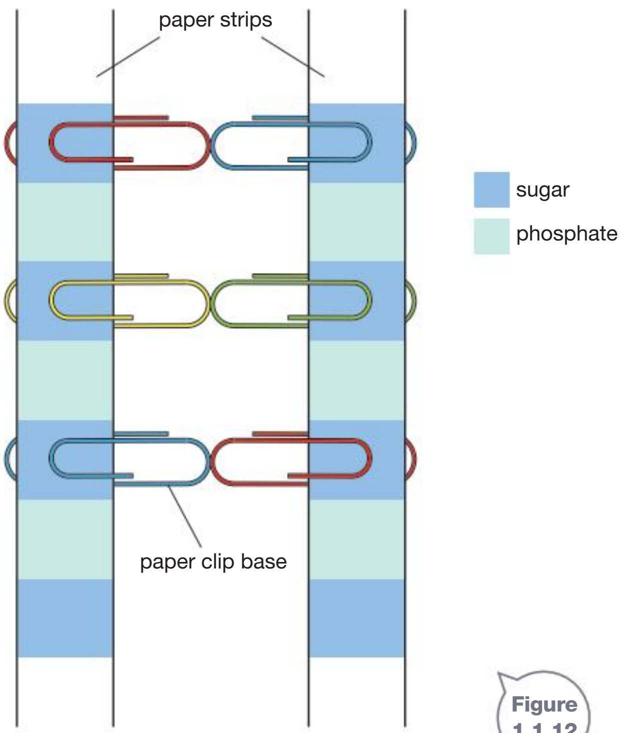


Figure 1.1.12

Procedure

1. Use paperclips to represent the bases in your DNA molecule. Choose a different colour for each of the bases adenine, guanine, cytosine and thymine. Make a note of bases and their colours. (Note: If all groups use the same colours, it will be easier to compare results at the end of the experiment.)
2. Mark the two strips of paper into 2 cm sections.
3. Shade the two strips of paper in alternating blocks of colour to represent the sugar and phosphate molecules, as shown in Figure 1.1.12.
4. Attach ten of your coloured clips randomly (in any sequence you like) to the 'sugar molecules' along one of the strips.
5. Use the base-pairing rules described on page 3 to build and attach the complementary strand.

Results

Draw a diagram of the DNA molecule you have made.

Discussion

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

3 Make your own DNA

Purpose

To design and build a model of DNA from scratch.

Materials

Materials of your own choice

Procedure

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

Discussion

Compare your model with what DNA is really like.

1.2 Making new cells

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

INQUIRY science 4 fun

Variation

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

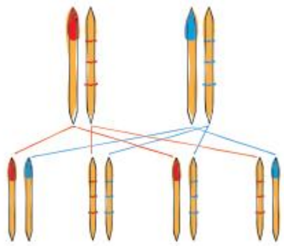
Yes

Collect this ...

- 8 toothpicks
- 4 colours of marker pen (e.g. red, blue, green and purple)

Do this ...

1. Create a red pair of toothpicks by colouring the tip of one red and placing two or three red stripes on the other. Create blue, green and purple pairs in the same way.
2. Sort the toothpicks into their colour pairs.
3. Sort the red and blue toothpicks into two groups with one red and one blue toothpick in each. Now try a different combination of red and blue. Make as many different groups as possible. Use the diagram on the right as a guide.
4. Record the number of pairs you created.
5. Add in the pair of green toothpicks. Again sort the toothpicks into two groups each with three toothpicks—one toothpick of each colour. Create as many different groups as you can.
6. Record the number of different groups you created.
7. Add in the purple toothpicks and sort all the toothpicks into two groups of four, following the same rules about colour.
8. Record the number of different groups you created.



Record this ...

Describe how you were able to change the number of groups you created.
Explain why this happened.

Replicating the DNA

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

Replication

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

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

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

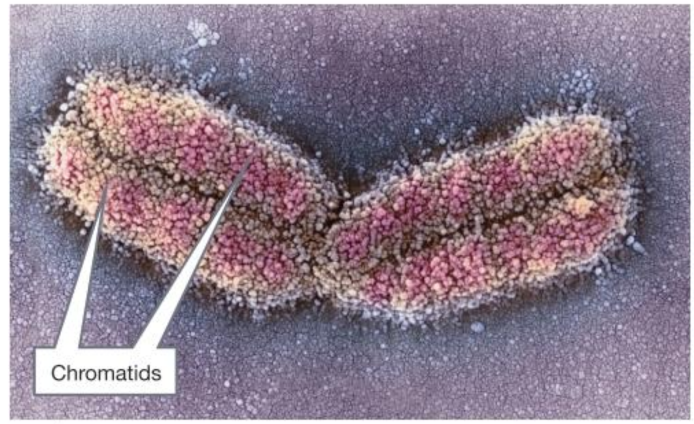


Figure 1.2.2 Scanning electromicrograph (SEM) of a human chromosome that has replicated and which consists of two identical chromatids

SciFile

Slow copy

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

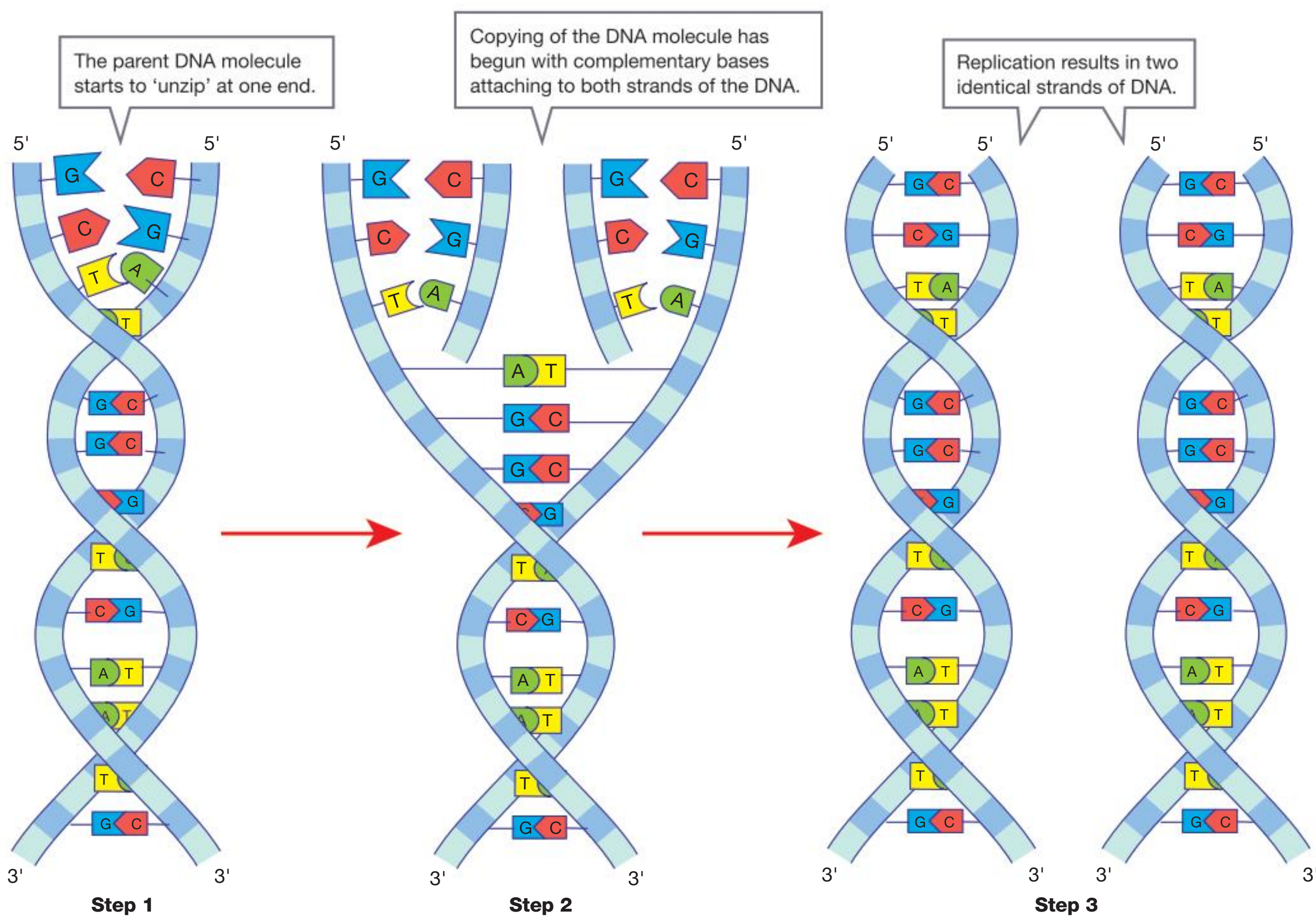


Figure 1.2.1 DNA replication involves three distinct stages.

Cell division

There are two types of cell division:

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

Mitosis

Mitosis is a continuous process. However, scientists have identified several distinct stages in the process. These can be seen in Figures 1.2.3 and 1.2.4.

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

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

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

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

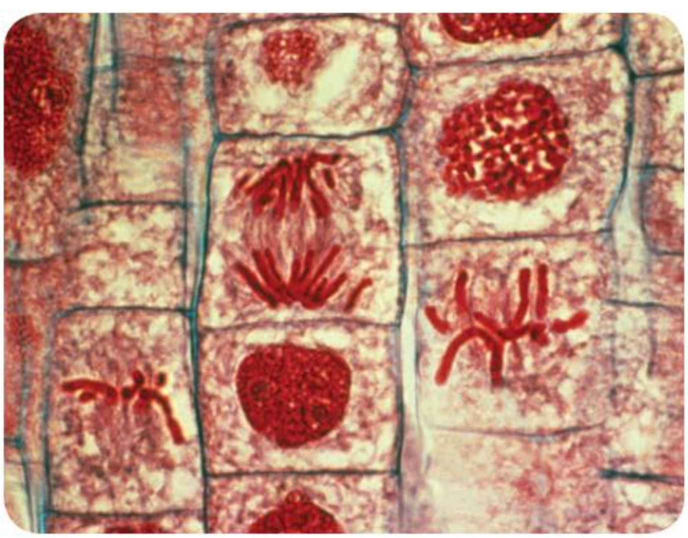


Figure 1.2.3 Light micrograph of phases of mitosis in cells from an onion

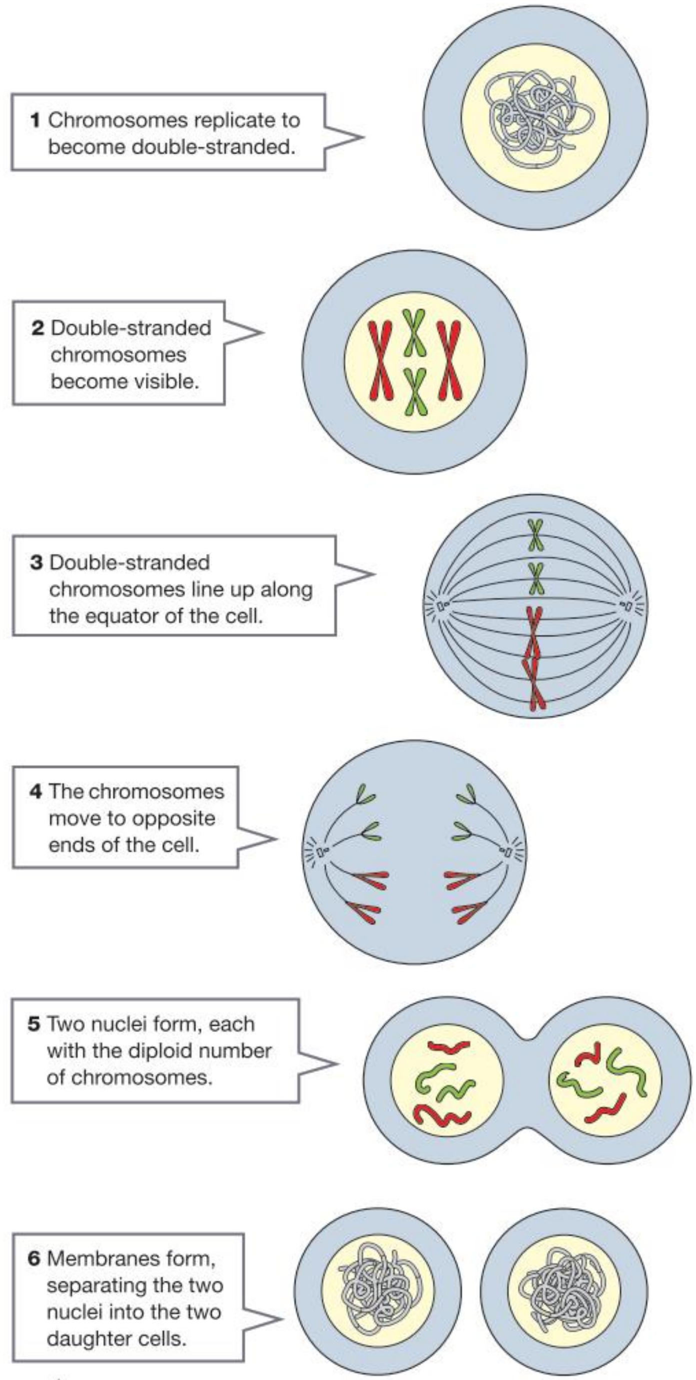


Figure 1.2.4 The stages of mitosis

Chromosome number

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

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

1 p17 1.3

gametes, the number of chromosomes from generation to generation is kept constant at 2N.

Of the 46 chromosomes in your cells, two are **sex chromosomes**—the ones that determine whether you are male or female. The other 44 chromosomes are not sex chromosomes and are known as **autosomes**. In human females, the sex chromosomes are a pair of X chromosomes (XX). In males, the sex chromosomes are one X and one Y chromosome (XY).

The autosomes in your cells are grouped into 22 pairs. The chromosomes in the pair are homologous. **Homologous chromosomes** are the same length, have the **centromere** (the point where the two chromosomes join) in the same position. Homologous chromosomes also have genes for particular characteristics at the same location along their length. For example, the gene for hair curliness is found in the same position on the pair of homologous chromosomes shown in Figure 1.2.5. Therefore, each new cell formed by mitosis of the zygote has two copies of the gene for each characteristic, one on each chromosome of the homologous pair.

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

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

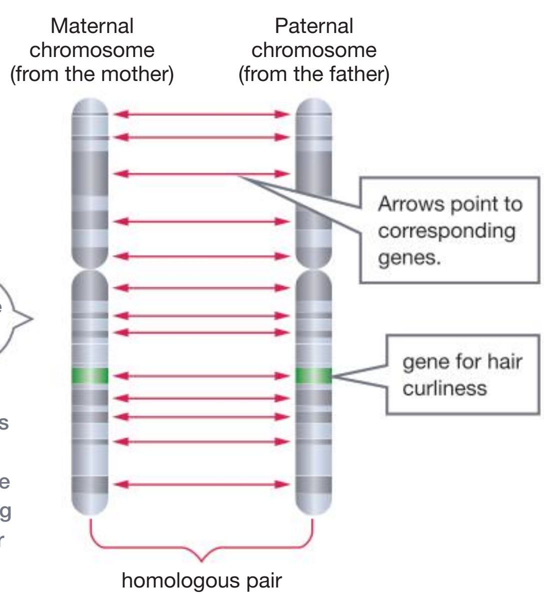


Figure 1.2.5 Homologous chromosomes showing the position of the corresponding genes for hair curliness

Meiosis

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

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

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

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

2 p17
1.4

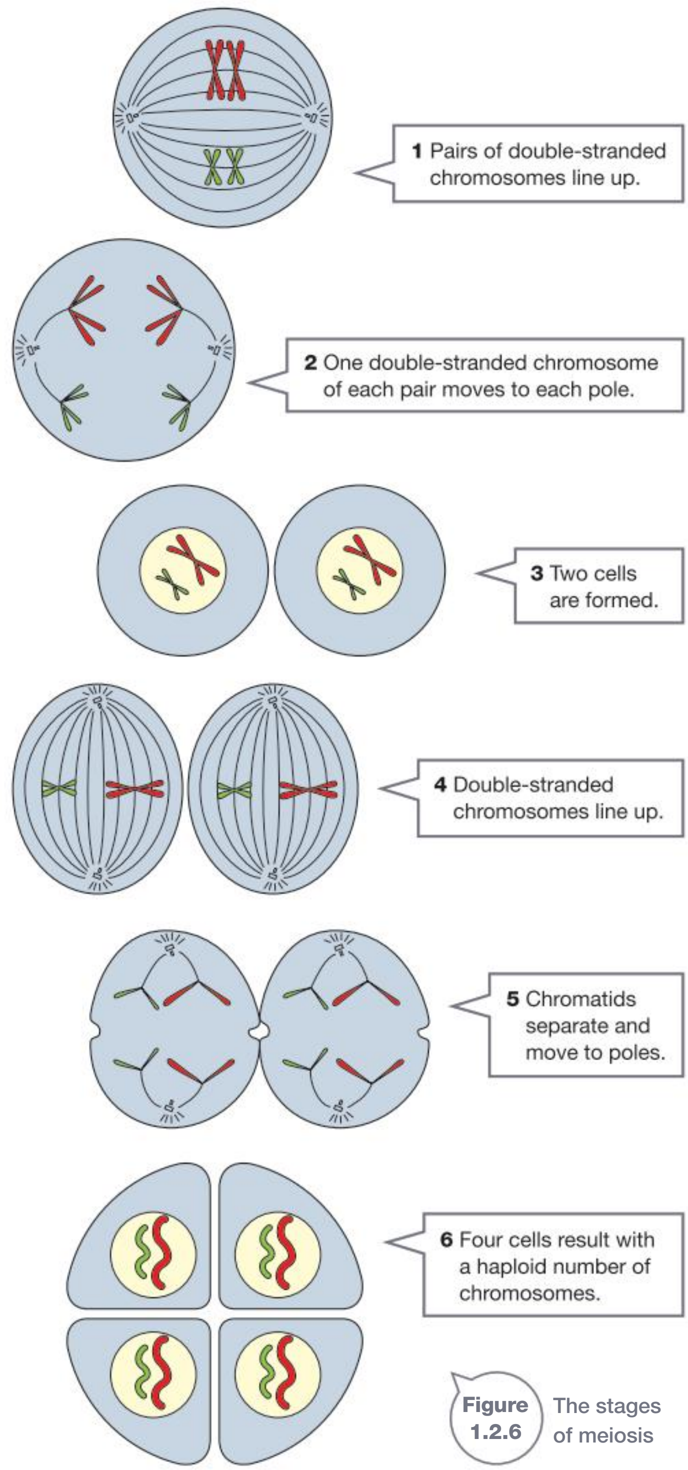


Figure 1.2.6 The stages of meiosis

Asexual and sexual reproduction

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

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

Figure 1.2.8 This grass is reproducing using asexual reproduction.

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

Sexual reproduction creates variation in a population. The four gametes produced by meiosis of one cell are all different. They all have the same number of chromosomes and carry the information about the same characteristics. However, the specific information is different. All the gametes your body ever produces will be different from each other.

Figure 1.2.9 is an example of a homologous pair of chromosomes carrying the gene for eye colour. In this example, one chromosome holds information for blue eyes, while the other specifies brown eyes. When this cell forms gametes, half will have the chromosome carrying information for blue eyes and the other half will have the information for brown eyes.

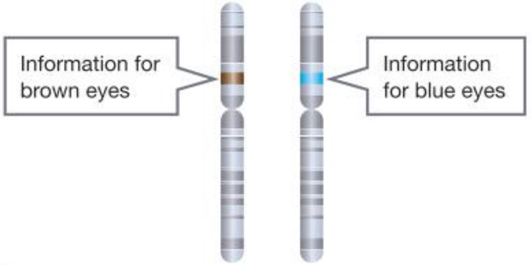


Figure 1.2.9 Homologous pair of chromosomes carrying the gene for eye colour

Another example is shown in Figure 1.2.10, in which a different pair of homologous chromosomes carries information about the length of the second toe. Some people have a second toe that is longer than their big toe. In others the second toe is shorter. If one chromosome has the information for a long second toe and the other has the information for a short second toe, then half the gametes will have information for a short toe and half will have information for a long toe.

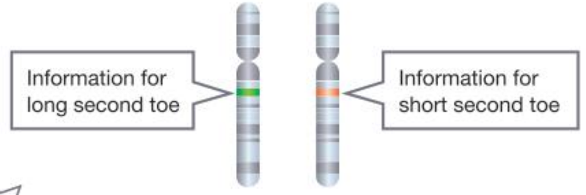


Figure 1.2.10 Homologous chromosomes for toe length

Consider the chromosomes for eye colour and toe length in one person. During meiosis when the chromosomes in a pair separate, the homologous chromosomes randomly go to either end of the cell. Figure 1.2.11 demonstrates that the four gametes produced could carry different combinations of the information about eye colour and toe length.

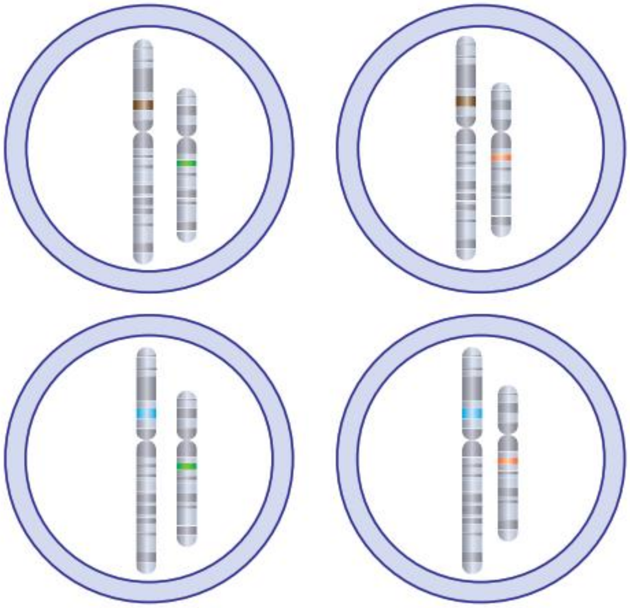


Figure 1.2.11 The gametes produced from the homologous chromosomes shown in Figures 1.2.9 and 1.2.10

1.2 Unit review

Remembering

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

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

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

Understanding

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

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

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

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

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

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

Applying

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

11 **Calculate** how many chromosomes will be in the cells of a tomato plant where there are 12 chromosomes in a gamete.

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

13 **Identify** what Figure 1.2.12 represents.

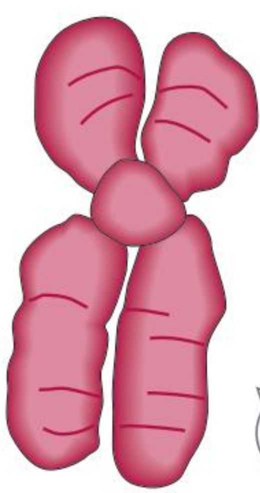


Figure 1.2.12

14 **Identify** the homologous pair in the chromosomes in Figure 1.2.13.

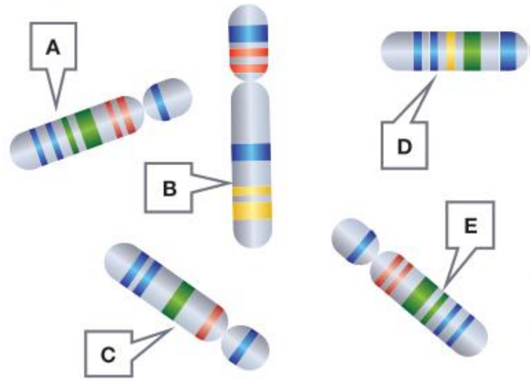


Figure 1.2.13

Analysing

15 **Contrast** haploid with diploid cells.

16 **Compare** chromosomes and chromatids.

17 Characteristics of two pairs of chromosomes are shown in Figure 1.2.14. **Demonstrate** all the combinations that would be possible in gametes if this cell were to undergo meiosis.

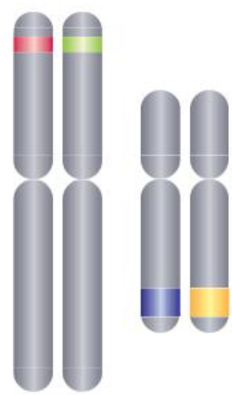


Figure 1.2.14

Evaluating

18 a Figure 1.2.15 represents a section of single-stranded DNA. **Deduce** what the strand would be like after replication and **use** a diagram to represent your idea.
  b **Justify** your structure in part A.

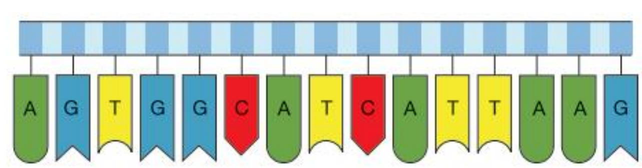


Figure 1.2.15

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

a Copy the table into your workbook.

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

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

20 **Propose** what is happening in the cells labelled A, B and C in Figure 1.2.16.

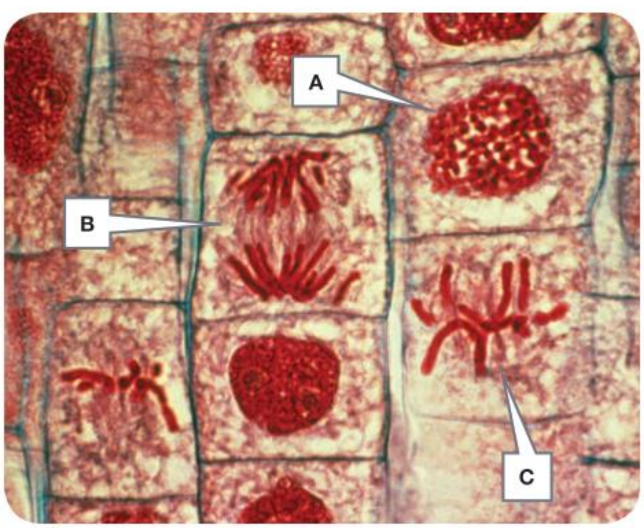


Figure 1.2.16 These cells are undergoing mitosis.

Creating

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

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

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

24 **Design** an activity where making kebabs could be used to demonstrate the concept of homologous chromosomes.

Inquiring

1 Research whether there is a relationship between the diploid number of chromosomes in a species and the level of complexity and intelligence of that species.

2 Research how living things grow and what controls the rate of cell division.

3 Research the relationship between mitosis and cancer.

1.2 Practical activities

1 Observing mitosis

Purpose
To observe mitosis in plant roots.

Materials
- prepared slides of onion root tips
- microscope

Procedure
1. Using a prepared slide and the low power on the microscope, focus on cells just behind the tip of the root (Figure 1.2.17).
2. Search for nuclei that appear to contain threads instead of appearing as dark circles. These are the cells that will be undergoing mitosis.
3. Focus on these cells and then switch to high power and focus on a cell where the chromosomes are clearly visible.
4. Find other cells that seem to be in different stages. For example, look for evidence of two newly formed cells.

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

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

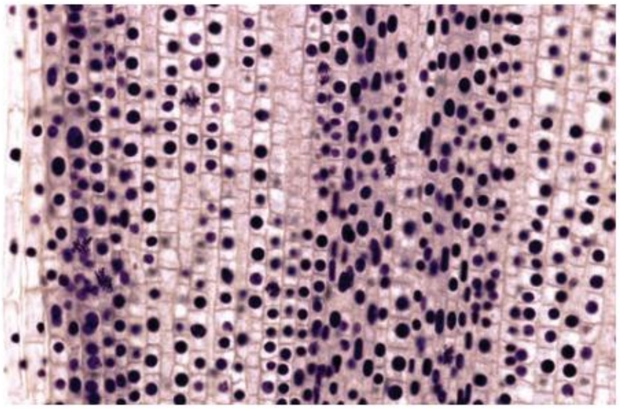


Figure 1.2.17 Stained onion root tip cells

2 Observing meiosis

Purpose
To observe meiosis in the anther of a flower.

Materials
- prepared slide of an anther
- microscope

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

Results
Draw diagrams of the cells you have found.

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

1.3 Characteristics and inheritance

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

INQUIRY science 4 fun

Family resemblances

What are your family's traits?

Yes

Collect this …

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

Do this …

Observe the photographs to see where there are similarities.

Record this …

Describe the resemblances you found.

Explain the relationship between the people displaying these characteristics.

Discovering genetics

Genetics is the study of inherited characteristics called traits. In Austria in 1856, a monk called Gregor Mendel (1822–84) (Figure 1.3.1) carried out experiments on pea plants. The results of these experiments led him to construct theories that became the basis for the study of modern genetics, and are still recognised and used today.

Figure 1.3.1 Gregor Mendel was not a world-renowned scientist. He was the only son of farmers who lived in the area now known as Austria.

Dominant/recessive inheritance

In one series of experiments, Mendel worked with pure-breeding red-flowered pea plants and pure-breeding white-flowered pea plants. In **pure-breeding** lines, all the individuals have the same genetic information. Therefore, only red-flowered offspring could be produced from red-flowered parents and white-flowered offspring from white-flowered parents.

When pollen from red-flowered plants was used to cross-pollinate the white-flowered plants, all the plants in the next generation produced red flowers. Mendel called the red characteristic the **dominant** characteristic. The dominant characteristic is the characteristic that can be observed in the appearance of the individual. The other characteristic he called the **recessive** characteristic—the one that remained hidden.

Mendel then cross-pollinated these red flowers of the first generation, or F_1 generation. Each set of crosses that he performed produced both white and red flowers in the next generation—the F_2 generation. As shown in Figure 1.3.2, the proportions were roughly ¾ red flowers and ¼ white flowers.

The conclusion from these results is that genes work in pairs to determine which characteristic is shown or expressed. The gene that was studied in this situation was the gene for flower colour and this gene came in two varieties. Variations of genes are known as **alleles**. In this instance, the gene for flower colour had an allele for the red flower trait and an allele for the white flower trait.

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

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

When an individual has two alleles the same, such as the RR and rr combinations shown in Figure 1.3.3, then the individual is said to be **homozygous** for that allele. The individual is described as a homozygote. Individuals with the Rr combination of alleles are **heterozygous**. These individuals are heterozygotes.

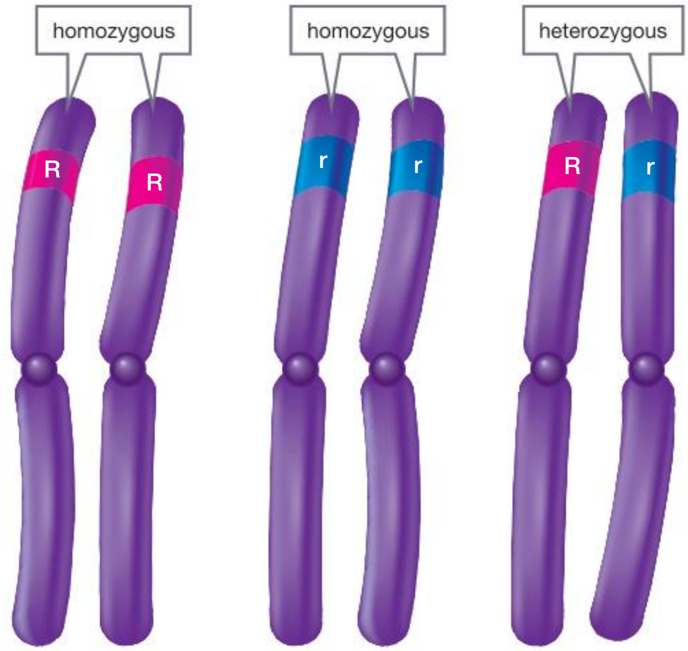
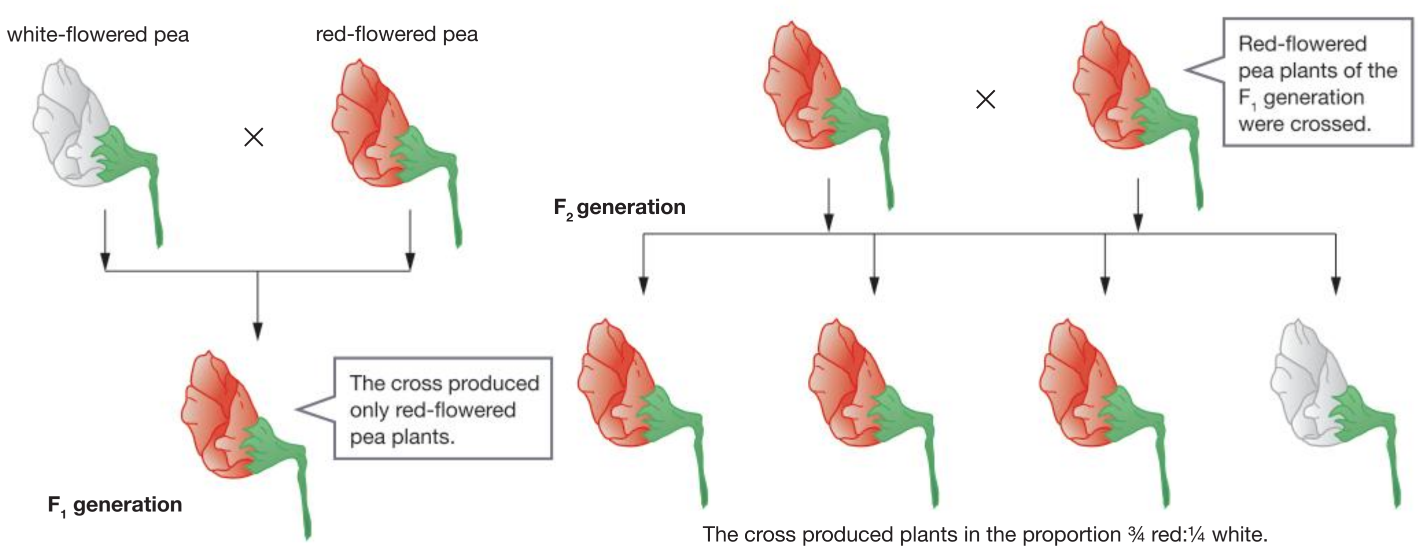


Figure 1.3.3 Individuals with the pairs of homologous chromosomes on the left and centre are homozygous. One is homozygous for the dominant allele (RR). The other is homozygous for the recessive allele (rr). The chromosomes on the right belong to an individual that is heterozygous (Rr).

Figure 1.3.2 The results of some of Mendel's experiments showing the flower colours appearing in the first (F_1) and second (F_2) generations of offspring.



When working out the possible characteristics of offspring, it is important to refer back to meiosis and the movement of the genes as gametes are produced. Figure 1.3.4 demonstrates how gametes of a heterozygote end up with the different alleles of the flower colour gene.

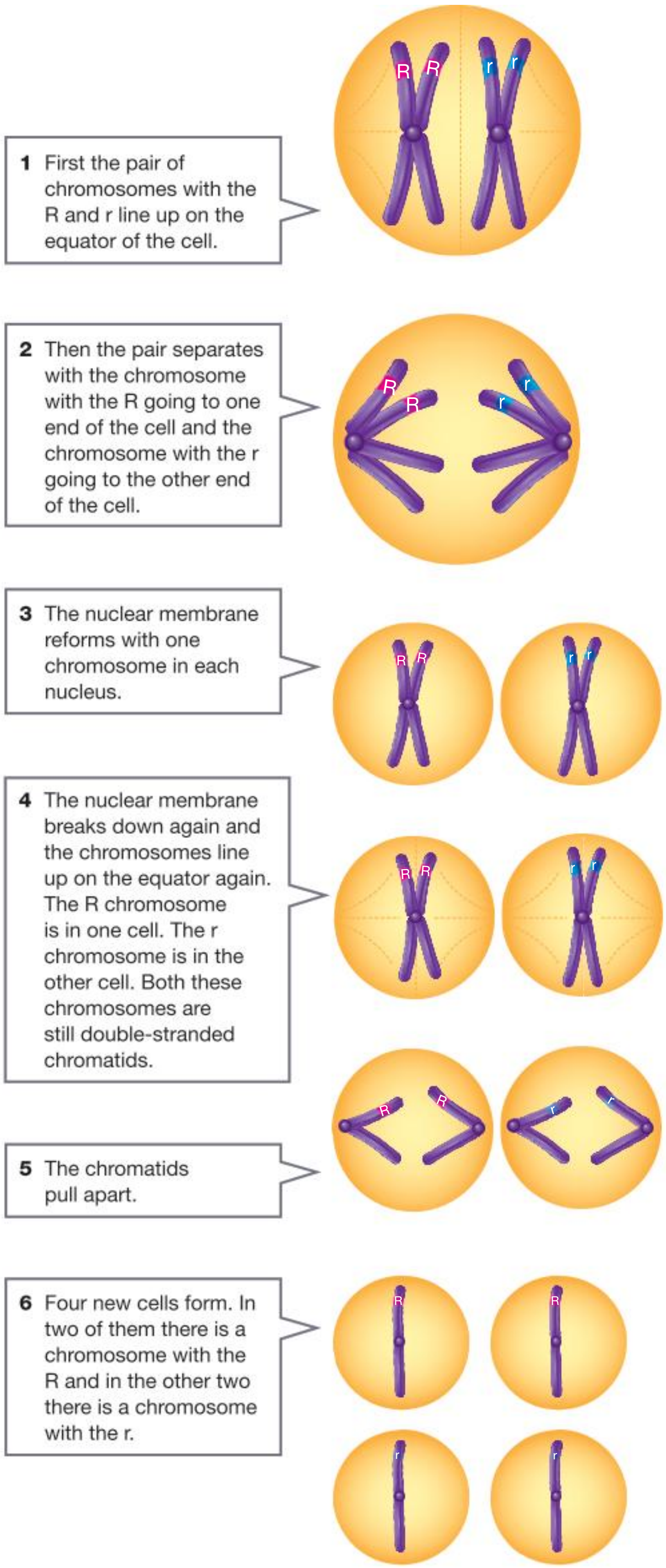


Figure 1.3.4 The behaviour of chromosomes during meiosis determines the alleles that end up in each of the gametes.

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

Punnett squares—like those shown in Figure 1.3.5—are one way of showing all the possible types of offspring that could result from a cross. You cannot assume that the offspring will appear in exactly this order and in this exact ratio. It represents a probability.

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

Homozygous (Gametes from one parent across the top; Gametes from other parent down the side; Possible outcomes of fertilisation in the squares)

	r	r
R	Rr	Rr
R	Rr	Rr

Heterozygous

	R	r
R	RR	Rr
r	Rr	rr

R	alleles for red-flowered pea
r	alleles for white-flowered pea

Figure 1.3.5 The top Punnett square shows the possible outcomes of a cross between two homozygous individuals. The bottom Punnett squares shows the possible outcomes of a cross between two heterozygous individuals.

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

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

In the example in Figure 1.3.5, RR and Rr have different genotypes but they both have the same phenotype—they both have red flowers.

SciFile

Shared genes

All the variation between humans is caused by 0.1% of their DNA. The other 99.9% is identical no matter where you come from or what you look like.

We also share about 98% of our genes with chimpanzees and 90% with mice.

Predicting the results of a cross

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

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

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

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

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

A Punnett square can help you predict the outcomes.

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

From the table the expected genotypes are:

¼ FF, ½ Ff and ¼ ff

Because F is dominant to f the expected phenotypes are:

¾ trait F and ¼ trait f

If P_1 and P_2 had 12 offspring, you would expect *about* 8 trait F and 4 trait f.

WORKED EXAMPLE
Predicting the results of a cross

Problem

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

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

Solution

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

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

Step 2 Deduce the genotypes of the parent plants.

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

Step 3 Set up your cross in a Punnett square.

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

Step 4 Write down the expected genotypes.

¼ YY, ½ Yy, ¼ yy

Step 5 Work out the expected phenotypes.

¼ YY + ½ Yy = ¾ yellow

¼ yy = ¼ green

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

¾ × 100 = 75 green

¼ × 100 = 25 yellow

1.5 1.6

Incomplete dominance

Some genes do not have dominant and recessive alleles. Some alleles show **incomplete dominance**, and the appearance of a heterozygous individual results from a 'blending' of two such alleles. A heterozygote will look different from both its homozygous parents.

One example is in domestic chickens in which black feathers are incompletely dominant to white feathers. The heterozygous chicken has blue-grey feathers. The blue-grey colouring of cockatiels (Figure 1.3.6) is also the result of incomplete dominance.

The shorthand convention in this situation is to use uppercase letters related to the two different alleles such as B for black and W for white feathers. This is a reminder that neither allele is dominant to the other.

Figure 1.3.6

Feather colour in cockatiels is inherited in the same way as in chickens. The blue-grey colour of the feathers is the result of incomplete dominance.

Sex determination

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

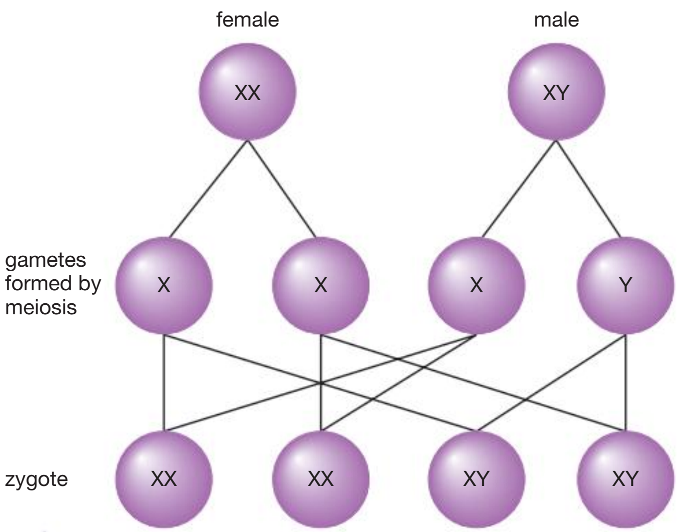


Figure 1.3.7 Inheritance of the sex-determining chromosomes

Sex linkage

Some genes are found on the X chromosome and not on the Y chromosome. These are called **sex-linked genes** because they are present on one of the chromosomes that are also responsible for the determination of sex.

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

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

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

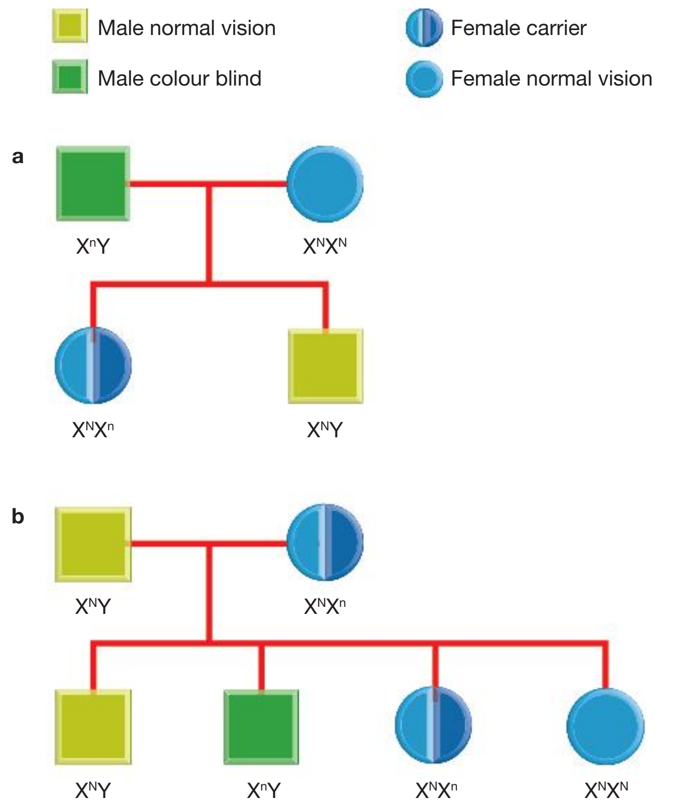


Figure 1.3.8 **a** The daughters are all carriers because they have inherited the colour-blindness allele from their father. However, their vision will be normal. The sons have normal vision.

b Half the sons of a carrier mother will have normal vision. The other half will be colour-blind. All the daughters will have normal vision, but half will be carriers of the disease.

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

Chromosomal abnormalities

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

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

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

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

1.3 Unit review

Remembering

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

2 **Recall** the term used to describe:
- a alternative forms of gene
- b an organism with different alleles for a particular gene
- c the observable characteristics of an individual
- d an individual with two copies of the same allele of a gene.

Understanding

3 **Predict** the number of chromosomes that would be found in the following human cells.
- a ovum
- b muscle cell
- c skin cell
- d sperm cell

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

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

Applying

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

7 **Identify** the option a–g that matches each description i–vii in the table below.

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

8 In guinea pigs, black coat is dominant to brown coat colour.
- a **Use** an appropriate symbol to represent the alleles for coat colour.
- b **Use** a Punnett square to **demonstrate** the genotype and phenotype of the offspring you would expect from a cross between heterozygous black and a homozygous brown guinea pig.

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

Analysing

10 **Contrast**:
- a homozygous and heterozygous
- b phenotype and genotype
- c autosome and sex chromosome.

11 **Analyse** the following Punnett square where R is red and r is white. **Identify** the:
- a type of inheritance
- b ratio of genotypes in the offspring
- c ratio of the phenotypes and appearance in the offspring.

	R	r
r	Rr	rr
r	Rr	rr

Evaluating

12 **Deduce** the genotype of the parents, given the characteristics of the offspring.
- a All the offspring for three generations had red flowers.
- b All the plants in the study were tall but when the next generation came along about one-quarter of them were short.

Creating

13 a **Design** an experiment that you could carry out to determine the dominance or recessiveness of black coat and white coat in mice.
- b **Explain** why this experiment would provide the evidence you need to make your decision.

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

15 **Construct** a drawing of an imaginary animal or plant. Decide on a characteristic for which there will be two alleles. It could be something like flower colour or hair colour. Decide on letters to represent these alleles. Now make diagrams to represent the phenotype of your creature in each of the following situations. Include the genotype with each drawing.
- One allele is dominant to the other and the creature is heterozygous.
- The creature is homozygous for the recessive characteristic.
- The gene is carried on the X chromosome.

Inquiring

Research the symptoms and effects on the individual of the following genetic diseases: Down syndrome, Klinefelter's syndrome, haemophilia, Duchenne's muscular dystrophy, cystic fibrosis, Huntington's disease and phenylketonuria. Present the results of your research in a table.

1.3 Practical activities

1 Chance variation

Purpose

To model the variation in potential offspring.

Materials

- die
- 20 cards about the size of playing cards
- marker pen
- the information in Table 1.3.1

Table 1.3.1

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

Procedure

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

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

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

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

Table 1.3.2

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

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

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

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

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

Results

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

Table 1.3.3

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

Discussion

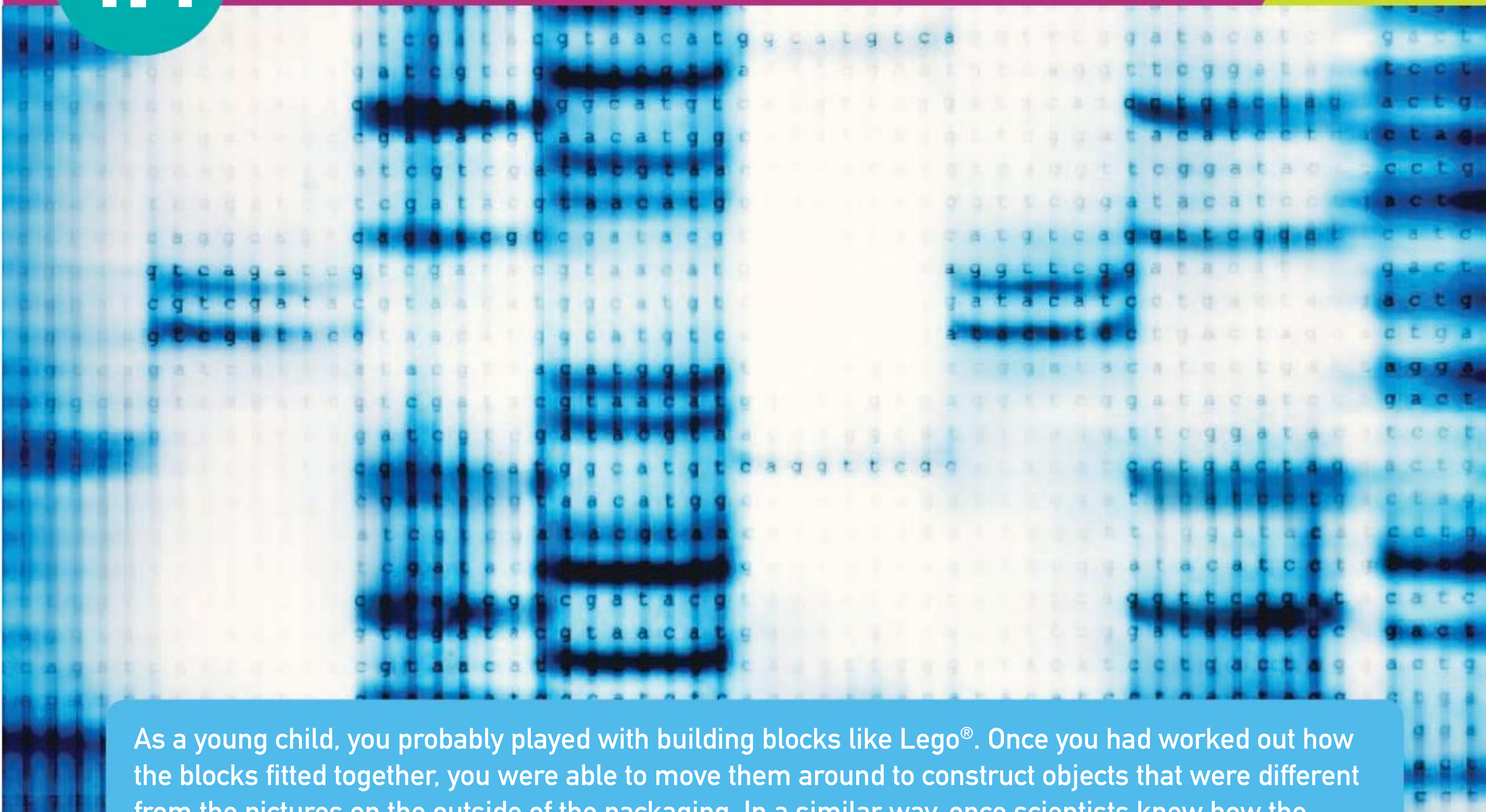
1 **Compare** the zygotes you created.

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

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

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

1.4 Gene technology



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

Genetic modification

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

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

Canola

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

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

Rice

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

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

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

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

1.8 · 1 p33

SciFile: More food needed

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

INQUIRY science 4 fun

Spliced vegetables

What happens when genes are spliced?

Yes

Collect this ...

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

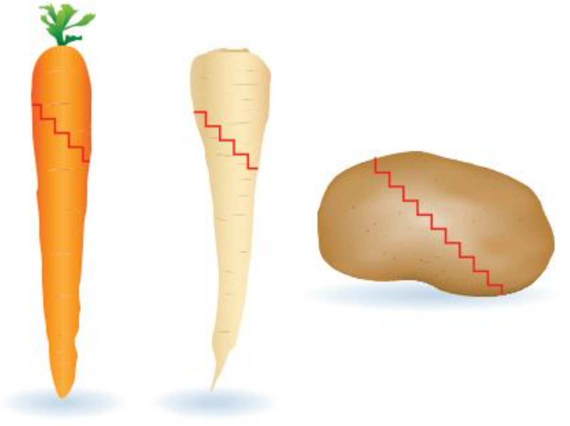
Do this ...

1. Use a step-like cut to cut the carrot into two parts across the middle.
2. Using the same pattern, halve the parsnip or potato.
3. Join one half of the carrot to one half of the parsnip or potato.
4. You have spliced the two vegetables together in a similar way to the way genetic engineers splice genes into chromosomes.

Record this ...

Describe what the final 'vegetable' looked like.

Explain why it was important to have the cuts on both vegetable a similar shape.



Gene splicing

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

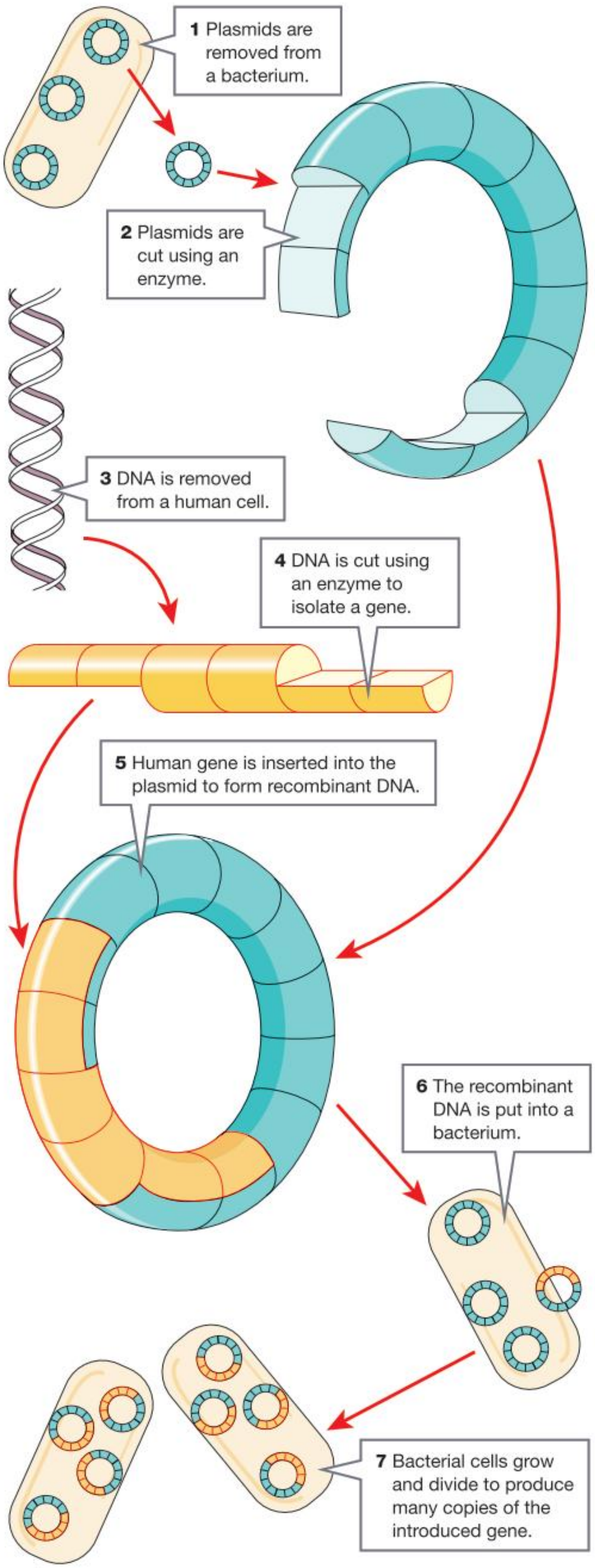


Figure 1.4.3 The process of gene splicing to create recombinant DNA

Human Genome Project

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

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

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

All humans share about 99.9% of their DNA. Figure 1.4.5 on page 28 shows variation caused by the other 0.1%. Scientists have identified millions of locations that differ by only one base from one human to another. These differences, known as **single nucleotide polymorphisms (SNPs)**, may be associated with common diseases such as cardiovascular disease, diabetes, arthritis and cancers.

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

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

Gene testing

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

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

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

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

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

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

SciFile

Who owns your genes?

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

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

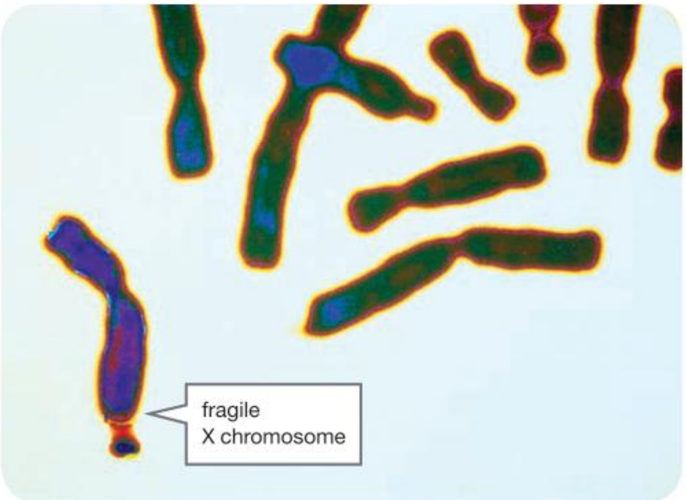


Figure 1.4.7 The defective end section of the fragile X chromosome is the fragile area. The body cannot use information in this area of the chromosome to manufacture a protein essential for normal brain development.

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

Other uses of genetic testing include:

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

Drawbacks

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

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

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

Gene therapy

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

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

Treating cancer

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

2 p33

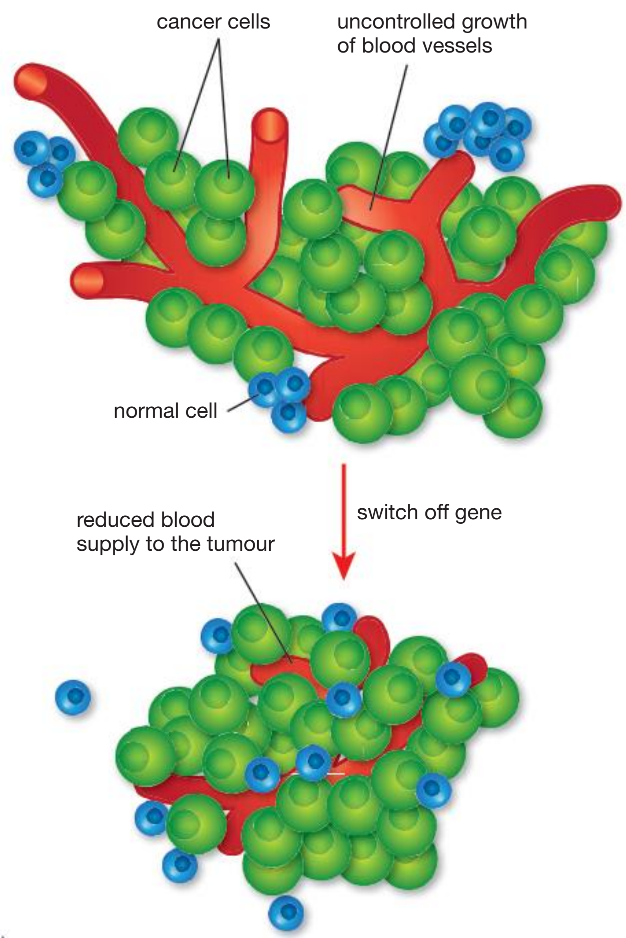


Figure 1.4.8 By switching off the RGS5 gene, the blood supply to a cancerous tumour is reduced.

SciFile

Cancer

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

SCIENCE AS A

HUMAN ENDEAVOUR

Nature and development of science

Stem cells

Figure 1.4.9 Stem cells can become many different types of cells.

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

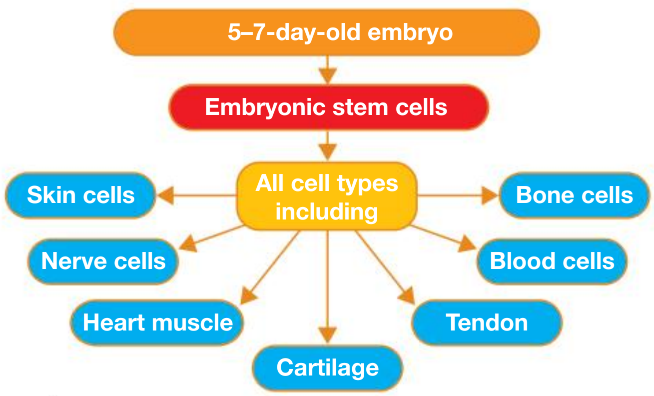


Figure 1.4.10 Embryonic stem cells can differentiate to become any of the types of cells found in the human body.

In a late stage embryo, the cells have **differentiated** (changed) and become fixed as skin cells, cardiac muscle cells or nerve cells in the brain (Figure 1.4.10). However, some cells in your body remain capable of dividing to make new cells so that you can heal wounds or replace worn-out cells.

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

Adult stem cells lie deep within organs that need a constant supply of new cells, such as the skin. They are surrounded by millions of ordinary cells. Adult stem cells are specialised to some extent. This means that they are only able to make certain types of cells as shown in Figure 1.4.11.

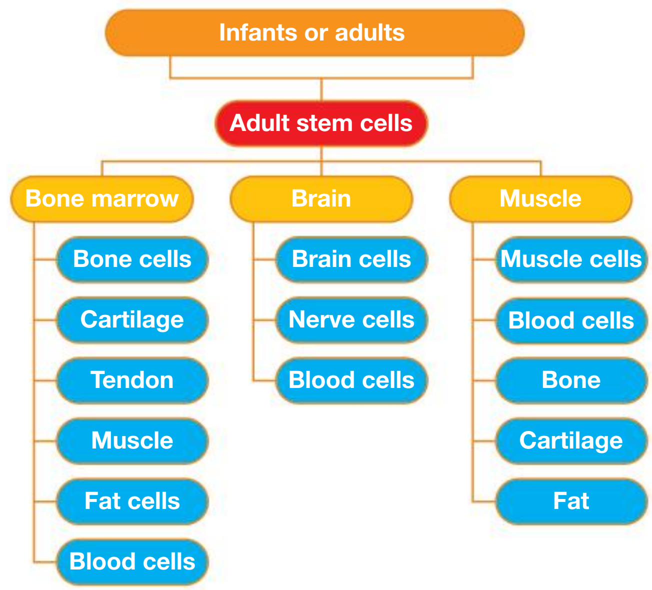


Figure 1.4.11 Adult stem cells can only differentiate to become certain types of cells.

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

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

In 2006, Shinya Yamanaka of the University of Kyoto in Japan discovered a way of returning mature skin cells from a mouse to their pluripotent state. An outline of the process is shown in Figure 1.4.12. Yamanaka called these cells **induced pluripotent skin cells** (**iPSCs**). Over the last few years, other scientists have successfully repeated Yamanaka's experiments.

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

Once these problems are solved, scientists believe that these cells have the potential to produce replacement parts of cells or organs damaged by disease. For example, they could replace nerve cells damaged through accidents (Figure 1.4.13), by Parkinson's disease and multiple sclerosis, or replace cardiac muscle damaged by heart attack. There would be no problems with rejection of the replacement tissue because it could be made from the patient's own cells.

Scientists have demonstrated that iPSCs can cure the genetic disease sickle cell anaemia in animals but there are many safety issues to deal with before there can be any human trials. 1.9

Figure 1.4.13 Many people who have suffered spinal injuries hope that stem cell research will find a way of repairing the damage.

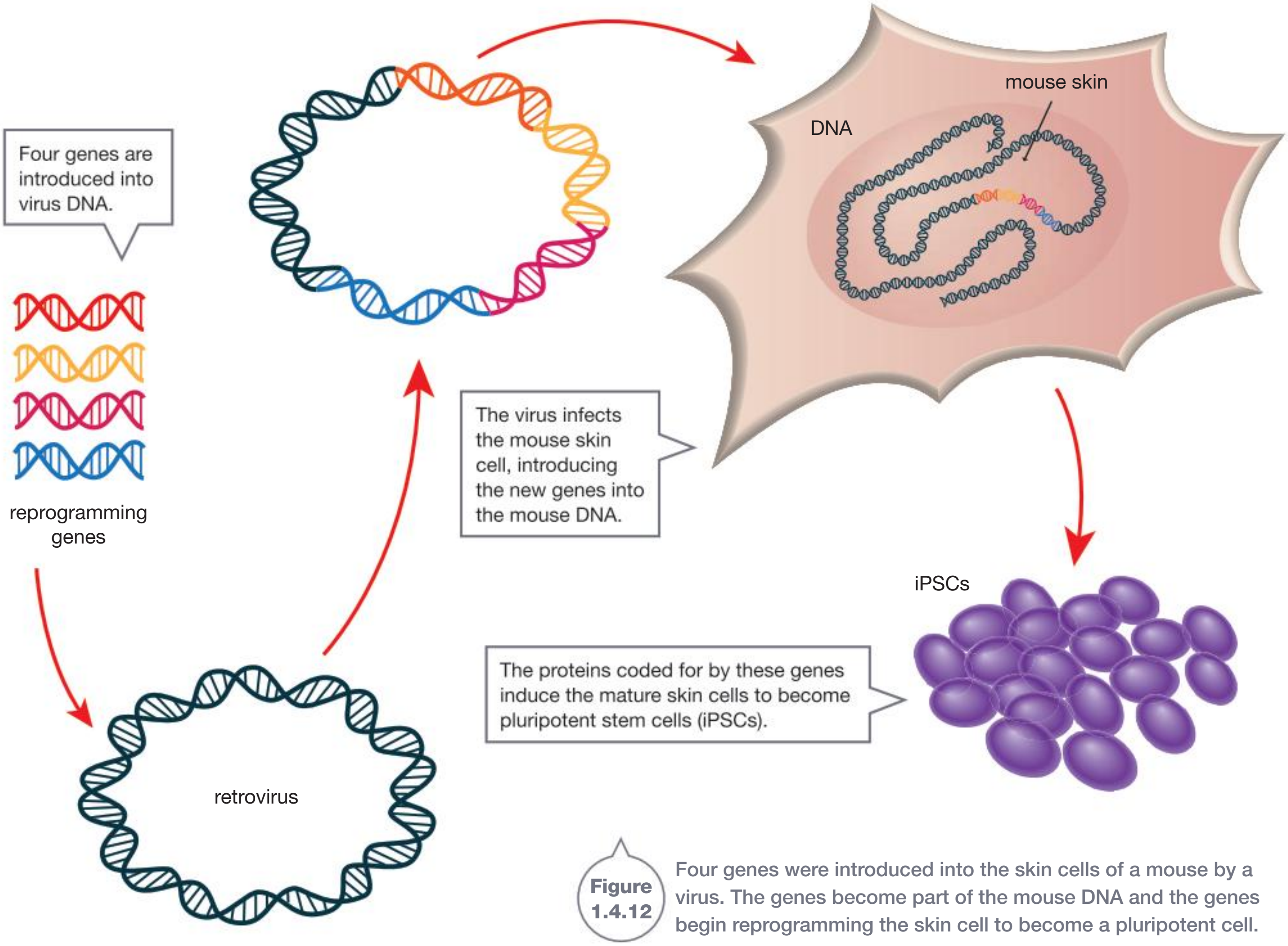


Figure 1.4.12 Four genes were introduced into the skin cells of a mouse by a virus. The genes become part of the mouse DNA and the genes begin reprogramming the skin cell to become a pluripotent cell.

1.4 Unit review

Remembering

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

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

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

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

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

Understanding

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

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

- **a** rice
- **b** canola.

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

- **b** **Propose** ways that single nucleotide polymorphisms can occur.
- **c** **Explain** why single nucleotide polymorphisms may be linked to human disease.

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

Applying

10 **a** The DNA profile of an individual can be shown as a series of bands. **Use** the DNA profiles in Figure 1.4.14 to **identify** the two people who are most closely related.

- **b** **Explain** your choice.

Figure 1.4.14

Analysing

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

12 **Compare** the possible effect on an individual of knowing that they have the genes predisposing them (making it more likely) to type-2 diabetes and the dominant allele that causes Huntington's disease.

Evaluating

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

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

Creating

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

Inquiring

1 Investigate the arguments used against the introduction of genetically modified plants such as Golden rice-2.

2 Research and present a report on the advances made in genetic modification of animals for use in human organ transplants.

3 Research the source of embryonic stem cells used in medical research. Identify the arguments used for and against the use of these stem cells and present a report on your own ideas of whether embryonic stem cell research should be allowed to continue.

1.4 Practical activities

1 Genetic modification—public opinion

Purpose

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

Materials

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

Procedure

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

Results

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

Discussion

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

2 Genetic technologies

Purpose

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

Materials

- access to the internet and other reference materials

Procedure

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

Results

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

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

Discussion

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

1 Chapter review

Remembering

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

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

3 **Name** the following processes:
- a adding genes into or removing genes from DNA
- b replacing a defective gene with a normal gene
- c selective breeding where offspring that show the most positive traits and fewest negative traits are selected and then crossed with one of the original parents.

Understanding

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

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

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

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

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

Applying

9 **Identify** the parts of the nucleotide labelled A, B and C in Figure 1.5.1.

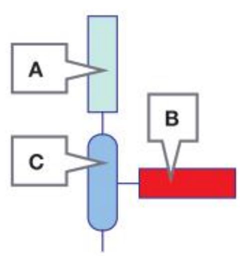


Figure 1.5.1

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

11 **Demonstrate** how two homozygous parents could have a heterozygous child.

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

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

Analysing

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

14 **Compare** haploid and diploid cells.

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

Evaluating

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

Creating

17 a **Use** the information in Table 1.5.1 to **construct** graphs showing the change in amount of land planted with three GM crops.

Table 1.5.1 Area of land planted with GM crops

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

b **Use** the information in Table 1.5.1 and the graphs you constructed to **calculate** the:
- i crop that had the largest percentage increase in area of land planted in the years 1997–2009
- ii years that showed the greatest increase in land planted with GM canola
- iii years that showed the smallest increase in land planted with GM soy.

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

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

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

Thinking scientifically

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

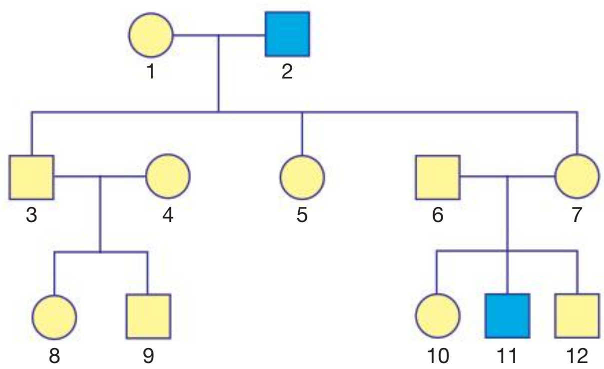
A All the offspring will be blue.

B All offspring will be green.

C ½ Gg: ½ gg

D ½ GG: ½ gg

Q2 The following diagram is called a pedigree. The individuals shaded blue have thalassemia, a disease that is inherited according to the rules of dominant–recessive inheritance. Based on the information in the family pedigree, identify the option in which both statements are true.



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

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

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

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

Q3 In snapdragons, there are two alleles for the gene for flower colour—red and white. Red flower colour is incompletely dominant to white.

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

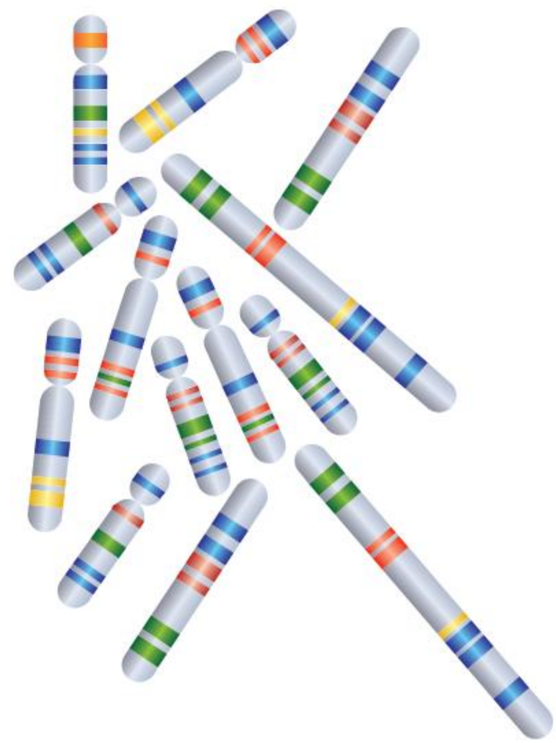
A Half the offspring would be red and half the offspring would be pink.

B Half the offspring would be red, one-quarter would be pink and one-quarter would be white.

C The heterozygous parent had pink flowers.

D The homozygous parent had red flowers.

Q4 Identify the number of pairs of homologous chromosomes in the following diagram.



A 7

B 6

C 5

D 4

Q5 Identify the small section of DNA that could be part of the longer DNA strand:

TAGTAGTCATACCGAATTGCCGGAATACTAGTAGGATC
ATCATCAGTATGGCTTAACGGCCTTATGATCATCCTAG

A TACCGAATCCCGGAATTC
ATGGCTTAGGGCCTTAAG

B TACCGAATTGCCGGAATAC
ATGGCTTAACGGCCTTATG

C TACCGAATGCCGGAATAC
ATGGCTTACGGCCTTATG

D TACCGATGCCGCAATAC
ATGGCTACGGCGTTATC

Thinking scientifically

Q6 The data in the table provides information on the costs to farmers from four different states in India of growing genetically modified cotton.

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

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

A The state that made the greatest savings on chemicals also had the highest yield and the greatest profit.

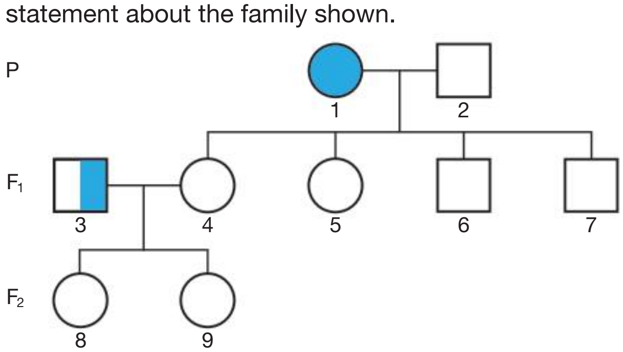
B The states of Maharastra and Kamataka both saved more than the national average on chemical costs and had a yield and profit above the national average.

C The state that had the greatest advantage in terms of total income also had the greatest advantage in terms of total cost and yield.

D Andhra Pradesh made a loss because the farmers in that state had to spend more on chemicals.

Q7 Hair curliness is an example of incomplete dominance. The diagram below illustrates a pedigree showing three generations of a family. The mother is homozygous for curly hair. The father is homozygous for straight hair. Individual 3 marries into the family and his genotype is shown to be heterozygous. The remaining phenotypes of the F_1 and F_2 generations are *not* shown.

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



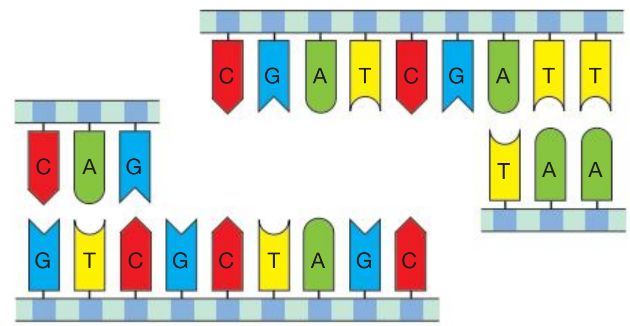
A Some of the F_1 generation will have curly hair and some will have straight hair.

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

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

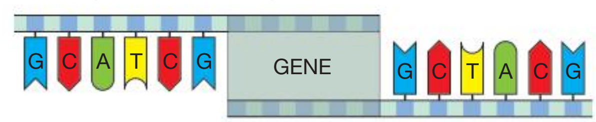
D Individual 8 must have wavy hair.

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

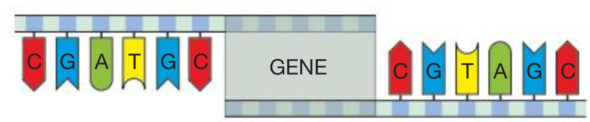


From the four genes below, identify the gene that could be spliced into that piece of DNA.

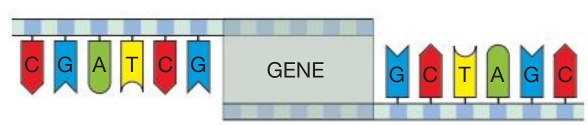
A



B



C



D

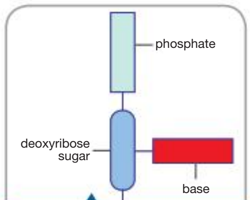
Glossary

Unit 1.1

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

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

Deoxyribonucleic acid (DNA): a nucleic acid with deoxyribose sugar and phosphate as the backbone; the molecule that determines the genetic characteristics of most living things



Deoxyribonucleic acid (DNA)

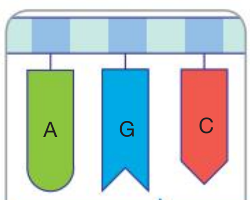
Deoxyribose sugar: one of the parts that make up a nucleotide

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

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

Nucleotides: the building blocks of DNA

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



Nucleotide

Unit 1.2

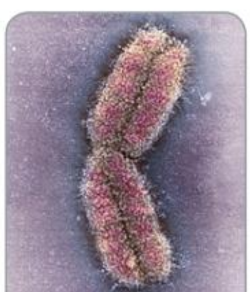
Autosomes: all the chromosomes in a cell other than the sex chromosomes

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

Chromatid one of the strands of a chromosome following replication

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

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


Chromatid

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

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

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

Replication: the process of making copies of DNA

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

Unit 1.3

Alleles: different forms of the same gene

Dominant: the characteristic that is expressed in the homozygous condition

Genotype: genetic information carried by an individual

Heterozygous: having two different alleles on homologous chromosomes

Homozygous: having two identical alleles on homologous chromosomes

Incomplete dominance: where the appearance of a heterozygous individual results from a ‘blending’ of the two alleles because one allele is not completely dominant over the other

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

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

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

Recessive: the characteristic that remains hidden in the homozygous condition

Sex-linked genes: genes present on the sex chromosomes

Unit 1.4

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

Differentiate: become different from others

Embryonic stem cells: cells found in the embryo that are capable of becoming any cell type found in the body of a complex organism

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

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

Genetically modified: having the genes changed

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

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

Induced pluripotent skin cells (iPSCs): mature cells that have been induced to revert to their pluripotent (capable of becoming any type of human cell) state

Plasmid: ring of DNA found in bacteria

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

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


Plasmid

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

2 Geological time

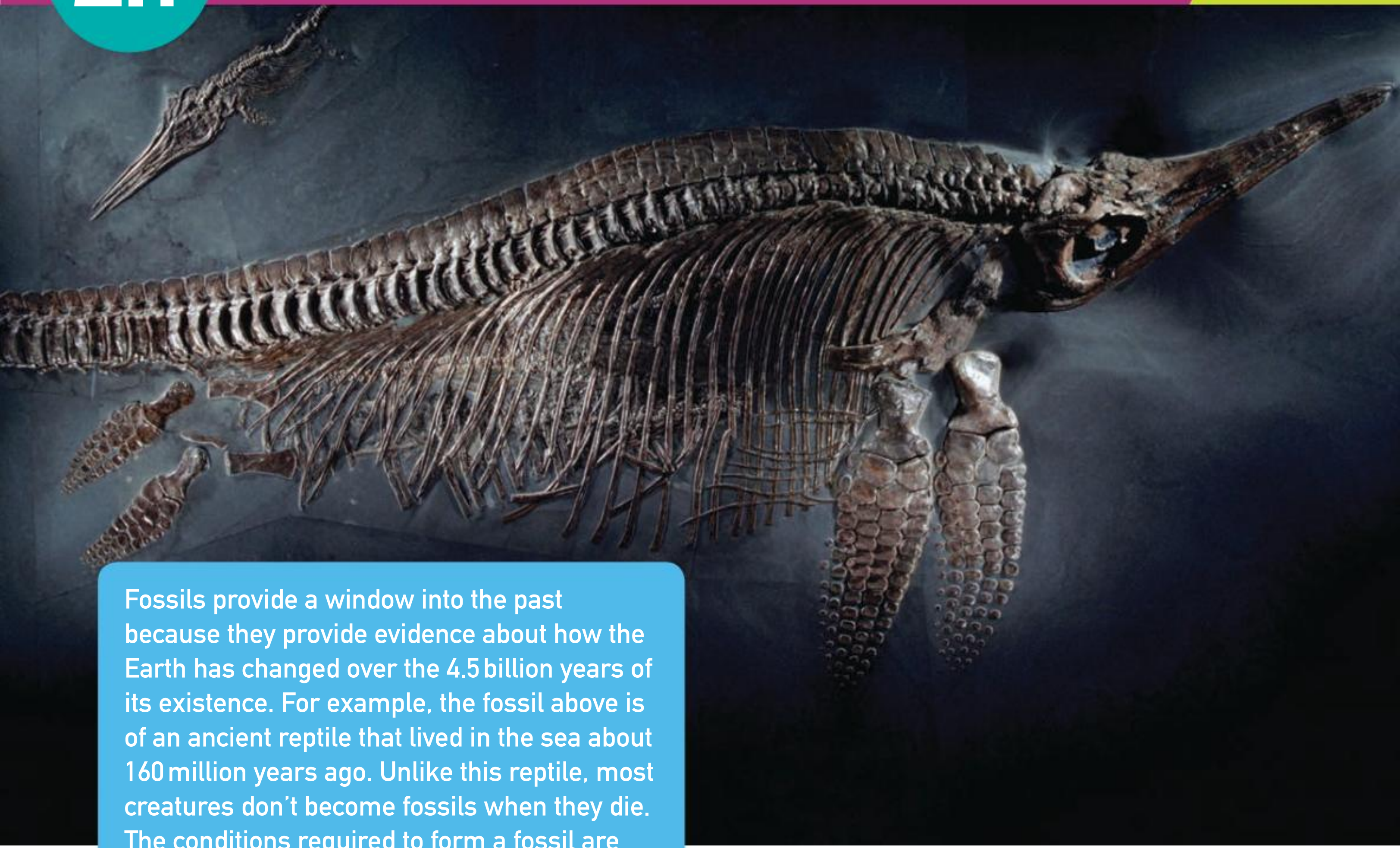
HAVE YOU EVER WONDERED...

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

After completing this chapter students should be able to:

- evaluate evidence for evolution, including the fossil record, chemical and anatomical similarities and geographical distribution of species
- discuss the role of different sources of evidence for evolution by natural selection, including biochemical, anatomical and fossil evidence.

2.1 Fossils



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

INQUIRY science 4 fun

Fossil kits

What can you tell from fossils?

No

Collect this ...

- fossil kit

Do this ...

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

Record this ...

Describe your fossil by sketching it and recording its name and age.

Explain how fossils like this tell you a little about past life.

What is a fossil?

Fossils are the preserved evidence in rocks or soils of organisms that once existed on Earth. The fossil may be the whole body of the organism, part of it or traces of its activities such as its burrows, tracks or dung (faeces). To be preserved as a fossil, the dead organism must not be eaten by scavengers and it must then decay very slowly. These two conditions are most likely to occur when dead organisms are covered in sediment, which then turns to rock.

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

Formation of fossils

The **fossil record** is a list showing all the species of living organisms that have been found as fossils as well as their location and age. The record can be thought of as a timeline of Earth, tracking the Earth's development since its formation 4.5 billion years ago. However, not all organisms are represented equally in the fossil record. This is because the soft parts of organisms decay much faster than the hard parts. For this reason, it is extremely rare for soft parts to be preserved.

Organisms that are only composed of soft parts, such as jellyfish, slugs, algae and mosses will be rare in the fossil record. Hard objects such as skeletons, shells, teeth and wood are most commonly found as fossils. Fossils of organisms with hard parts, such as dinosaurs, giant kangaroos, crabs, shellfish and trees, will be more common.

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

Erosion and movements within the soil and rock can then expose the rock layers containing the fossil or bring them to the surface. Fossils are found in sedimentary rock and not in igneous or metamorphic rocks. The heat and pressure needed to form igneous and metamorphic rocks destroy any traces of organisms in them. In contrast, sedimentary rock traps the remains for possible future discovery.

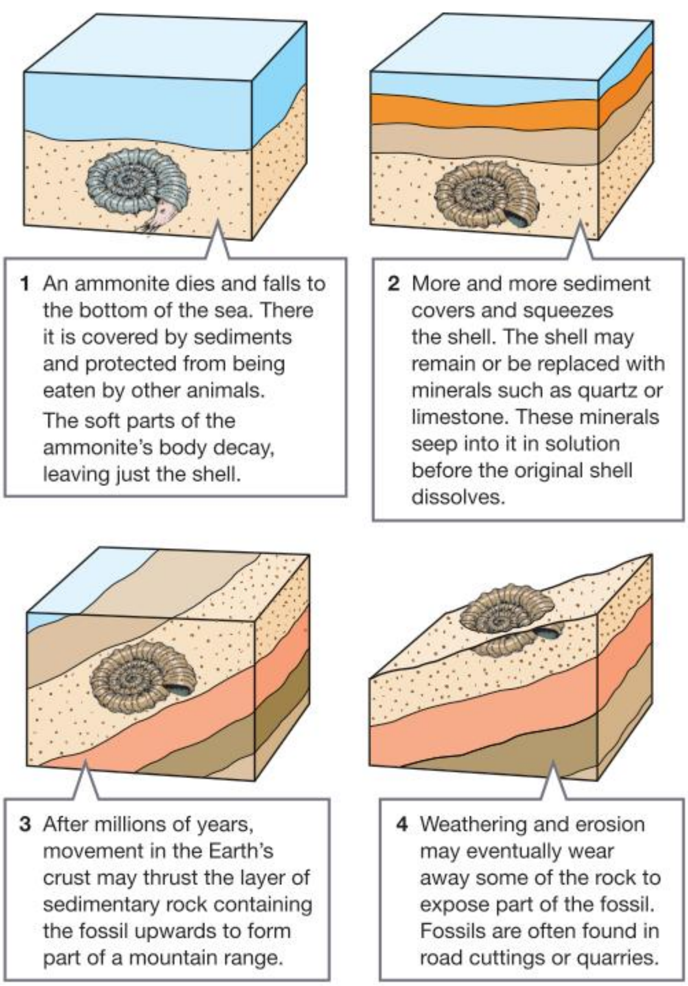


Figure 2.1.1 Fossilisation can happen when the remains of an organism are trapped in the layers of a sedimentary rock.

Types of fossils

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

- original
- replacement
- carbon film
- indirect fossils.

Original fossils

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

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

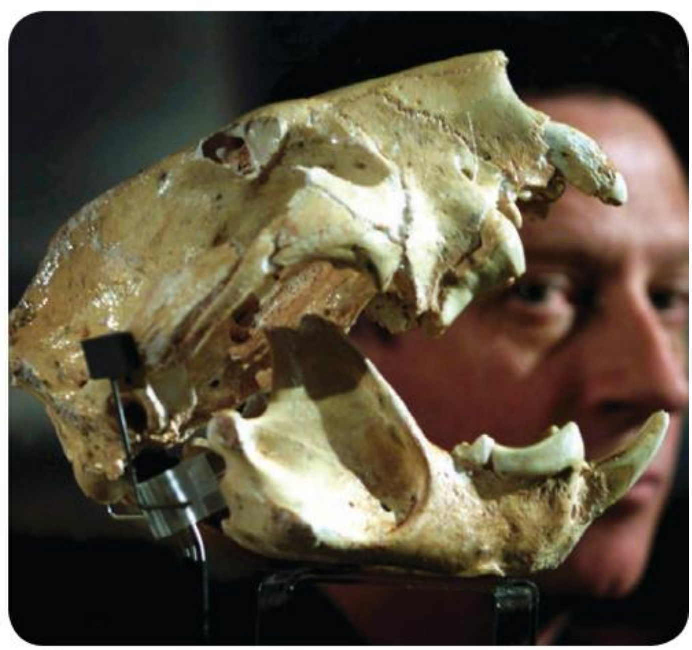


Figure 2.1.2 This is an original fossil. It was found on the Nullarbor Plain in Western Australia and is the remains of a marsupial lion that died 45 000 years ago. The fossil shows that it had large dagger-like teeth for catching its prey.

INQUIRY science 4 fun

Bendy bone

What is bone made of?

Yes

Collect this …

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

SAFETY!

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

Do this …

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

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

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

Record this …

Describe what happened.

Explain why you think this happened.

SciFile

Turkana Boy

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

Replacement fossils

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

Figure 2.1.3

This plesiosaur backbone is a replacement fossil. The bones have slowly been replaced by silica, turning into opal.

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

SciFile

Fake!

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

Figure 2.1.4

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

Carbon film fossils

Carbon film fossils occur when the dead body partially decays and leaves a thin black deposit of carbon. These fossils are also known as carbon trace fossils. Figure 2.1.5 on page 42 shows the carbon film fossil of an ancient fern. Plant fossils are commonly carbon film fossils. The traces of carbon left are still in the shape of the organism that decayed and often show its finer details. Coal is formed by this process, although no traces of the plants that were part of the coal can be identified in it.

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

Indirect fossils

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

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

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

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

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

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

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

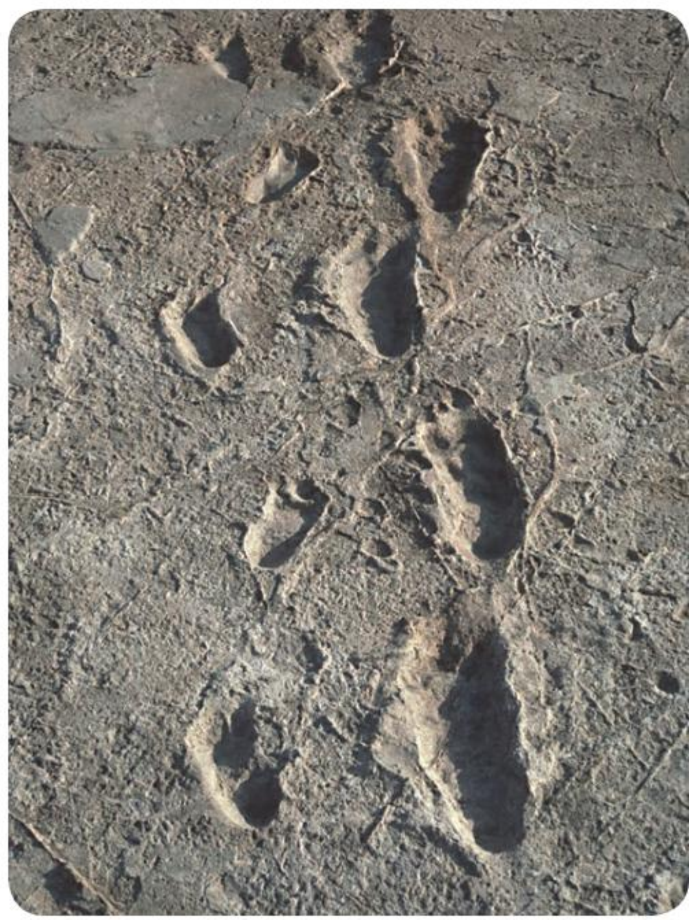


Figure 2.1.7 These fossil footprints at Laetoli in Tanzania, which are 3.6 million years old, were left by an animal that walked on two legs, much as humans do today.

1 p47 2 p47

Preserving environments

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

Permafrost

Near the Arctic Circle, the land is permanently frozen. Bacteria and fungi that cause decay cannot grow if the temperature is below freezing. This has preserved some amazing original fossils. The most famous are the fossil mammoths of Siberia, Russia. In 2007, a baby one was found that had been preserved in the ice for about 40 000 years. You can see it in Figure 2.1.8.

Figure 2.1.8 This baby mammoth was preserved in permafrost for over 40 000 years.

Amber

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

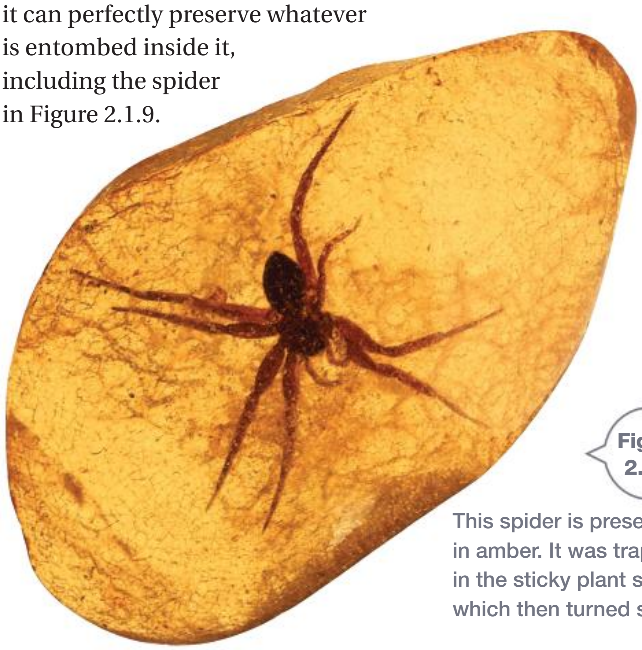


Figure 2.1.9 This spider is preserved in amber. It was trapped in the sticky plant sap, which then turned solid.

Tar

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

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

Peat

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

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

Dry air

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

The fossil record is incomplete

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

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

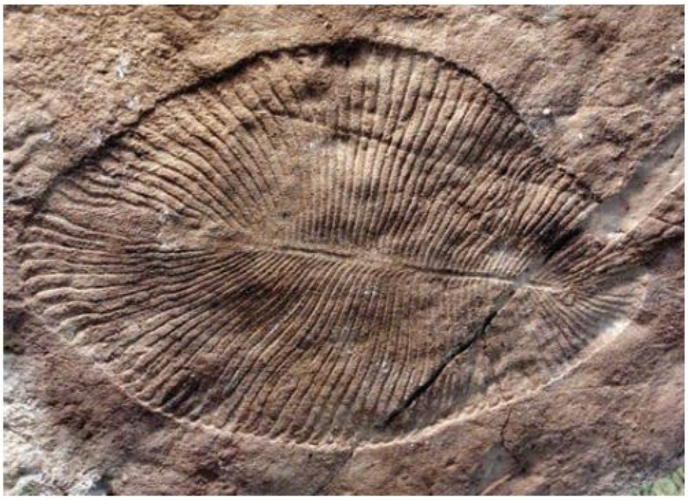


Figure 2.1.12 This fossil is thought to be of a flat worm from Ediacara in the Flinders Ranges of South Australia. A new geological period called the Ediacaran was named after these fossils.

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

2.1

Famous fossil sites

Famous sites with many fossils are:

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

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

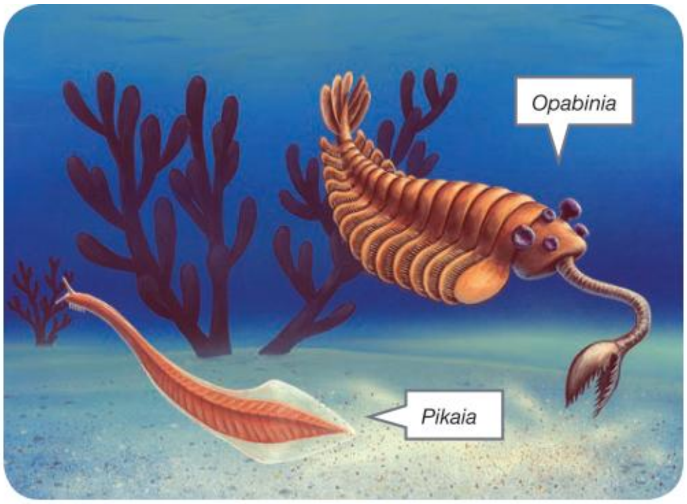
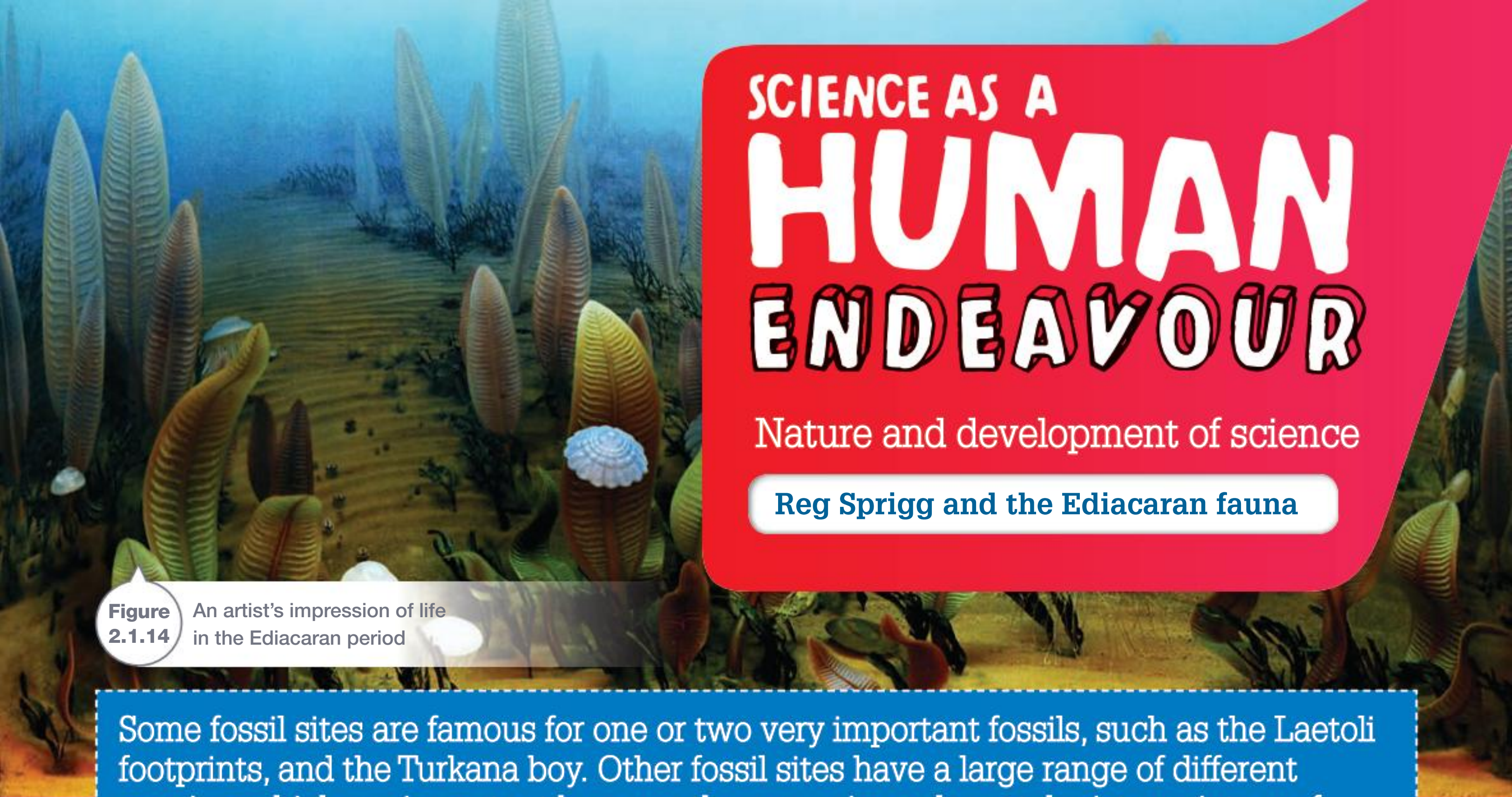


Figure 2.1.13 This is an artist's impression of two organisms from the Burgess Shale, which has some very well-preserved soft-bodied organisms.

SciFile

Spot the relative

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



SCIENCE AS A HUMAN ENDEAVOUR

Nature and development of science

Reg Sprigg and the Ediacaran fauna

Figure 2.1.14 An artist's impression of life in the Ediacaran period

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

In Australia, the most famous site for a wide range of fossils is the Ediacaran Hills in the Flinders Ranges of South Australia. A South Australian geologist, Dr Reg Sprigg (1919–94), discovered what is now believed to be the oldest group of multicellular organisms that are ancestors of all the life that followed. Artists' impressions of them are shown in Figures 2.1.14 and 2.1.15. Sprigg found the fossils in 1946 when he was just 26 years old, and published his findings.

In 2004, the International Commission on Stratigraphy finally recognised a new geological period, which they named the Ediacaran. The **Ediacaran** period is the first new geological period to be named in the past 120 years. It spans 635–542 million years ago and is the first ever to spring from the Southern Hemisphere. The Ediacaran Hills are now part of the Flinders Ranges National Park.

Figure 2.1.15 Reg Sprigg's contribution to palaeontology is recognised on a 50-cent stamp.

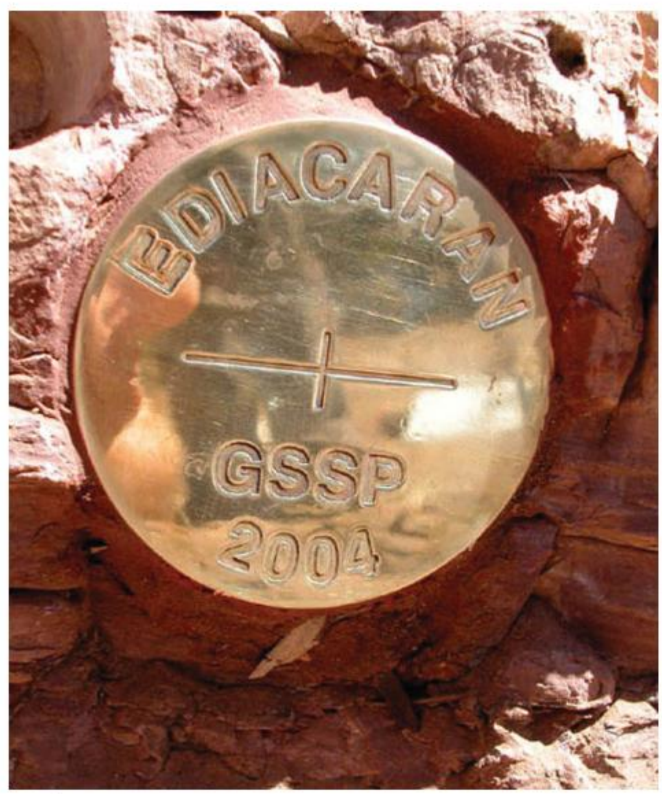


Figure 2.1.16 This point in a rock is the 'Golden Spike' marking the Ediacaran period. It is the reference point for defining the period and is officially known as the Global Stratotype Section and Point (or GSSP). Other sites around the world have since been discovered with similar fossils and these too are classified as Ediacaran.

2.1 Unit review

Remembering

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

2 **State** what a palaeontologist does.

3 **Recall** the contribution that Reg Sprigg made to palaeontology.

Understanding

4 **Define** the term *fossil*.

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

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

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

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

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

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

12 Imagine you found some worm burrows preserved in rocks. **Discuss** whether they are fossils or not.

11 **Explain** the significance of the Ediacaran fossil finds.

Analysing

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

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

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

Evaluating

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

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

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

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

Creating

19 **Construct** a sign to be erected at the site of the Golden Spike, identifying the importance of the Ediacaran fossil site. Your sign should show a title, position of any diagrams or photos, and where you would place the writing. Then provide the written information you would put on the sign.

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

Inquiring

1 Research two human fossils from different environments, such as ice or swamps, that preserved the soft tissues. Name the places where these different fossils were found, compare the appearance of the fossils and explain why they were so well preserved.

2 Research an important Australian fossil site other than Ediacara (such as Dinosaur Cove or Riversleigh) and explain why it is an important site.

3 Research the fossil known as the Lake Turkana Boy. Discuss where he was found, what fossils were found and what palaeontologists think he looked like when he was alive.

4 Western Australia was the first state in Australia to declare a fossil emblem to represent the state. It chose the Gogo fish. Research important fossils of your state or territory and produce an A4 poster that justifies the choice of the fossil as your state fossil emblem. If you live in Western Australia, then think of a fossil emblem for Australia and justify your choice.

5 The 'fossilised' remains of a few historic ships have been found buried deep in the mud they sunk into when catastrophe struck them. Research ships such as the *Mary Rose* to find out what stopped its wood, leather and steel from rotting and rusting away.

2.1 Practical activities

1 Making fossils

Purpose
To make fossil moulds and casts.

Materials
- modelling clay
- plaster of Paris
- margarine container
- objects to mould, such as shells and bones
- petroleum jelly
- wooden spatula for mixing plaster
- rubber gloves

SAFETY

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

Wear safety glasses and rubber gloves.

Never tip plaster down the sink.

Procedure
1. Soften the modelling clay into a flat sheet about 1 cm thick.
2. Smear some petroleum jelly onto the shell or bone and then press it into the modelling clay.
3. Carefully remove the shell or bone without breaking the modelling clay. This imprint in the modelling clay is known as a mould
4. Using the spatula, mix some plaster and water in the margarine container
5. Pour the plaster mix into the mould in the modelling clay. Flatten the surface of the plaster.
6. Leave the plaster to set. When the plaster is solid, carefully remove it from the modelling clay. This is the cast.
7. If you have time, make another mould and cast from a different object.

Discussion
1. **Compare** your plaster cast and mould with the original shell or bone, indicating if they are accurate copies.
2. **Explain** whether the cast and mould tell us what the original organisms looked like.
3. Carefully **describe** how you think a mould could form naturally.
4. **Explain** what would have to happen for a cast to be made naturally.
5. **Explain** what information a cast gives that a mould may not give.

2 Modelling fossils

Purpose
To model the formation of different types of fossils.

Materials
- modelling clay
- plaster of Paris
- plastic container for mixing
- stirring rod
- variety of objects such as shells, leaves, bones, and nuts
- petroleum jelly
- newspaper for keeping the desk clean
- rubber gloves

SAFETY

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

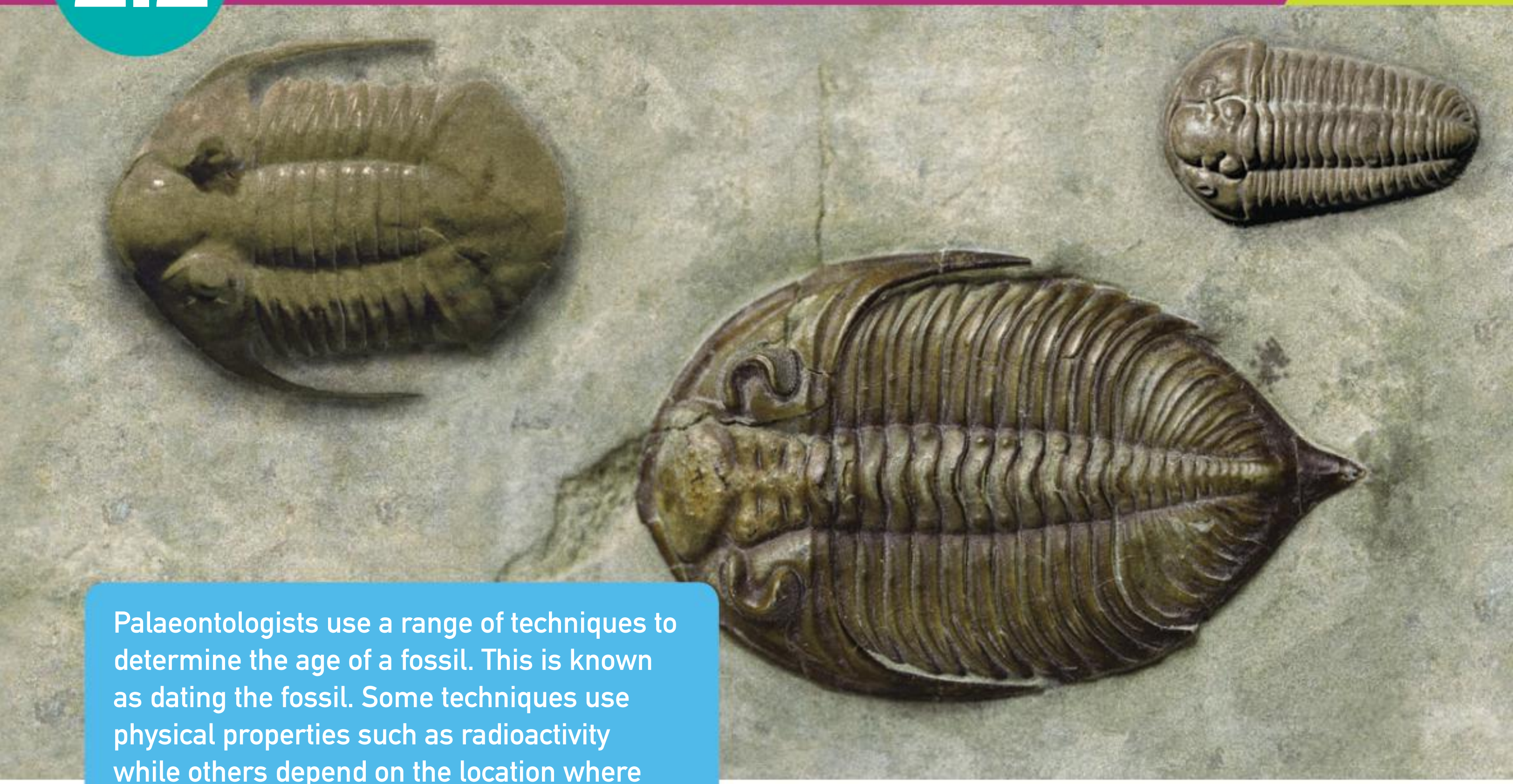
Wear safety glasses and rubber gloves.

Never tip plaster down the sink.

Procedure
1. Think of a way to model the process of forming some fossils, using only the materials you have been given. Each fossil has to be made in the plaster.
2. The fossils that you have to make in the plaster are a:
   - mould of the outside of one side of a leaf or shell
   - cast of the outside of complete shell (such as gastropod) or the outside of a eucalypt fruit (gumnut).
3. Describe or draw how you will make each fossil. Show it to your teacher and then make the fossil if your teacher agrees.

Discussion
1. **Assess** whether your method worked well and if you could improve on it.
2. **Identify** the material that you are simulating with the plaster.

2.2 Dating techniques



Palaeontologists use a range of techniques to determine the age of a fossil. This is known as dating the fossil. Some techniques use physical properties such as radioactivity while others depend on the location where the fossil was found. Dating fossils allows palaeontologists to construct a timeline showing when each organism lived on Earth. These fossils are of trilobites, a group of organisms that can be used to compare the age of rocks in different places.

Relative dating

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

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

Layer by layer

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

Sometimes, however, the lowest stratum will not be oldest. This is because the layers of rock have folded over each other and been turned upside down by earth movements.

Index fossils

Evidence from the fossil record and rock strata indicates that most species only existed on Earth for a relatively short time. Each fossil species is only found in a narrow band of the rock strata in any one location. For example, a species of arthropod that appears in a particular layer in the sequence of rock strata in Victoria will also be found in a particular layer in the sequence of strata in New South Wales. This fossilised arthropod can then be used to compare the age of the two strata in Victoria and New South Wales.

The fossilised arthropod only lived at a certain time in the past and so rocks containing the same fossils must be of the same age. This would be true even if the rocks are different, such as limestone and shale. This is relative dating. It allows palaeontologists to determine how old one fossil is relative to another, but not the actual age for each.

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

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

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

2.2

SKILL BUILDER

Using stratigraphy

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

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

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

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

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

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

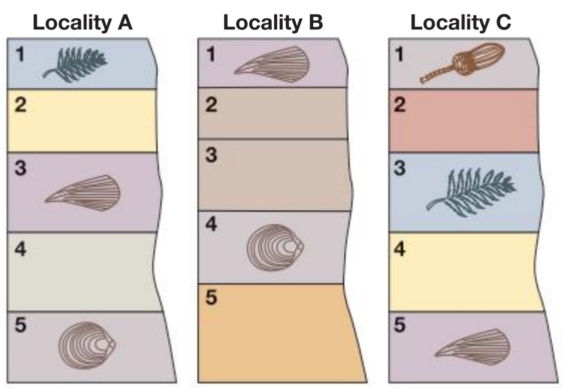


Figure 2.2.1 Rock layers can be compared in different places by using index fossils.

Examples of index fossils

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

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

SciFile

Three lobes

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

SciFile

Trilobite eyes

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

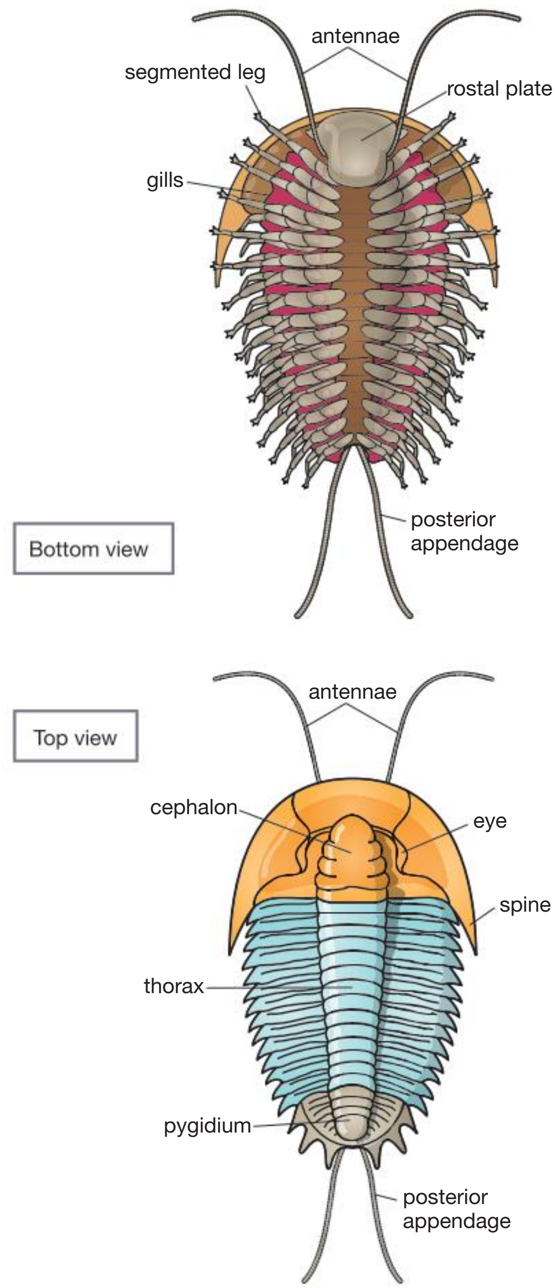


Figure 2.2.2 Trilobites are useful index fossils.

Trilobites as index fossils

Figure 2.2.3 on page 50 shows the order in which different trilobites lived. It was constructed by studying many different rock strata around the world. These same trilobites kept occurring in the same order, with *Ceraurus* and *Isotelus* consistently lowest (and therefore oldest) in the rock strata. Hence, rocks with *Ceraurus* in them can be considered to be older than rocks with *Dalmanites* in them.

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

Dalmanites and *Calymene* occur in rocks in New South Wales and Victoria, which were covered by an ancient sea at the time when the trilobites were fossilised. The trilobites on page 48 belong to these species. Geologists finding rocks with these trilobites in them would then classify the rocks as being the same age. They would classify the rocks as Silurian.

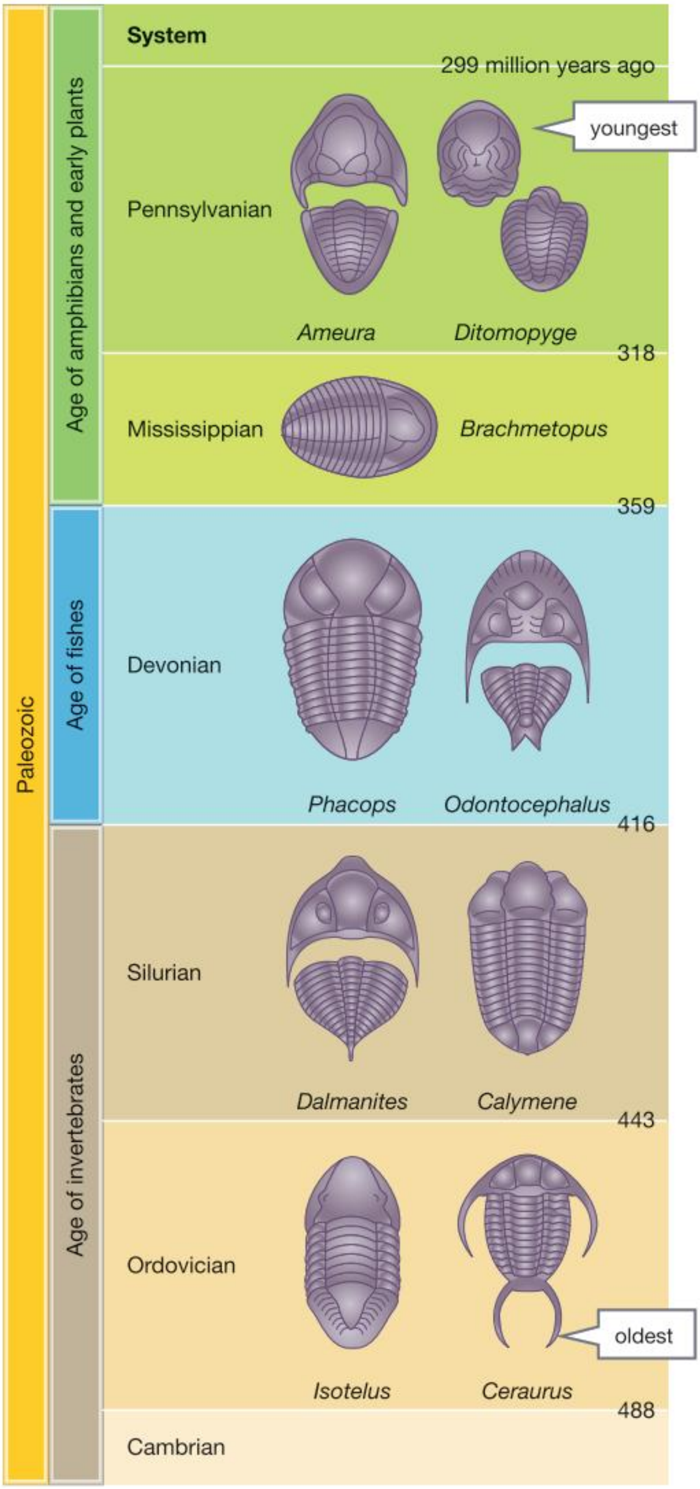


Figure 2.2.3 Trilobites are good index fossils because they were relatively common, widespread and different species existed at different times.

SciFile

Naming rock layers

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

Fluorine analysis

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

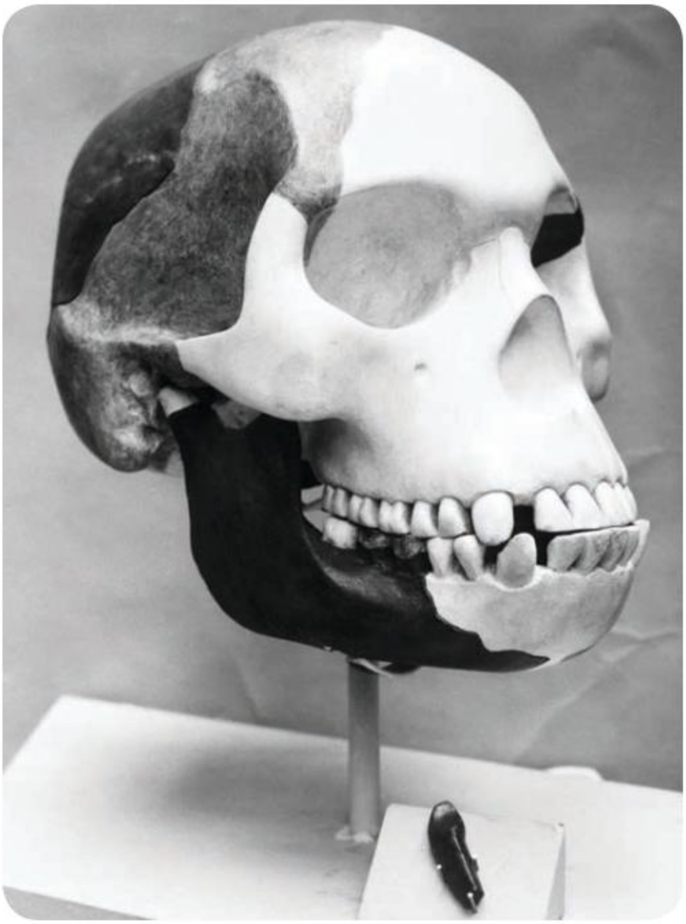


Figure 2.2.4 Fluorine analysis proved Piltdown Man to be a forgery. These bones came from three different animals. No one knows for certain who was responsible for the hoax.

Absolute dating

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

Radioactive dating

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

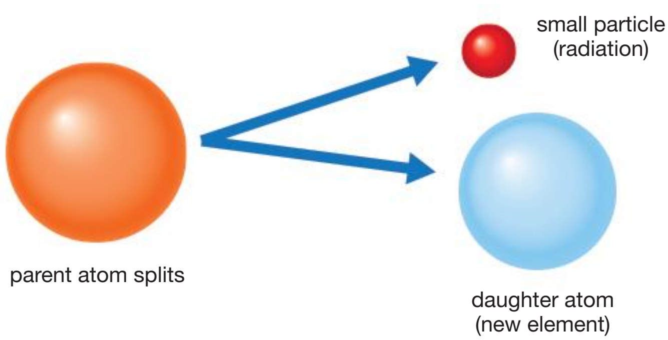


Figure 2.2.5 Radioactive elements break down to form new elements and release radiation.

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

This decay allows scientists to estimate how long ago the rock was laid down. There are many elements that can be used, depending on the type of fossil and the type of rock. Radioactive potassium-40 is found mainly in rocks containing volcanic ash. Potassium-40 decays into argon, which can be measured. By measuring how much argon has been formed in the rock and how much potassium-40 is left, you can calculate an age for the rock. This can be done by using a graph called a decay curve. You can see the potassium–argon decay curve in Figure 2.2.6.

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

Carbon dating uses the decay of carbon-14 to determine the age of **organic matter**. Organic matter is made of chemicals that contain a very small amount of radioactive carbon-14. A fossil may still retain some of the original chemicals from its body tissue and so the amount of carbon-14 remaining can be used to measure the age of the fossil. Carbon dating is useful as far back to less than 40 000 years. However, beyond that, the method is not reliable as the amount of carbon-14 remaining is too small to measure.

WORKED EXAMPLE

Problem

If the potassium to argon ratio in a sample of rock containing a fossil was 0.8, how old is the fossil?

Solution

Using the graph in Figure 2.2.6, run a horizontal line across from 0.8 on the vertical axis. Where it meets the plotted line of the graph (the green line), draw a vertical line down to the horizontal axis. This gives an answer somewhere between 400 and 450 million years.

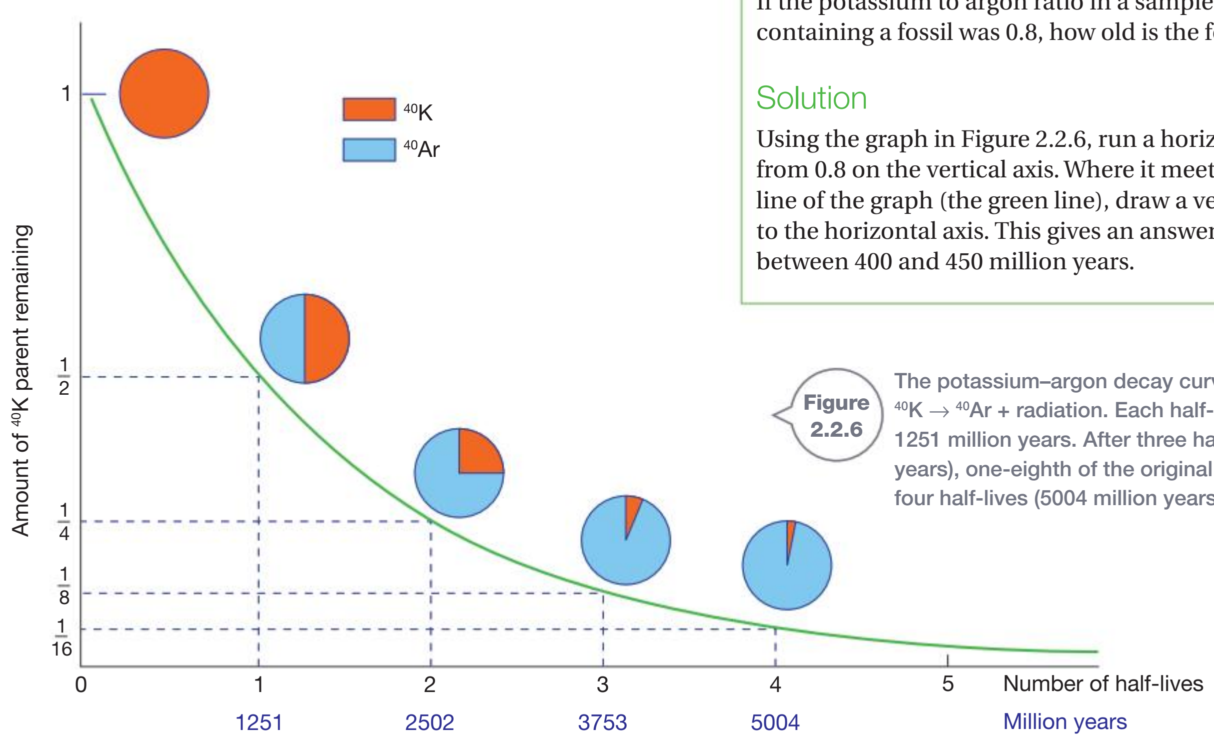


Figure 2.2.6 The potassium–argon decay curve: $^{40}K \rightarrow {}^{40}Ar$ + radiation. Each half-life is equivalent to 1251 million years. After three half-lives (373 million years), one-eighth of the original ^{40}K is left. After four half-lives (5004 million years) $\frac{1}{16}$ is left.

Tree rings

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

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

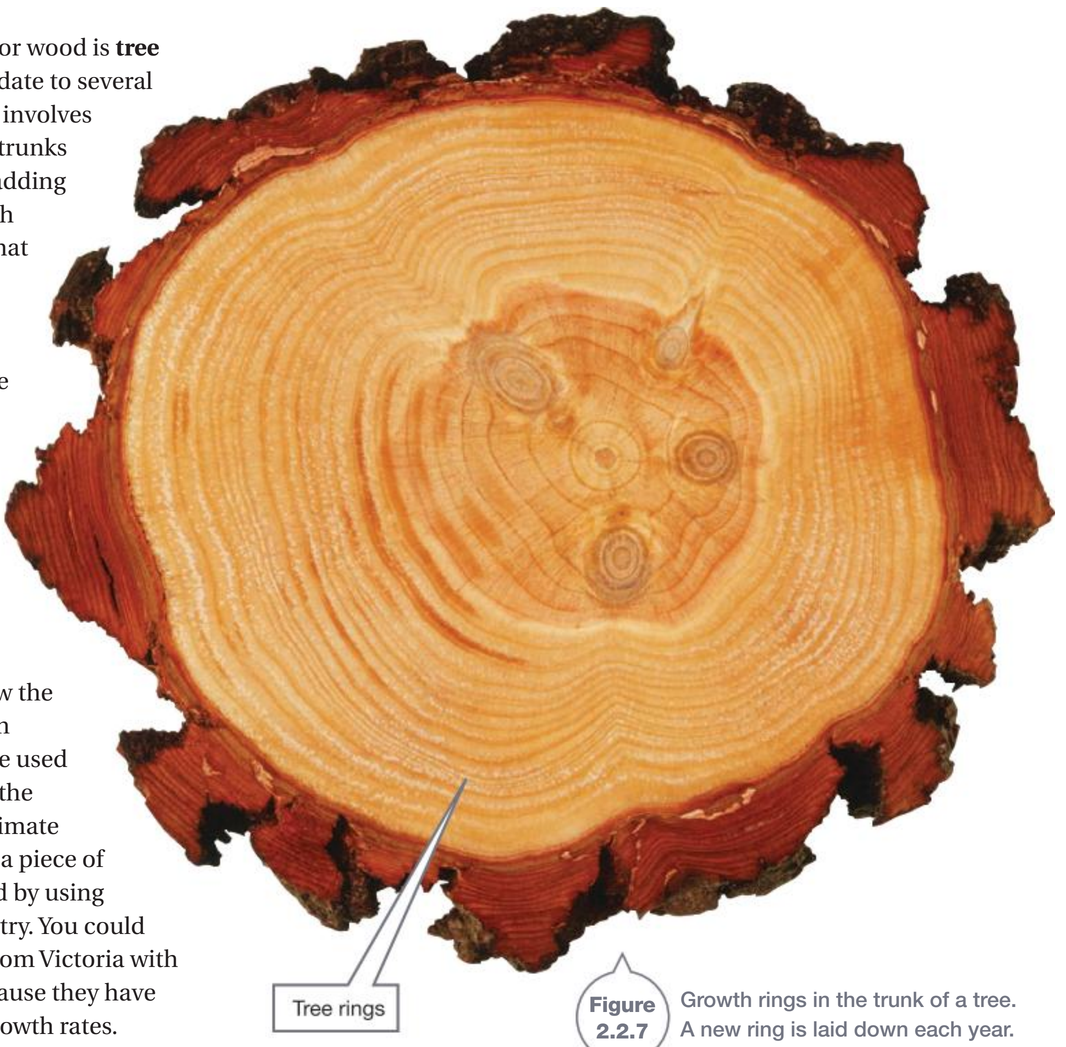


Figure 2.2.7 Growth rings in the trunk of a tree. A new ring is laid down each year.

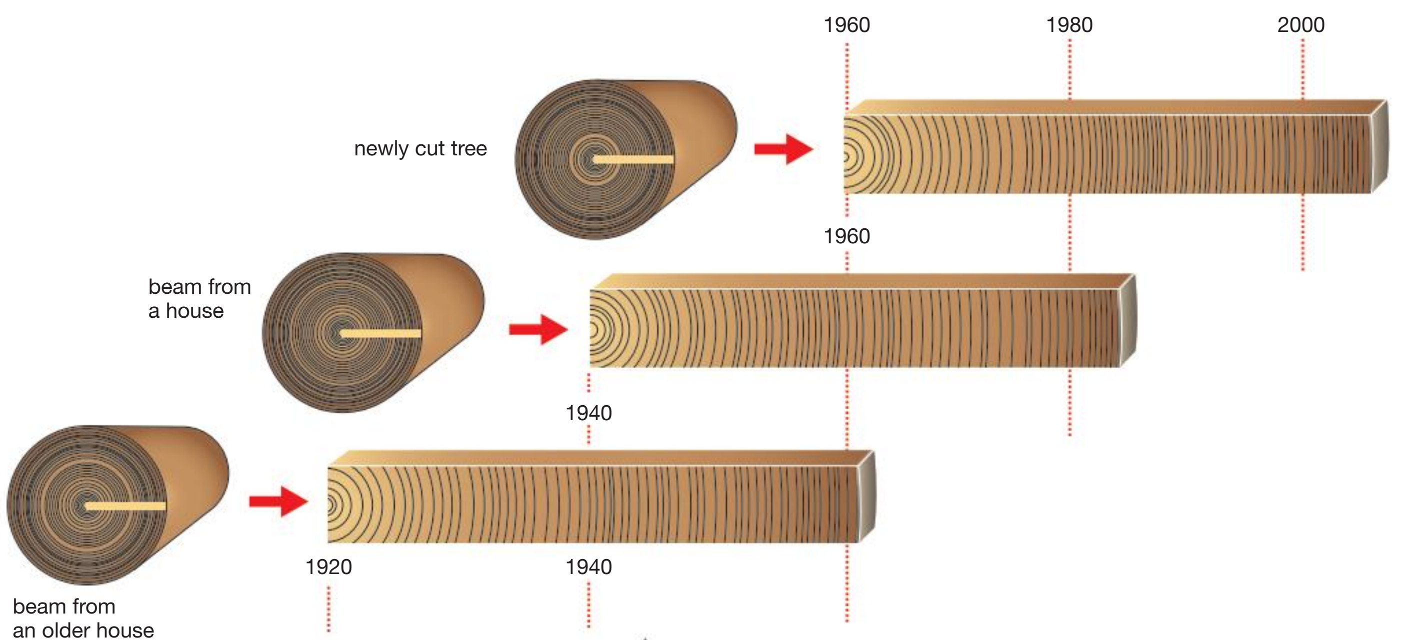


Figure 2.2.8 Growth rings are compared to find an age. By starting with a piece of wood of known age, similar spaced rings in different samples of wood can be matched and overlapped. In this way, a continuous record can be produced that extends back many thousands of years.

2.2 Unit review

Remembering

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

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

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

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

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

Understanding

6 **Define** the terms:
  a relative dating
  b stratigraphy
  c absolute dating.

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

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

9 **Explain** how fluorine analysis is useful in relative dating.

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

Applying

11 **Use** Figure 2.2.3 on page 50 to **identify** two trilobites which lived towards the end of trilobite history.

12 Figure 2.2.9 shows a trilobite called *Ptychagnostus atavus*. This is one of the earliest trilobites yet discovered. It was only a few millimetres long and was blind because it had no eyes. Scientists have concluded that it lived in the depths of the ocean. Fossils of this species have been found in Australia, Vietnam, China, Korea, Russia, Scandinavia, Great Britain, Greenland, Canada and the US. Dating by stratigraphy placed the first appearance of this species to 506 million years ago. In 2005, scientists agreed to make this trilobite an index fossil for this time in the Earth's history. The species was shown to only occur in strata from 500–506 million years ago.
  a **Use** Figure 2.2.3 on page 50 to **identify** the name of the time period in which this species lived.
  b **Identify** two trilobite species that appeared in the fossil record not long after this species.
  c **List** the rules for index fossils and **demonstrate** how they apply to this trilobite species.

Figure 2.2.9 *Ptychagnostus atavus*

Analysing

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

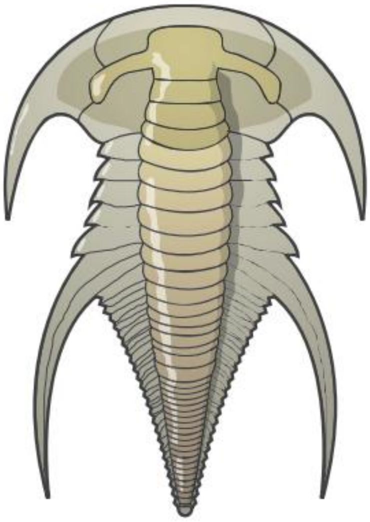


Figure 2.2.10 *Emuella polymera* fossil

  a **Analyse** the information here and discuss how Emu Bay could be dated.
  b **Critically analyse** the information and comment on whether *Emuella* could be used as an index fossil.

14 **Compare** tree ring dating and radioactive dating as possible methods for wood preserved as a:
- a carbon film fossil
- b replacement fossil.

Evaluating

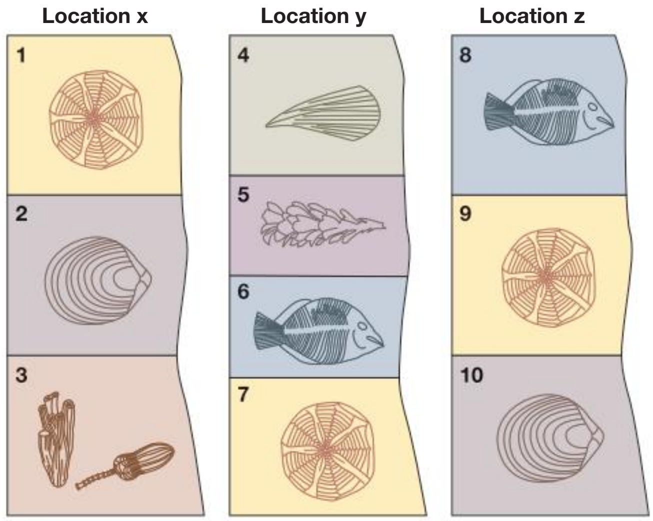


Figure 2.2.11

15 a **Deduce** the strata that are of the same age in Figure 2.2.11.
- b **Explain** how you decided this.
- c **Deduce** the layers in order from the oldest to the youngest.

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

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

18 **Propose** reasons why all trilobite fossils would not look like Figure 2.2.2 on page 49.

19 **Propose** why tree rings may not be able to be used to date wood found in an ancient sunken ship.

Creating

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

Inquiring

1 Research the ammonites as a group of animals. Describe what they looked like and explain how they are useful as index fossils.

2 There is a primitive crablike creature alive today called a horseshoe crab. Find images of the crabs and compare them with trilobites. Research any features these groups share and discuss whether palaeontologists think trilobites may be related to the horseshoe crab.

3 Pollen can be a good index fossil. Petroleum geologists use it to find new oil and gas. Research and explain how they do this.

4 Design a way of determining the age of a twig or a small branch from a tree.

2.2 Practical activities

1 Radioactive decay

Purpose

To simulate radioactive decay and draw a decay curve.

Materials

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

Procedure

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

Results

1. Copy and complete the following table by writing in your results from the record sheets. The first two entries should be 0 and 100. Your table will start like the one shown here, but have many more rows.

Time	% Undecayed
0	100
1	
2	

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

   Your graph should be similar to Figure 2.2.12.

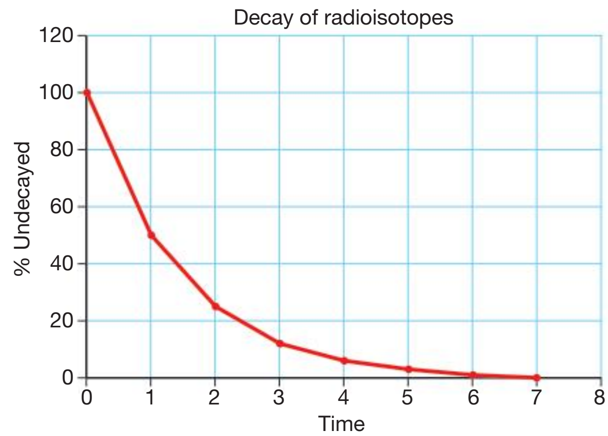


Figure 2.2.12

Discussion

1. In this experiment, **identify** what represents a decayed atom.
2. a **Describe** the shape of your graph.
   b **Compare** its shape with Figure 2.2.6 (page 51).
3. Use the graph to **estimate** how many throws it took for half (50%) of your atoms to decay. This is the half-life of your radioactive source.
4. The half-life in this experiment should have been one unit of time (i.e. 1 throw), because every counter had a 50% chance of decaying. So half of the counters should have decayed. **Compare** your estimate from the graph with what was expected.
5. **Propose** how you could make this experiment more accurate.

2.3 Geological time scale

Dinosaurs, diprotodons and mammoths have come and gone. They are extinct, never to live on Earth again. Over 4.5 billion years, many fascinating organisms have lived on Earth. The fossil record of these organisms can be used to construct a likely time scale that tracks the history of life on our planet. New fossils are constantly being found that require adjustments to be made to this time scale.

Creating a time scale

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

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

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

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

SciFile

The Jurassic

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

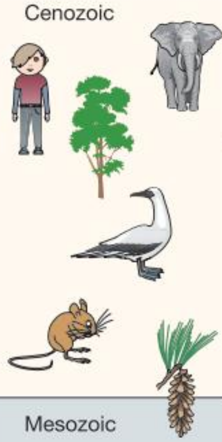
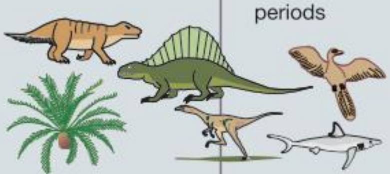
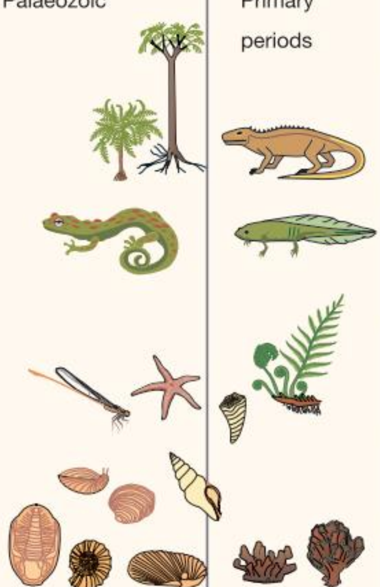
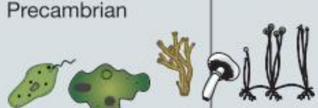
Geological era				
Cenozoic 	Quaternary periods	Holocene (current)	Some mammals disappear. Modern humans. Warmer climate	0.015
		Pleistocene	Ice ages. Large mammals. Primitive humans	2
	Tertiary periods	Pliocene Miocene Oligocene Eocene Paleocene	Life as we know it develops—birds and mammals increase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

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

The earliest organisms

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

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

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

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

One study in 2006 claimed that the fossil stromatolites from the Kimberley are the most ancient life form discovered so far. The rocks are over 3400 million years old. You can see a cutaway section of a stromatolite in Figure 2.3.3. Palaeontologists have concluded that the black carbon layers are carbon film fossils of the bacteria that formed the layers.

The next major event on the geological time scale is the Ediacaran, followed by the appearance of the more complex Cambrian life forms such as the Burgess Shale communities. The Cambrian period and Burgess Shale were discussed in Unit 2.2.

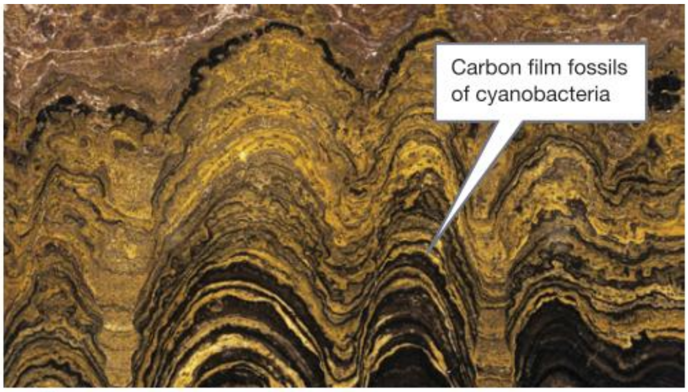


Figure 2.3.3 A cutaway section through a stromatolite

Vertebrate fossil history

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

1 p64

Moving from water to land

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

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

SciFile

Coelacanths and lungfish

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

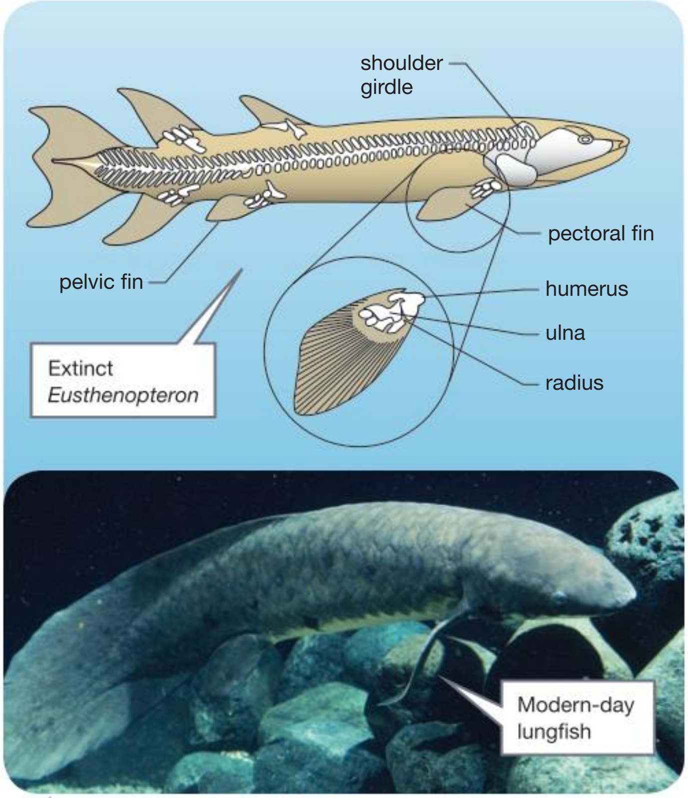


Figure 2.3.4 An extinct lobe-finned fish called *Eusthenopteron*. Lobe-finned fish are important because some of them probably represent ancestors of organisms such as lungfish.

Land vertebrates

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

2.4

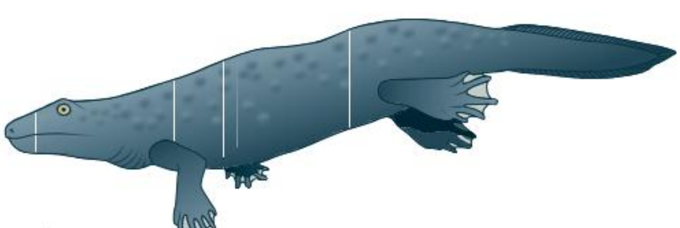


Figure 2.3.5 Ichthyostega was an early amphibian-like animal.

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

Figure 2.3.6 Dinosaurs dominated the Earth in the Mesozoic era.

Birds

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

One early example was ***Archaeopteryx*** (which means 'ancient wing'), an amazing organism known from eleven fossils found in Germany. As Figure 2.3.7 shows, *Archaeopteryx* had feathers and a wishbone in the chest. Both these features are important for flight in modern birds.

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

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

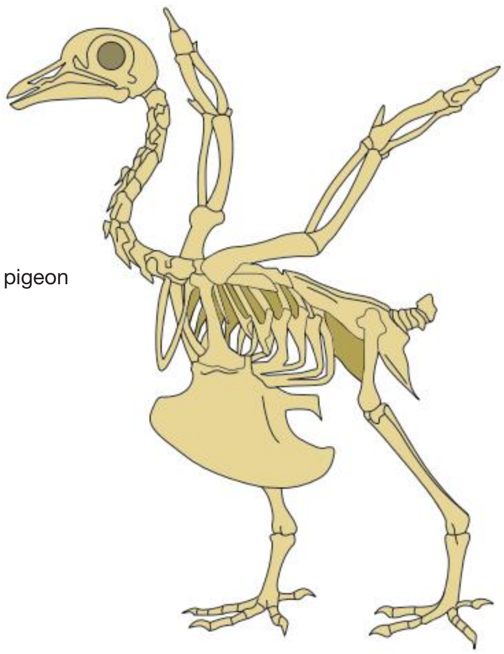
There are many more ancient bird fossils being found in China. These are much more like modern birds than *Archaeopteryx*, and yet they also clearly have some dinosaur-like features as well.

2.5

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

Humans

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



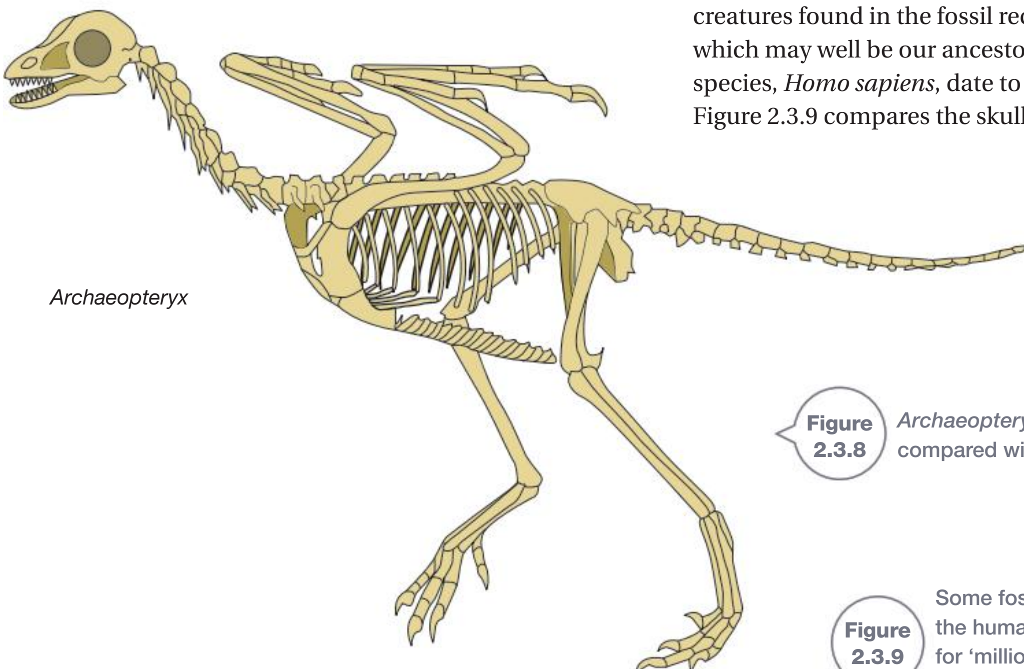
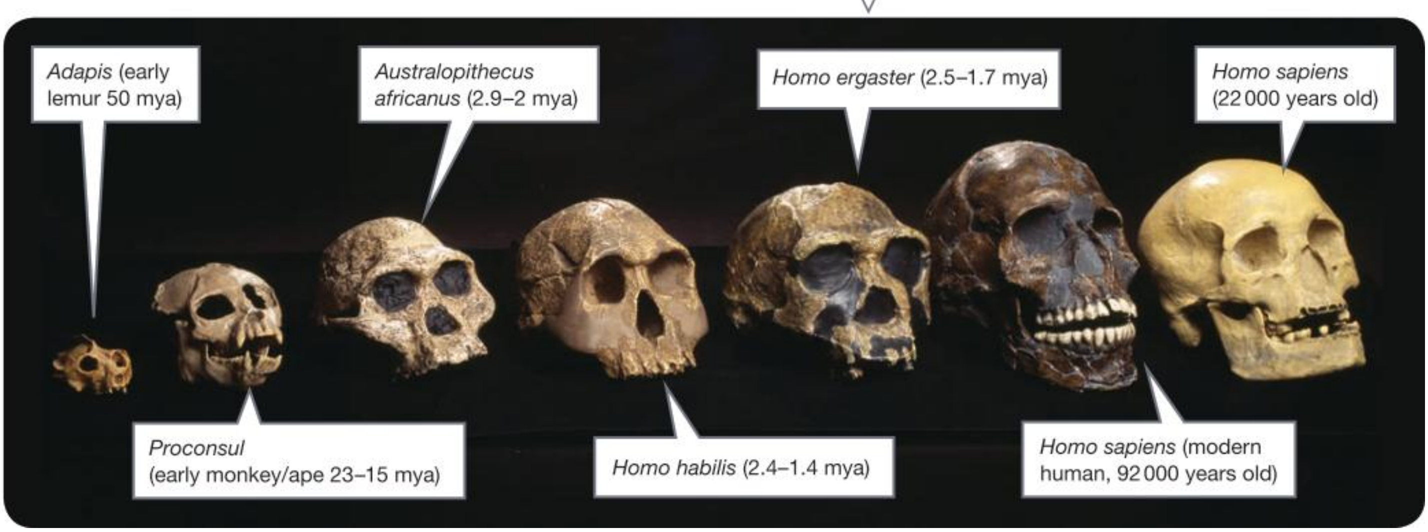


Figure 2.3.8 *Archaeopteryx* skeleton compared with a modern bird

Figure 2.3.9 Some fossil primate skulls, including members of the human family. The abbreviation mya stands for 'millions of years ago'.



TV shows often reconstruct what dinosaurs might have looked like.

Figure 2.3.10

SCIENCE AS A HUMAN ENDEAVOUR

Nature and development of science

Reconstructing dinosaurs

Palaeontologists use evidence to reconstruct the appearance of organisms. TV documentaries often show how dinosaurs moved, what they ate, how they raised their young, who ate who and if they were 'warm blooded' or not. Some critics suggest that these representations are just made up. However, there is evidence to support much of what is portrayed about dinosaurs.

Appearance

The techniques used to reconstruct a dinosaur are similar to those used in forensic science. The dinosaur's appearance can be predicted from its skeletal structure.

One problem in reconstruction is missing bones. This can sometimes be overcome if there is a similar bone on the other side of a skeleton. For example, a missing legbone such as a femur can be copied from the other leg. Another technique is to study living species that are related to the specimen and use their bones as a guide. Anatomists can relate bone size to body mass using well-known research data. For example, bones become larger and stronger as body size increases.

When as much as possible of the skeleton is present, it is arranged in a posture suggested by the bones. Then the bones are carefully studied for marks left by muscle attachment. This can indicate how large the muscles were and where they were positioned. This is shown in Figure 2.3.11. The muscle bulk of living relatives can also be used as a guide.

Skin is then placed on the muscle masses and a texture and colour pattern given to it, or the fur or feathers that covered it are reproduced. That is done by studying the colour patterns of the nearest living relatives. The skin covering is known for some dinosaurs. A few dinosaurs had feathers, and some were slightly furry. Fossil moulds indicate that some dinosaurs had leathery skin.

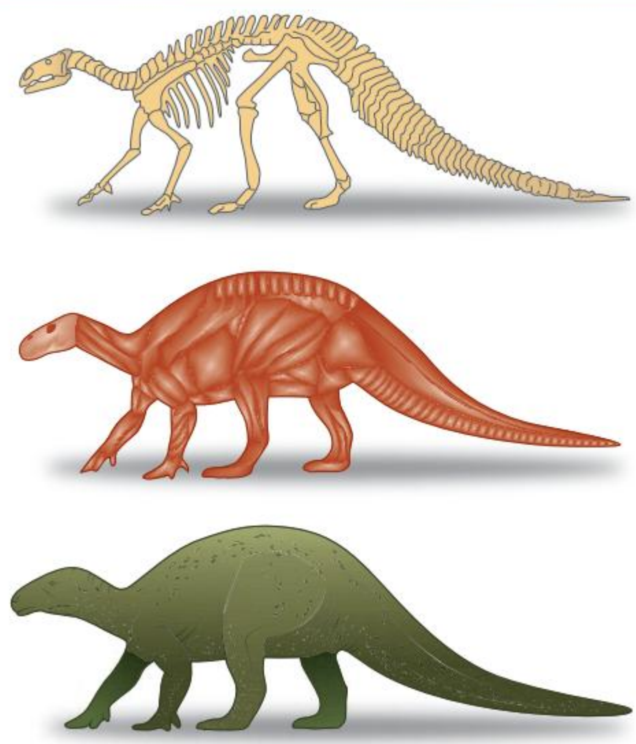


Figure 2.3.11 Constructing dinosaurs using clues from the skeleton to work out muscle size and position

Figure 2.3.12 This dinosaur baby had just hatched out of the egg when it died and was fossilised.

Reproduction

Dinosaurs laid eggs. Scientists know this because many eggs and nests have been found. Intact eggs can be studied with X-rays. There are some examples of eggs just hatching. You can see one in Figure 2.3.12. Some fossils even show parents guarding nests.

Movement

Estimates of how fast dinosaurs could move are based partly on their fossilised footprints (Figure 2.3.13). They are also based on computer simulations. By measuring the distance between footprints and comparing this with body size, scientists can estimate the dinosaur's running speed.

Figure 2.3.13 The distance between dinosaur footprints enables an estimate of their running speed.

Body temperature

There is disagreement on whether dinosaurs were able to control their body temperature like mammals and birds can. Some dinosaurs (most likely the small, fast-moving ones or large predators) may have been warm blooded. Fossilised bone structure is inconclusive at present, although the bone does look more like warm-blooded birds and mammals than reptiles. More research needs to be done in this area before we will know for certain.

Social behaviour

Dinosaur tracks are a good guide that many dinosaurs lived in groups. There are some very good fossil sites that show a herd of dinosaurs' footprints.

Diet

Teeth are a good guide to diet. Carnivores have many sharp teeth, whereas herbivores generally have flatter teeth to grind plant material. So scientists are fairly sure what type of food each dinosaur ate. Another guide to diet is the fossilised dung of dinosaurs, which is known as coprolites. These showed that herbivorous dinosaurs mainly ate plants called gymnosperms. The carnivorous dinosaurs often ate each other, according to fossil sites showing dinosaurs that died in a battle with each other.

2.6 2.7

2.3 Unit review

Remembering

1 **State** the term that means 'the time scale of life and geology in the past'.

2 **State** what geological eras are divided into.

3 **State** two possible reasons why the early part of the geological time scale does not show any living organisms.

4 **List** the sequence and time of appearance in the fossil record for the current classes of vertebrates.

Understanding

5 **Explain** how the geological time scale was constructed

6 **Define** the term *stromatolite*.

7 **Explain** why stromatolites are important in the history of life

8 **Explain** why lobe-finned fish are important in the history of life.

9 **Explain** why scientists think some dinosaurs and birds are related.

Applying

10 *Archaeopteryx* would not be a useful index fossil. **Demonstrate** why.

Analysing

11 **Use** Figure 2.3.8 on page 60 to **compare** the skeletons of *Archaeopteryx* and modern birds, listing their similarities and differences.

Evaluating

12 **Propose** why plants would need to spread to the land first before animals could live on land.

13 Some major differences between amphibians and reptiles are their method of respiration, how the young are born and what the body is covered with.

Amphibians are thought to be the ancestors of reptiles. **Use** the table below to **propose** why reptiles were successful in moving into a wide range of habitats on land.

Feature	Amphibian	Reptile
Respiration	Live in water as young and breathe by gills. Develop lungs as adults and breathe air	Live on land and breathe by lungs
How young are born	Eggs with thin membrane easily dehydrated. Laid in water and hatch into water	Eggs with waterproof flexible membrane. Hatch in air
Body covering	Thin moist skin	Thick leathery scaly waterproof skin

Creating

14 **Construct** a notice to be posted at the Shark Bay stromatolite site detailing reasons why tourists should protect the area.

15 In a group, **construct** a timeline for geological time on A3 paper or butcher's paper. Use a scale of 1 mm to 1 million years. Make the paper at least A4 width (about 30 cm) and at least 9 A3 pages long (about 3.7 metres). On your timeline add the names of the geological eras and periods. Write the major fossil groups for each era or period and highlight important events such as life on land. Add diagrams or drawings of some of the major fossils.

Inquiring

1 Research the living coelacanths and lungfish and explain why they are so important.

2 Research the latest finds of fossil birds and bird-like dinosaurs in China, describing the fossils and what they tell us about the origin of birds.

3 Research the primitive fish from the Cambrian era dated at about 525 million years ago, which have been found at the Chinese fossil site called Chengjian. Explain why they are considered important fossils.

4 Research three theories about the extinction of the dinosaurs. Rate which one you think is most likely to be true.

5 Imagine you found some moulds of footprints of a bipedal dinosaur in mudstone. They are about the size of a human footprint. The tracks go for 50 metres. Design a method you could use to determine its speed. Check your method with your teacher and run your experiment if you get their approval.

2.3 Practical activities

1 Vertebrate skeletons

Purpose

To compare different vertebrate skeletons.

Materials

- skeletons of human, cat, bird, frog, bony fish and lizard
- If actual skeletons are not available, then there are excellent images on the internet.

Procedure

1. Copy Tables 1 and 2 shown in the Results section into your notes.
2. Carefully observe each specimen and complete Table 1 by placing a tick in the table if the feature is present.
3. Use Table 1 to complete Table 2 in your notes. You can observe the animals again if necessary. Record the animals that are most alike and least alike for each of the features.

Discussion

1. Using Table 2, **deduce** which two animal skeletons seem to be most alike, and which two are least alike.
2. Fish live in the ocean and the rest of these animals live on land. Look very carefully again at the specimens and note how the fins and limbs are attached to the rest of the skeleton. **Propose** how the large differences in these parts of the skeletons are related to the environment in which these creatures live.
3. Most of these animals have remarkably similar skeletons. They have many bones that are in the same places and doing the same jobs. **Describe** some examples of this.
4. **Propose** why these animals have skeletons which are so similar.
5. If fossil bones from the limbs of these creatures were discovered, then **discuss** whether you think you could easily identify which of these creatures the bones belonged to.
6. The fish fins were very different from the frog limbs. **Discuss** whether there is any evidence of fish fins having bones in them as land animals do.

Results

Table 1 Vertebrate skeletons

Animal	Skull	Vertebral column	Ribs	Front limbs	Rear limbs	Front limb girdle	Rear limb girdle
Human							
Cat							
Bird							
Frog							
Bony fish							
Lizard							

Table 2 Comparing vertebrate skeletons

Feature	Most alike	Least alike
Skull		
Vertebral column		
Ribs		
Front limbs		
Rear limbs		
Front limb girdle		
Rear limb girdle		

Chapter review 2

Remembering

1 **List** the sequence of appearance for the vertebrate groups in the geological time scale.

2 **Name** a major event from the geological record for each of the following.

a Ediacaran
b Cambrian
c Devonian
d Permian
e Triassic
f Jurassic
g Cretaceous
h Pleistocene

Understanding

3 **Define** the following terms.

a fossil
b index fossil
c radioactive dating
d geological time scale

4 **Describe** five different types of fossils and how they form.

5 **Explain** why the fossil record is incomplete.

6 **Describe** how the age of a fossil or rock can be determined.

7 **Explain** how the geological time scale was constructed using absolute and relative dating methods.

8 **Describe** how a replacement fossil of a trilobite may form.

9 **Outline** how you could reconstruct the appearance of a dinosaur from a fossilised skeleton, but with half the bones missing.

10 **Modify** the following statements to make them correct.

a Only a preserved body part can be considered a fossil.
b Palaeontologists cannot interpret fossils to determine the appearance of an organism.
c There is no way to tell how long ago a particular fossil was formed.
d All species lived at all times throughout the history of the Earth.
e All species were equally distributed over the Earth in the past.
f The fossil record would be complete if all the sedimentary rocks with the fossils could be exposed.
g Palaeontologists should stop looking for fossils because they already know the history of life on Earth.
h The geological time scale will not change as new fossils are discovered.

Applying

11 Some scientists have estimated that only 25% of the dinosaurs that existed have been discovered as fossils. **Use** your knowledge of fossils to **explain** why we will never find examples of all the dinosaurs.

12 **Use** the decay curve for potassium to argon in Figure 2.2.6 on page 51 to **calculate** the age of a fossil that had one-tenth of its potassium-40 remaining.

Analysing

13 Birds and bats that fly over swamps can sometimes be exposed to poisonous gases. **Analyse** how this may affect their chances of being fossilised.

14 **Compare** relative and absolute dating.

15 **Contrast** a fossil mould and a cast.

Evaluating

16 Scientists have extensive knowledge of trilobites, ammonites, molluscs, coral and fish, but know very little of ancient marine worms, earthworms, bats and desert plants. **Propose** reasons why.

17 a Refer to Figure 2.3.1 on page 57 and **assess** which are the ten most important events in the history of life on Earth.
b **Justify** your choice.

Creating

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

fossil
preserving environments
fossil record
absolute dating
relative dating
index fossil
stratigraphy
geological time scale
vertebrate history
dinosaurs

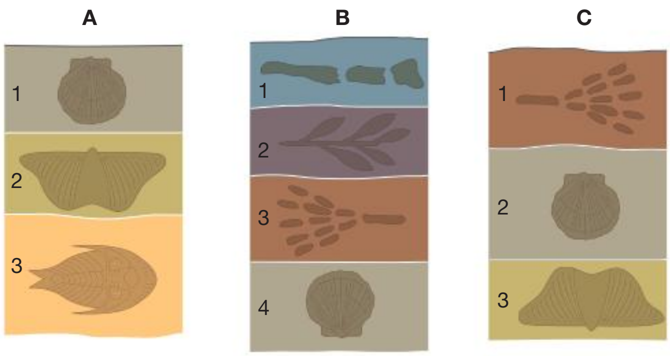
2.8

Thinking scientifically

Q1 In which of the following environments are soft-bodied animals least likely to form fossils?

A In a peat swamp
B In a rain forest
C In the ice of the tundra
D In dry deserts which have strong winds and dust storms

Questions 2 to 5 are based on the following diagram showing ten strata in three different locations, A, B and C. The strata are numbered.



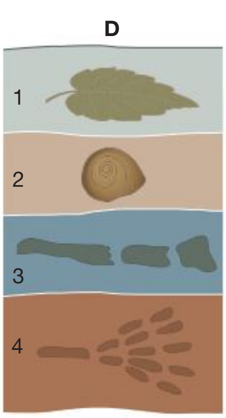
Q2 Which of the following strata are the same age?

A A1, B1, C1 **B** A3, B4, C3
C A1, B4, C2 **D** A2, B3, C3

Q3 Which is the oldest layer of the ten strata?

A A3 **B** B4
C C3 **D** B1

Q4 At location D, the following strata and fossils were discovered.



Which layer found in location B appears to be missing from location D when it would have been expected to be found at D?

A B1
B B2
C B3
D B4

Q5 Which is the youngest layer in the four sites?

A A1
B B4
C C1
D D1

The following information applies to questions 6 and 7.

The half-life for a radioactive substance is the time it takes for half of the original radioactive material to break down. The half-life for dating using carbon-14 is 5730 years. Carbon-14 decays to form nitrogen-14. For the decay of potassium-40 to argon, the half life is 1251 million years. Fossil birds date from about 150 million years ago. House roof beams are usually no older than a few hundred years even if the timber is recycled.

Q6 Which of the following is a correct deduction using the above information?

A Potassium-40 decays faster than carbon-14.
B Potassium-40 could not be used to date rocks older than 500 million years.
C Carbon-14 could not be used to find the age of the oldest fossil bird discovered.
D Carbon-14 would not be useful to date wooden beams from a house.

Q7 How many years would it take before a 1 gram sample of carbon-14 decayed to a mass of less than 0.1 gram?

A less than 11 460 years
B between 11 460 and 17 190 years
C between 17 190 and 22 920 years
D more than 22 920 years

Glossary

Unit 2.1

Carbon film fossil: when the dead body partially decays and leaves a thin black deposit of carbon

Carbon film fossil

Cast: when an organism in rock decomposes and the space in the rock fills with soil that turns to rock

Ediacaran: time period on the geological time scale when complex life forms were developing

Fossil record: a list showing the classification of all the species that have been found as fossils

Fossils

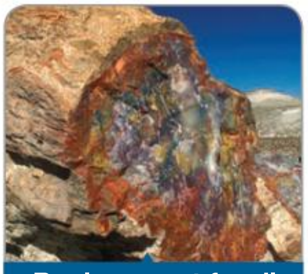
Fossils: the preserved evidence in rocks or soils of organisms that were once alive

Indirect fossils: preserved remains of things such as imprints of the body (such as footprints), fossilised dung and burrows

Mould: an imprint of the outside of the body in rock

Original fossils: when a part of the organism such as a skeleton is preserved and remains in its original form

Palaeontologist: scientist who studies prehistoric life



Replacement fossil

Palaeontology: the study of prehistoric life

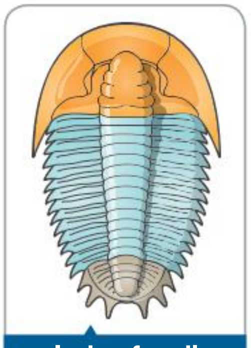
Petrified: when wood is replaced by minerals and fossilised

Replacement fossil: when a part of the organism is changed into another mineral

Unit 2.2

Absolute dating: a way of determining the actual age of rocks and fossils

Fluorine dating: finding a relative age for two bones from the same area by comparing the amount of fluorine in them



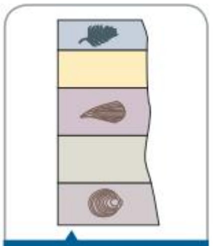
Index fossil

Hadrocodium: the oldest true mammal yet discovered

Half-life: the time it takes for half of a radioactive sample to decay

Index fossil: fossil that can be used to compare the relative age of rock strata in different locations

Isotope: different forms of the same element with different numbers of neutrons, and so different atomic masses



Stratigraphy

Organic matter: chemicals such as proteins that were made by a living thing

Relative dating: comparing the age of one fossil or rock against another to see if one is older or younger than the other

Strata: layers of sedimentary rock

Stratigraphy: comparing strata in different locations to determine their relative ages

Tree ring dating: counting growth rings in the woody trunks of trees to find their age

Tree ring dating

Unit 2.3

***Archaeopteryx*:** bird-like dinosaur that had feathers

Coelacanths: ancient group of fish related to the lobe-finned fish ancestors of the amphibians

Geological time scale: a scale showing the history of life and geology

***Ichthyostega*:** early amphibians which were the first of the group called tetrapods

Lobe-finned fish: fish with bones in their fins similar to land animals

Lungfish: relatives of the lobe-finned fish that made the move from sea to land

Primates: order of mammals to which humans belong

Stromatolite: circular rocky structures thought to be the earliest evidence of living organisms called the cyanobacteria

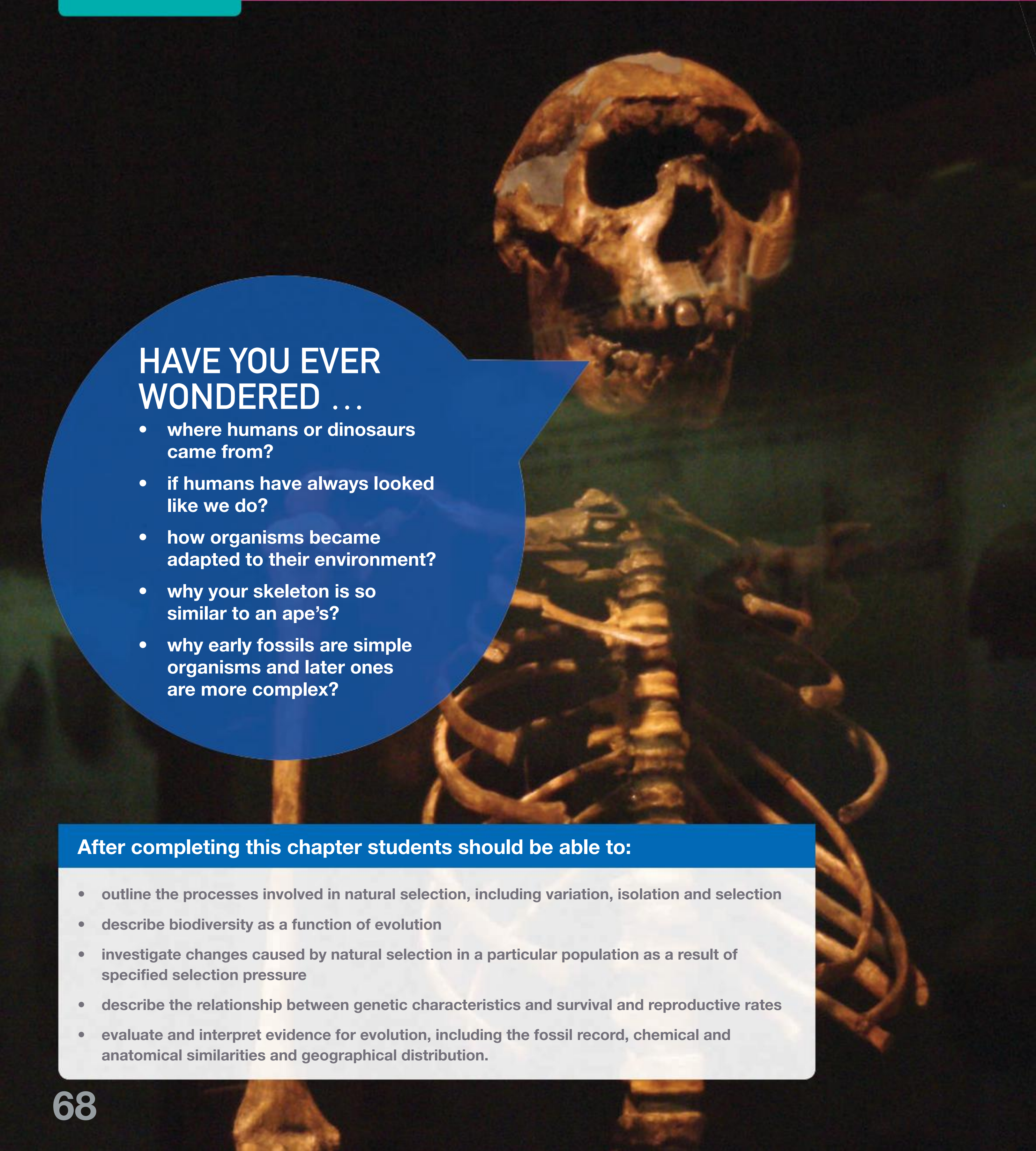
Stromatolite

Tetrapods: land animals with four limbs. Living tetrapods are now classified as amphibians, reptiles, birds and mammals

Theropods: a dinosaur group closely related to birds and from which birds probably developed

Tetrapod

3 Natural selection and evolution



HAVE YOU EVER WONDERED ...

- where humans or dinosaurs came from?
- if humans have always looked like we do?
- how organisms became adapted to their environment?
- why your skeleton is so similar to an ape's?
- why early fossils are simple organisms and later ones are more complex?

After completing this chapter students should be able to:

- outline the processes involved in natural selection, including variation, isolation and selection
- describe biodiversity as a function of evolution
- investigate changes caused by natural selection in a particular population as a result of specified selection pressure
- describe the relationship between genetic characteristics and survival and reproductive rates
- evaluate and interpret evidence for evolution, including the fossil record, chemical and anatomical similarities and geographical distribution.

3.1 Changes over generations

The discovery of dinosaur fossils thrilled the public of the 1800s and museums would display the latest wonders for people to view. Scientists tried to explain where such organisms had come from. Their early studies of fossils, the anatomy of living organisms and the breeding of plants and animals led to the revolutionary view that a species can change over many generations.

Fossils and evolution

Fossils have shown that birds and one branch of the dinosaurs (the theropods) have many similarities in their structure (Figure 3.1.1). They are so similar that biologists are now convinced that theropod dinosaurs were the ancestors of birds.

Figure 3.1.1

Fossilised feathers on a dinosaur called *Anchiornis* discovered in China in 2009. These fossil feathers were so well preserved that scientists could determine what colour the feathers were.

Fossils of the lobe-finned fish and amphibians of the Devonian period (see page 57) show many similar bones in the limbs. However, these limbs also have more than just bones in common. They also show a gradual change in the structure of the whole limb over geological time. Each different species seemed to have small changes in its general structure, such as bone shapes and the number and position of toes.

This apparent change in species over time is called evolution. **Evolution** is defined as a genetic change in the characteristics of a species over many generations, resulting in the formation of new species. A **generation** is the time between the birth of an individual and when that individual produces their own offspring.

The fossil history of the horse is a good example of changes occurring over many generations. Fossil skeletons have been found of a horse-like animal that was about the size of a small dog. The scientific name of the genus of this animal is *Hyracotherium* (Figure 3.1.2 on page 70). It is not classified as a horse, but is similar enough that biologists consider it to be a likely ancestor of horses. Radioactive dating methods show that *Hyracotherium* lived about 52 million years ago.

Figure 3.1.2 *Hyracotherium* is a likely ancestor of creatures that became horses, but is different enough not to be classified as a horse.

The fossil skeletons of at least 17 different genera and many more species of horse have been found and dated. All these different types of horse form a complex family tree with many side branches. Some of these branches lead nowhere. These represent the development of new types of horses that then died out, becoming extinct. Other branches evolved with species steadily changing into another. Despite the complexity of the horse family tree, palaeontologists have been able to trace a path through it that leads to the modern horse. In this way, they have established its family line and the genus and species of its ancestors. One of those ancestors is *Mesohippus*, a genus of horse that lived around 40 million years ago. *Mesohippus* is recognised as a direct ancestor of the modern horse. You can see its skeleton in Figure 3.1.3.

Figure 3.1.3 *Mesohippus* is an ancestor of the modern horse.

There seems to be a gradual change in many parts of the skeletons of all the different fossil horses. Some obvious changes are that the body increases in size, the legs become longer and the number of toes decreases. Figure 3.1.4 shows key features of some different types of horse.

The change in the number of toes is of particular interest to scientists. *Hyracotherium* had four toes on its front legs. *Mesohippus* appears fairly early in the horse family, at about 40 million years, and had three toes. Compared with those of earlier horse genera, the middle toe of *Mesohippus* clearly seems to be thicker while the side toes are smaller.

At about 20 million years ago, a genus called *Merychippus* appeared in the fossil record. *Merychippus* also had an enlarged middle toe. Many other genera and species appeared after this and eventually the genus *Equus*, which includes the modern horses, zebras and donkeys, appeared in the fossil record about 3.5 million years ago.

SciFile

On your toes

Modern horses run on one large 'toe' on each foot. This toe is comparable to your middle finger. Biologists think the loss of the other 'toes' is an adaptation that allows faster running while supporting a large body.

Structure and relationships

When organisms are classified on the basis of their structure, some groups seem very similar. An example is cats and lions. Others, such as cats and jellyfish, seem quite different. The first biologists who studied evolution over 150 years ago proposed that organisms that were very similar in structure must be related. This view was based on the knowledge that organisms seemed to inherit their characteristics from their parents. However, at that time nothing was known about genetics.

Genetics has since shown us that species with the same basic structure have many genes the same or genes that are similar in their effect. It is the genes that control structure and function in organisms. Organisms with some identical genes must be related. This is because particular genes are copied from previously existing genes during meiosis. The obvious inference is that two species that share genes must have had the same ancestor at some stage. Many of the same genes have then been passed down to both species.

SciFile

Hox genes

Most species contain Hox genes, a group of genes that control where body parts such as the head and legs occur. The amazing thing about these genes is that they can be taken out of one species, such as a chicken, and put into another, such as a fly, where they work in exactly the same way. Scientists see this as evidence that all life is related.

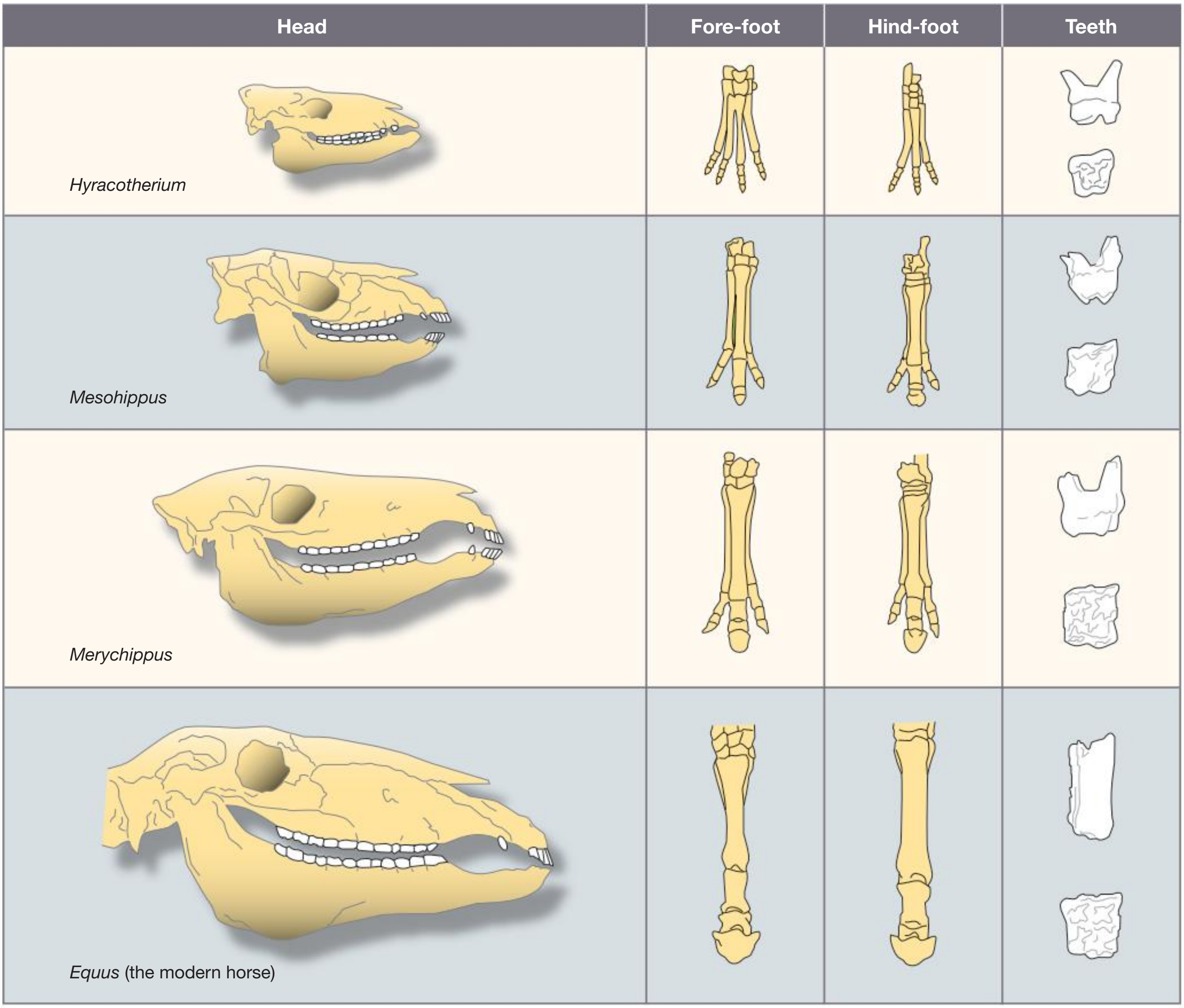


Figure 3.1.4 The fossil record of horses shows that the structure of the skull, jaw and feet changed over millions of years.

Homologous structures

In related species, characteristics that have the same basic structure are called **homologous** characteristics. Biologists have discovered that these are controlled by particular inherited genes. For example, the foot bones of the different fossil horses are homologous. A cat's paw and a lion's paw are considered homologous, but a cat's paw and an insect's foot are not homologous. A cat's paw and an insect's foot may have the same function, but their structure is very different.

In the last few decades, scientists have been able to isolate genes and study their chemical structures and how genes function. It has been discovered that the more alike two organisms are, the more genes they share. As you move from higher levels of classification to the lower levels, the more alike those genes become.

A homologous structure does not necessarily have the same function in all the groups that share it. For example, humans, whales and bats all have five digits at the end of their limbs. Humans have five digits (fingers and toes) on each of our hands and feet. Their function is to grip things and to get traction when walking. Five digits also form the bony structure of each of a whale's flippers, which are used to propel themselves through water. In contrast, the five digits that make up each of a bat's wings form the structure of their wings, allowing them to fly. A human hand, whale flipper and bat wing are homologous structures, despite having different functions.

1 p77 3.1

Analogous structures

Not all similar structures are homologous structures. For example, the dolphin and shark in Figure 3.1.5 have similar streamlined bodies and similar dorsal fins on their backs. However, these are not homologous structures because different genes are involved in their inheritance. Dolphins and sharks differ in most other structures. This shows that these animals are not very similar other than at the simplest (phylum) level—the fossil record shows that sharks evolved over 460 million years ago, while dolphins evolved about 10 million years ago.

Dolphins and sharks have similar body shapes and fins because they evolved in similar marine environments. Structures that look similar on genetically very different organisms are known as **analogous structures**.

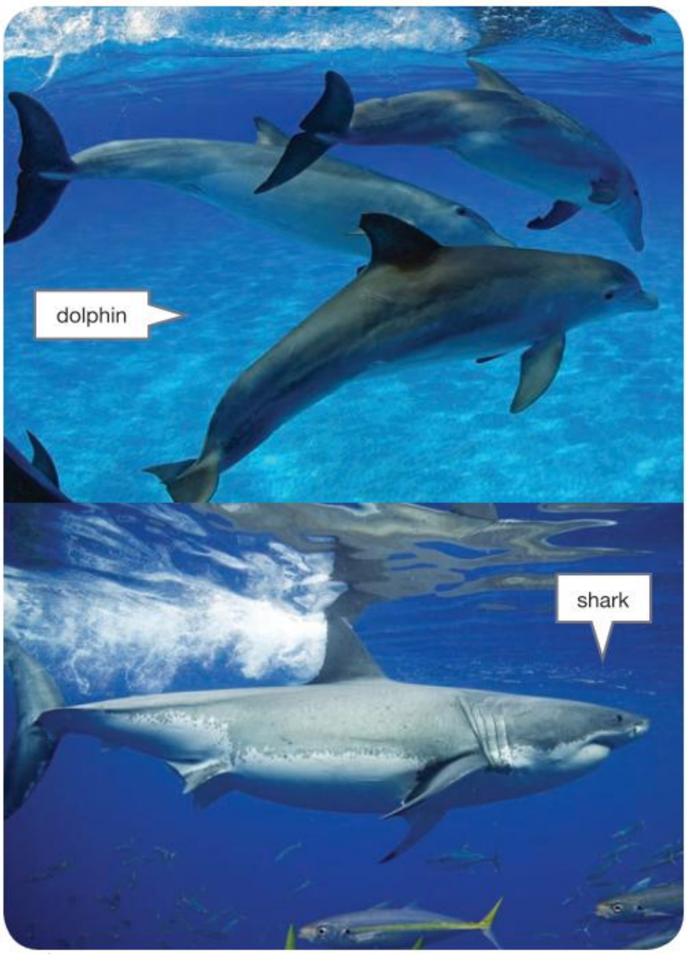


Figure 3.1.5 Sharks and dolphins are not closely related but look similar due to evolving in similar environments.

Dolphin ancestors

Dolphins are air breathers, and scientists think their ancestors must have been land-living animals that went back into the water. That probably explains why they have lungs and breathe air.

SciFile

Artificial selection

For many centuries, humans have selectively bred different animals and crossed different plants to gradually change the features of a species.

Artificial selection is the process by which we choose to breed particular organisms with desirable features. One example is breeding of budgerigars. Wild budgerigars are green and yellow. You can see one in Figure 3.1.6.

Figure 3.1.6 The wild budgerigar is green and yellow.

All the different pet budgerigars we have today have come from this wild type of budgerigar. Figure 3.1.7 shows some of the different colours. The different colours and patterns are the result of breeders choosing particular budgerigars as parents and breeding from them. They used wild budgerigars that showed small differences in colour, patterning and body size. These variations in the wild budgerigar population were all originally the result of mutations.

Figure 3.1.7 These budgerigars were all bred by artificial selection.

Figure 3.1.8 Different breeds of dog are all one species and were produced by artificial selection.

Occasionally new mutations occurred that the breeders had not seen in the wild birds. These were selected by the breeders and passed on to the offspring. For example, the blue colour in some budgerigars originated as a mutation of the gene controlling the green feather colour. All wild budgerigars are green, although occasionally blue ones are born, and sometimes all yellow ones are born. In this way, many new features were developed in pet budgerigars and they are markedly different from the original wild birds.

Artificial selection only happens over generations. The breeders cross (mate) the selected parents and then have to allow the offspring to reach maturity before selecting which will be bred.

The different colours in pet budgerigars have been produced in only about 100 years of artificial selection.

There are hundreds of other examples of species being changed by artificial selection. Domestic dogs are all one species (Figure 3.1.8), as are domestic cats. The different breeds in these two species have come from artificial selection.

Big and small

The biggest dog breed is the Irish wolfhound, and the smallest is the chihuahua. Both are the same species and the differences in them have been developed by artificial selection.

SciFile

Selective breeding methods

Selective breeding is used in two main ways. The first method is called **cross-breeding**. This is the process of combining in the offspring a desirable feature of one individual with a different desirable feature from another individual. An example is the creation of the dog breed called labradoodle. This is a cross between a labrador and a poodle, combining the features of both dogs. You can see a labradoodle in Figure 3.1.9.

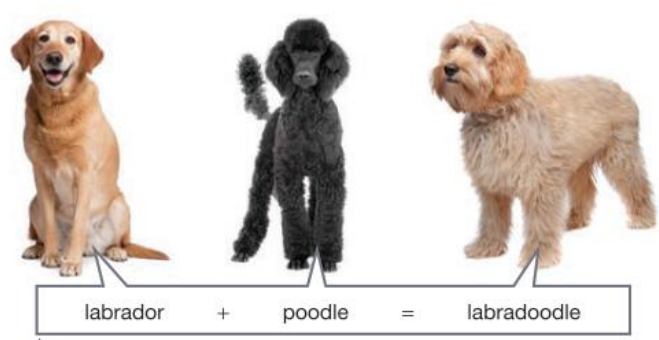


Figure 3.1.9 The labradoodle is the result of a cross between a labrador and a poodle.

Another method of selective breeding is **inbreeding**, or line-breeding. In this process, related individuals are allowed to mate. This method is not often used in animal breeding, as there can be health issues in the offspring. Deformities, sterility and genetic disease can be caused by inbreeding.

In plant breeding, there do not seem to be as many problems with breeding closely related plants, but this can depend on whether the species is self-pollinating or cross-pollinating.

SCIENCE AS A HUMAN ENDEAVOUR

Nature and development of science

Breeding a better lupin

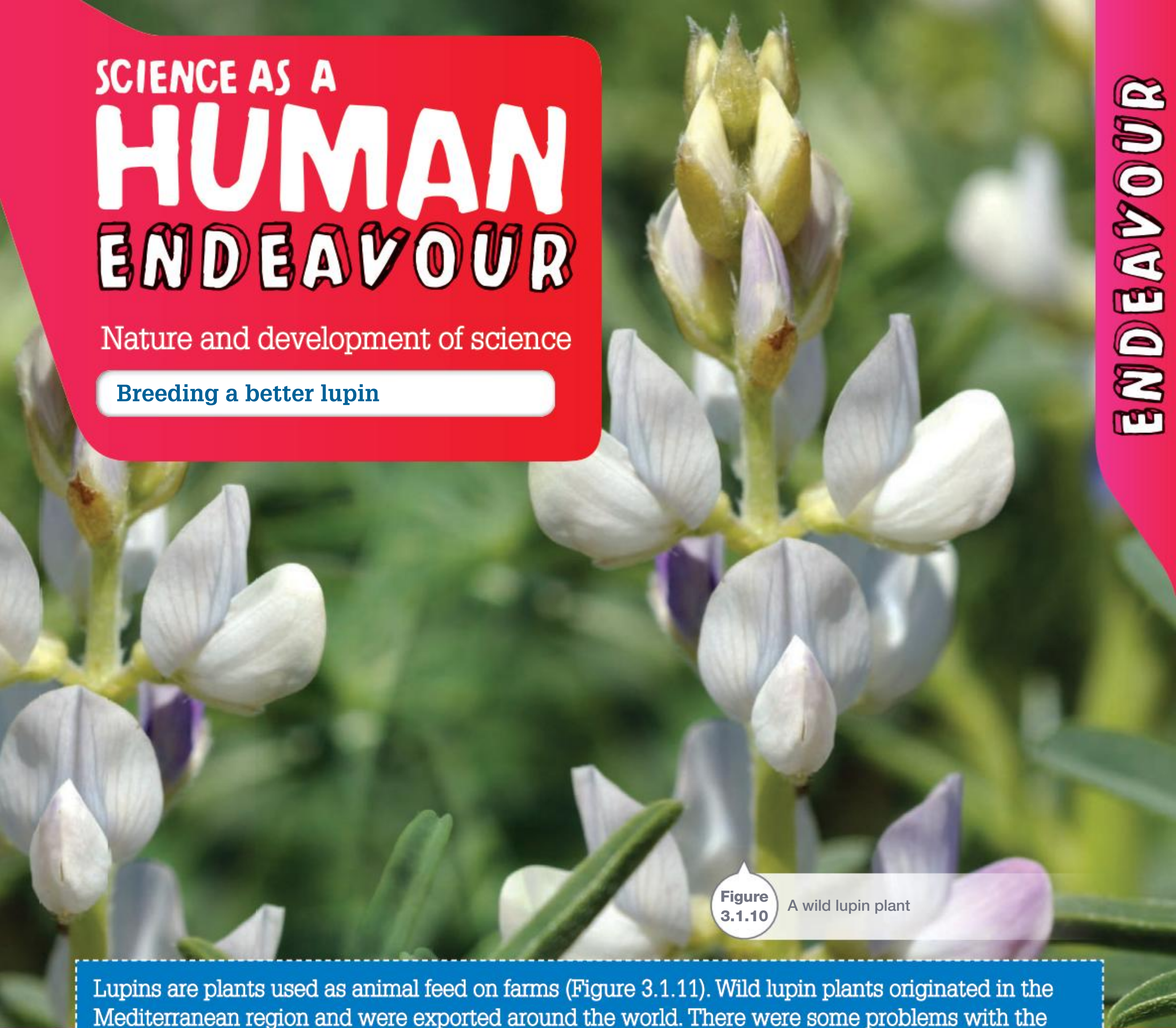


Figure 3.1.10 A wild lupin plant

Lupins are plants used as animal feed on farms (Figure 3.1.11). Wild lupin plants originated in the Mediterranean region and were exported around the world. There were some problems with the original plants, so selective breeding was used to improve them.

Figure 3.1.11 Lupins are used as animal feed on farms.

The original wild lupin seeds (Figure 3.1.10) had a rather bitter taste, so animals generally only ate the leaves. The seed pods also shattered and scattered their seeds, so farmers found it difficult to harvest the seeds for planting at a later time.

John Gladstones is a plant breeder from Western Australia. He thought he might be able to change lupins to make them into a better animal stock feed. He particularly wanted to produce seeds that animal stock would eat, and that would be easier to harvest. Gladstones began his research by searching through fields of lupins, looking for mutants that didn't have shattering pods. He eventually found two plants in which the seed pods had only partially shattered.

Figure 3.1.12 Wild lupin pods shatter but artificial selection produced non-shattering pods.

Studies of these two plants showed that pod shattering was controlled by two independently inherited recessive genes. These genes affected the seed pods in different ways to stop them shattering. Gladstones cross-bred these two plants and managed to produce a plant with completely non-shattering pods.

However, these lupins still had bitter seeds, which animals did not eat. So he crossed the bitter-seeded, non-shattering plants with lupins that had sweeter tasting seeds, but shattering pods. As Table 3.1.1 shows, some of the offspring were plants that had non-shattering pods and sweet seeds.

Gladstones then crossed these plants with lupins that had white flowers. He wanted to be able to easily spot the sweet-seeded non-shattering plants if they became mixed up with others. He finally succeeded in producing lupins that had non-shattering pods, sweet seeds and white flowers. This resulted in a stock feed that was worth many millions of dollars to farmers around Australia.

Table 3.1.1 Steps in selective breeding of lupins

Step	Plants crossed	Offspring included desired phenotype
1	Partially shattering pod × partially shattering pod	Non-shattering pod
2	Non-shattering pod with bitter seeds × shattering pod with sweet seeds	Non-shattering pod Sweet seeds
3	Non-shattering pod with sweet seeds and blue flowers × shattering pod with sweet seeds and white flowers	Non-shattering pod Sweet seeds White flowers

In terms of evolution, the story of lupins is important because it shows that the characteristics of a species can be changed by selecting which individuals breed. Selecting the phenotype (appearance) of the individuals means selecting their genotype (genetic make-up). In this way, the genetic make-up of a species can be altered by selection.

3.2

3.1 Unit review

Remembering

1 **List** some changes shown by fossil horses over geological time.

2 **List** some examples where artificial selection has changed a species.

3 **Recall** the fossil group that birds are most closely related to and the characteristic that these groups can share.

Understanding

4 **Define** the following terms.
- a evolution
- b generation
- c homologous

5 **Explain** how fossils can provide evidence for changes in the structure of a species over geological time.

6 Using an example, **explain** how artificial selection can alter a species.

7 **Explain** why scientists consider that species with the same basic structure are related.

8 a **Describe** what John Gladstones found when he searched through fields of wild lupins.
- b **Explain** where the genes for non-shattering pods would have come from originally.
- c **Explain** how this story of lupin breeding is similar to the one about breeding budgerigars.

Applying

9 **Demonstrate** that organisms whose appearances are very similar are not always closely related.

Analysing

10 For the different species of horse shown in Figure 3.1.4 on page 71, **compare**:
- a foot structure
- b head structure.

11 **Use** examples to **contrast** homologous and analogous structures.

12 'Homologous structures do not have to perform the same function in different species.'

Use a bat limb and a mouse limb to **justify** this statement.

Figure 3.1.13

13 **Compare** the processes of cross-breeding and inbreeding.

Evaluating

14 Breeders have bred blue budgerigars. **Propose** how they did this given that the wild population is commonly green and yellow.

15 **Justify** the view of palaeontologists that birds and dinosaurs are related.

Creating

16 a **Design** a series of steps for changing a rose with dark pink flowers and thorns into one with white flowers and no thorns.
- b **Explain** the processes used at each step.

Inquiring

1 Research the fossil history of vertebrates, discussing some evidence that fish evolved into amphibians and amphibians into reptiles.

2 Research the fossil history of mammals, discussing the evidence that mammals are related to reptiles.

3.1 Practical activities

1 Signs in the skeletons

Purpose

To compare vertebrate limbs and propose reasons for their similarities.

Materials

- skeletons of human, cat, bird, frog, fish and lizard

Procedure

1. Copy the table below into your workbook.
2. Use the labelled diagram in Figure 3.1.14 of the human arm to identify the same bones in the human skeleton.
3. Move around to the various specimens and carefully observe their front and rear limbs.
4. Identify any bones that are similar to the human forearm or leg. List similarities and differences between the different animals and the human.

Results

Complete your results table for each animal.

Discussion

1. Using your table, **identify**:
   a. the two animal skeletons that are most alike in their limb structure.
   b. two that are least alike.
2. a. **Identify** animals that you think may have homologous limb bones.
   b. **Identify** the particular bones involved.
3. **Explain** how these animals could have skeletons that are so similar.
4. The bony fish is a vertebrate, but an extremely distant relative of these other vertebrates. **Discuss** evidence in the skeletons that fish are related to these other vertebrates, but very distantly. (Hint: Look for other homologous structures.)

Animal	Description of front limbs	Description of rear limbs
Human		
Cat		
Bird		
Frog		
Fish		
Lizard		

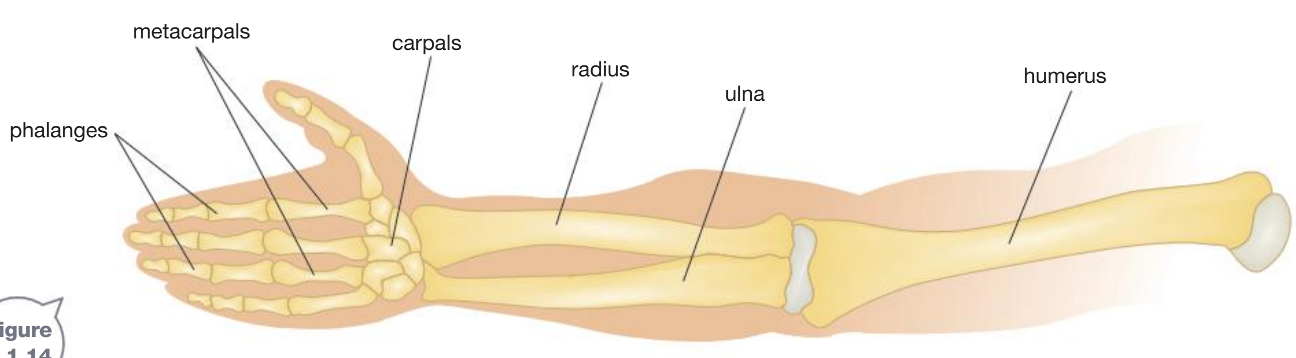
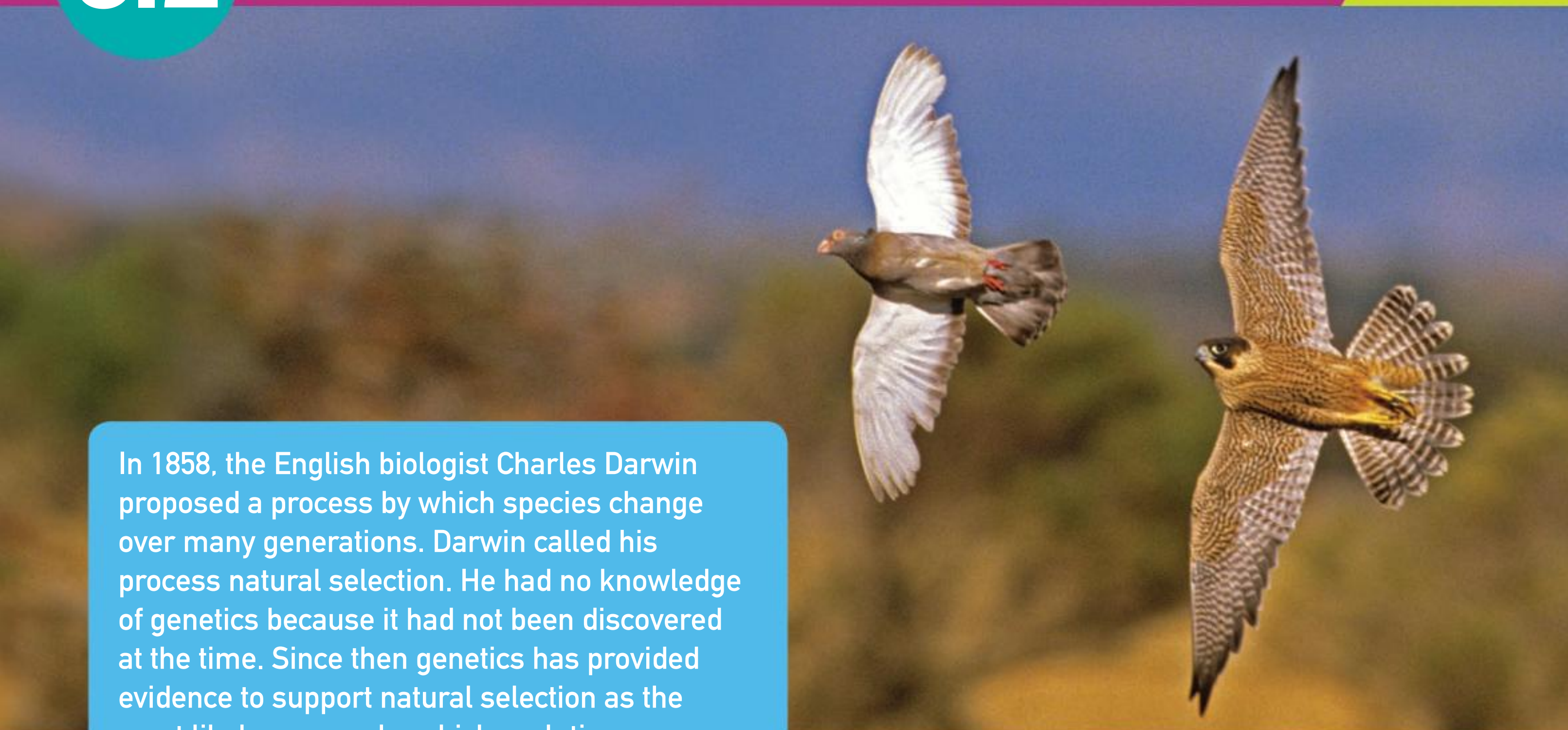


Figure 3.1.14

3.2 Natural selection



In 1858, the English biologist Charles Darwin proposed a process by which species change over many generations. Darwin called his process natural selection. He had no knowledge of genetics because it had not been discovered at the time. Since then genetics has provided evidence to support natural selection as the most likely process by which evolution occurs.

Darwin's ideas of natural selection

The following example will help you understand what Charles Darwin (Figure 3.2.1) meant by natural selection.

Consider a population of mice being preyed upon by owls. The mice have two different coat colours, dark brown and light brown. These colours are inherited. The owls swoop down to catch mice that are in the fields.

Imagine that there are equal numbers of dark-brown and light-brown mice. In areas where the ground colour is dark brown, the owls would find the light-brown mice easier to see. The owls would catch a greater number of light-brown than dark-brown mice. As a result, there will be more dark-brown mice surviving and breeding. The next generation would have more dark-brown mice than light-brown mice.

The dark-brown mice have been 'naturally selected' by the owls, as opposed to artificially selected by humans. Darwin meant that the selection was done by 'nature', not humans. The dark-brown mice had been selected to breed, but it was not intentional. They were favoured by selection to produce the next generation of offspring. Over many generations, this process would continue and the population would gradually become all dark brown and therefore better adapted to its dark brown environment.

This story of the mice shows natural selection at work. Different studies of mice have shown that natural selection also works on real mice, changing their population and characteristics.

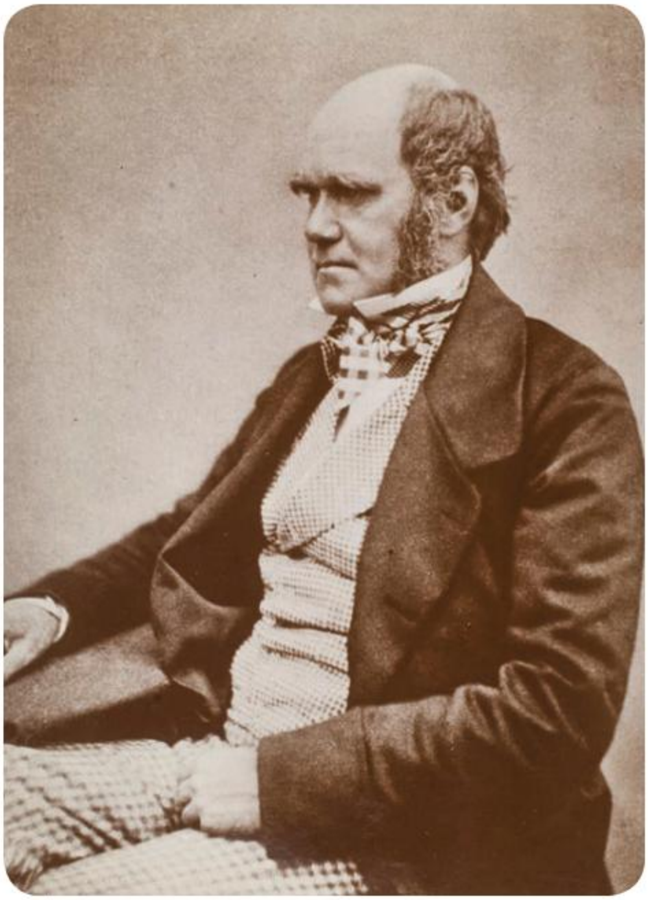


Figure 3.2.1 Charles Darwin (1809–1882) photographed in 1860, aged 51

Figure 3.2.2 In Arizona, USA, a study was performed to find out why rock mice living there has certain coat colours. It was found that by preying on mice that were easiest to see, owls were influencing particular coat colours in different locations. The end result was that each population became better adapted to its environment.

Natural selection defined

Natural selection is the process where an environmental factor acts on a population and results in some organisms having more offspring than others.

Biologists call the environmental factor that acts on the population the **selective agent**. The effect of natural selection on the population is referred to as 'selection pressure'. The selective agent in Figure 3.2.2 is the owl. The selective agent may be a biotic factor (another living thing), such as predation, bacterial infection or competition, or a physical factor, such as temperature, water, soil nutrients or fire (Figure 3.2.3).

Figure 3.2.3 Fire is a selective agent in Australia. Trees with thicker bark may better survive a fire as the bark can protect the living tissue beneath.

Many selective agents act by killing individuals. Such individuals are often less suited to surviving and are referred to as 'poorly adapted' or 'less fit'. For example, predators may find them easier to catch because they are slower runners, have poorer eyesight or are more easily seen. For example, light-coloured mice are less fit to survive on dark soil.

Selective agents do not always act by killing. For example, female birds often select brighter coloured males for breeding. Those males will produce more of the offspring in the next generation (Figure 3.2.4). Darwin called this **sexual selection**, because he thought of natural selection as being something that kills. But nowadays sexual selection is considered to be an example of natural selection because both change the characteristics of a species through selection.

Figure 3.2.4 This male great frigate bird with his air-filled throat pouch is trying to attract the female. Females are attracted to males with the most prominent red pouch.

The individuals that are favoured by the selective agent pass on their features to the next generation. So the next generation inherits those selected features. One outcome of natural selection is that the species gradually becomes better adapted to its environment. For example, the whole population of mice becomes more like the colour of the ground it lives on.

Variation

Darwin concluded that natural selection could only act if there is variation (natural differences) in the population. However, genetics was unknown in his time and so he did not know how or why this variation happened.

Since then, scientists have shown that **variation** is caused by differences in genes, which result in different characteristics. Since genes are inherited, so too are the characteristics they carry. Hence, variation is inherited too. Variation in most organisms is relatively easy to see. For example, humans show variation in height, nose shape, hairiness, baldness, leg length, and hair, eye and skin colour (Figure 3.2.5).

Figure 3.2.5 Variation in different people is due to inherited differences.

INQUIRY science 4 fun

Observing variation

Yes

Do this ...

1 Go outside into the garden or the bush. Try to find many plants of the same type (species).
2 Choose a particular feature such as flower structure or colour; leaf shape, size and colour; or fruits (seed cases).
3 Study many examples of your chosen feature, looking for any variation you can see in it.

Record this ...

Describe any differences you observed.
Explain what you observed.

Genetics and natural selection

A more modern definition of natural selection can be expressed in terms of genetics. Natural selection is the change in proportion of a particular genetic make-up (genotype) of a species over many generations due to environmental selection of a particular characteristic (phenotype). In simpler terms, this means the proportion of a particular characteristic (phenotype) in a species changes because individuals with a particular genetic make-up (genotype) within it are being favoured to breed.

Evidence for natural selection

The peppered moth

One of the first studies to collect evidence for natural selection was conducted earlier last century in England. Henry Bernard Kettlewell studied the peppered moth, which existed in two forms. The normal colour was white with black specks, although occasionally all-black mutant moths were born.

Kettlewell found that in the cities, almost all the peppered moths were black. In rural areas, they were almost all white. He concluded that this difference was due to a selective agent acting on the populations. The selective agents he observed preying on the moths were birds such as the flycatcher and nuthatch.

Kettlewell explained the process as follows:

- In the cities, all the building and tree trunks had been blackened by soot from over 150 years of industrial pollution. Any white moths resting on the trees could be seen more easily than the black moths (Figure 3.2.6). So the birds removed white moths faster than they removed the black ones. Black moths produce black offspring and so the population eventually became mainly black. So, the black form was considered to be better adapted to its polluted city environment.

Figure 3.2.6 Black and white peppered moths on a dark background

Figure 3.2.7 Black and white peppered moths on a light background

- In rural areas, the air was cleaner and tree trunks were of a lighter colour. This made the white moths harder to see (Figure 3.2.7). The black moths were eaten more often and so the population eventually became nearly all white. Now the white moths were better adapted to their environment.

Kettlewell carried out experiments where he placed the two different colours of moths on tree trunks and then observed birds feeding on the moths. He counted the numbers of light and dark moths eaten. His results showed that the birds ate mostly the dark moths on the light-coloured tree trunks and light-coloured moths on dark tree trunks. Some results are shown in Table 3.2.1.

Table 3.2.1 Natural selection of moths by birds

Place and background colour	Number of moths observed	Percentage dark eaten	Percentage light eaten
Birmingham wood—dark tree trunks	58	26%	74%
Dorset—light tree trunks	190	86%	14%

This experiment supported Kettlewell's observations made earlier in the country.

p84

Since Kettlewell's experiments, examples of camouflage against background colour have been found in many places around the world in species as varied as mice, snakes and snails. In England, over 100 species of moth demonstrate the same colour changes as observed by Kettlewell. Several of these studies have shown that the dark form of moth has declined in numbers in cities where pollution controls have been in force.

Natural selection highlights how much the environment affects living organisms, causing the characteristics of a species to change over many generations. Natural selection has been demonstrated more recently in many organisms such as bacteria, insects, snakes and cane toads. For example, many bacteria have become resistant to antibiotics and many insects are now resistant to insecticides.

3.3

Figure 3.2.8 Spraying crops with insecticides to kill insect pests

Figure 3.2.9 The diamond backed moth is a pest in vegetable crops such as cabbage and broccoli. It was the first crop pest in the world to develop resistance to the insecticide DDT. The moth is now resistant to all insecticides used before the mid-1990s.

Natural selection of insects

In the middle of last century, agricultural scientists developed chemical insecticides. These were sprayed onto crops to kill insects (Figure 3.2.8) and reduce crop damage caused by them. The scientists thought they would kill all the insects and that food production would rise greatly. However, these insecticides were only effective for a few years, requiring farmers to increase the concentrations of the insecticides they used. Also, not all the insects that were sprayed with insecticide died. Eventually the sprays had no effect, and none of the insects died. The scientists called this ability of insects to survive the poison spray **resistance** (Figure 3.2.9).

Although triggered by humans, the development of resistance to insecticides by insects is an example of natural selection.

The resistance that developed in insects was due to several mechanisms. One was that some insects could destroy the poison in their bodies. They had inherited cell chemistry that could do this. So there was variation in cell chemistry.

The resistant insects survived when the population was sprayed, but the non-resistant insects all died. The resistant insects then bred and produced offspring, most of which inherited resistance. Every time all the farmers sprayed, there would be a larger proportion of resistant insects on the crops. As many farmers sprayed over a large area, the insect population quickly became all resistant. This process is shown in Figure 3.2.10.

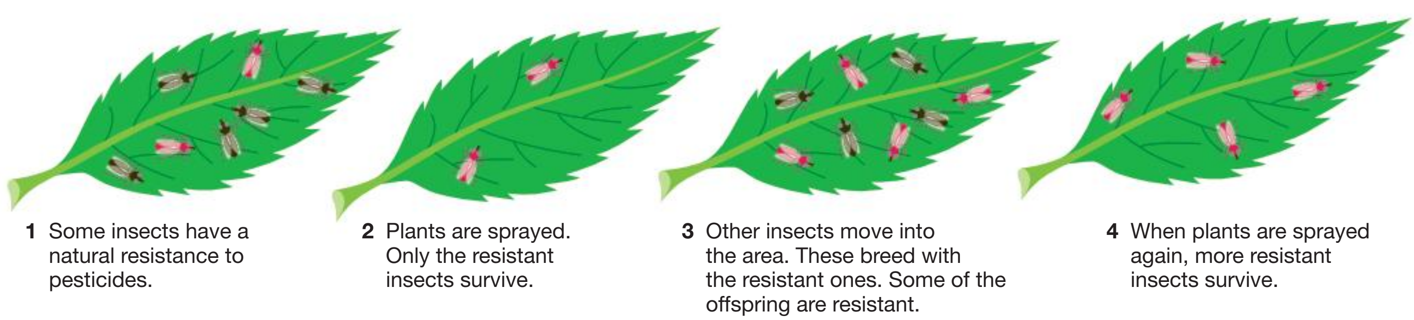


Figure 3.2.10 Insects become resistant to insecticides by natural selection.

Natural selection in bacteria

Bacteria are microscopic single-celled organisms. Some cause infectious diseases such as cholera, typhoid and pneumonia. In 1928, Scottish scientist Alexander Fleming found a way to kill bacteria. He discovered that some fungi make special chemicals to defend themselves against bacteria. The chemicals were given the name **antibiotics.** The first one to be isolated was called penicillin. Many more types of antibiotic have since been discovered.

Doctors sometimes prescribe antibiotics to kill any bacteria that are infecting you. This practice became widespread in medicine in the last few decades of the 20th century, and several types of antibiotics lost their effectiveness against many different bacteria. The bacteria had become resistant to them. You can see this in Figure 3.2.11.

Bacteria became resistant to antibiotics by natural selection. In the millions of bacterial cells infecting a person, some may have inherited cell chemistry that can destroy the antibiotic molecules, or may resist the antibiotic in some other way. This is similar to the resistance insects developed to pesticides. When you take the antibiotic, it kills all the bacterial cells that are not resistant. Any resistant ones may survive and reproduce, forming resistant offspring.

Bacteria reproduce by dividing in half, producing two copies of themselves. Each half divides again, often within 20 minutes. Hence, every 20 minutes or so the number of bacteria inside you could double. Eventually there will be enough resistant bacteria to make you ill. At this stage, taking more of the antibiotic will not work. You will need a different antibiotic, one to which the bacteria is not already resistant.

One very dangerous type of bacteria is golden staph, *Staphylococcus aureus*, seen in Figure 3.2.12. Golden staph is resistant to many antibiotics, and is very difficult to kill. It became resistant because of the widespread use of antibiotics in hospitals. Constant antibiotic use in hospitals kept selecting the resistant bacteria to survive. Eventually the species became resistant.

3.4

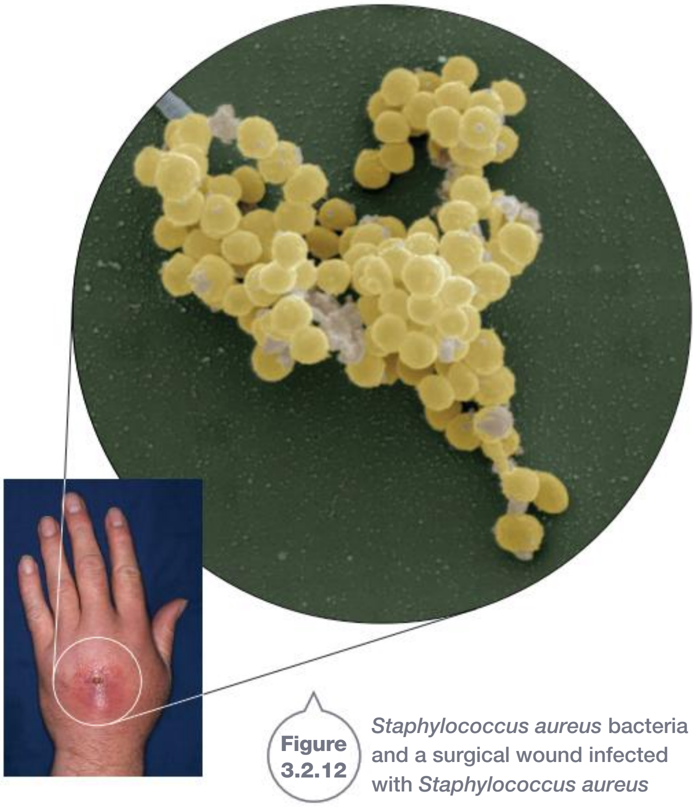


Figure 3.2.12 *Staphylococcus aureus* bacteria and a surgical wound infected with *Staphylococcus aureus*

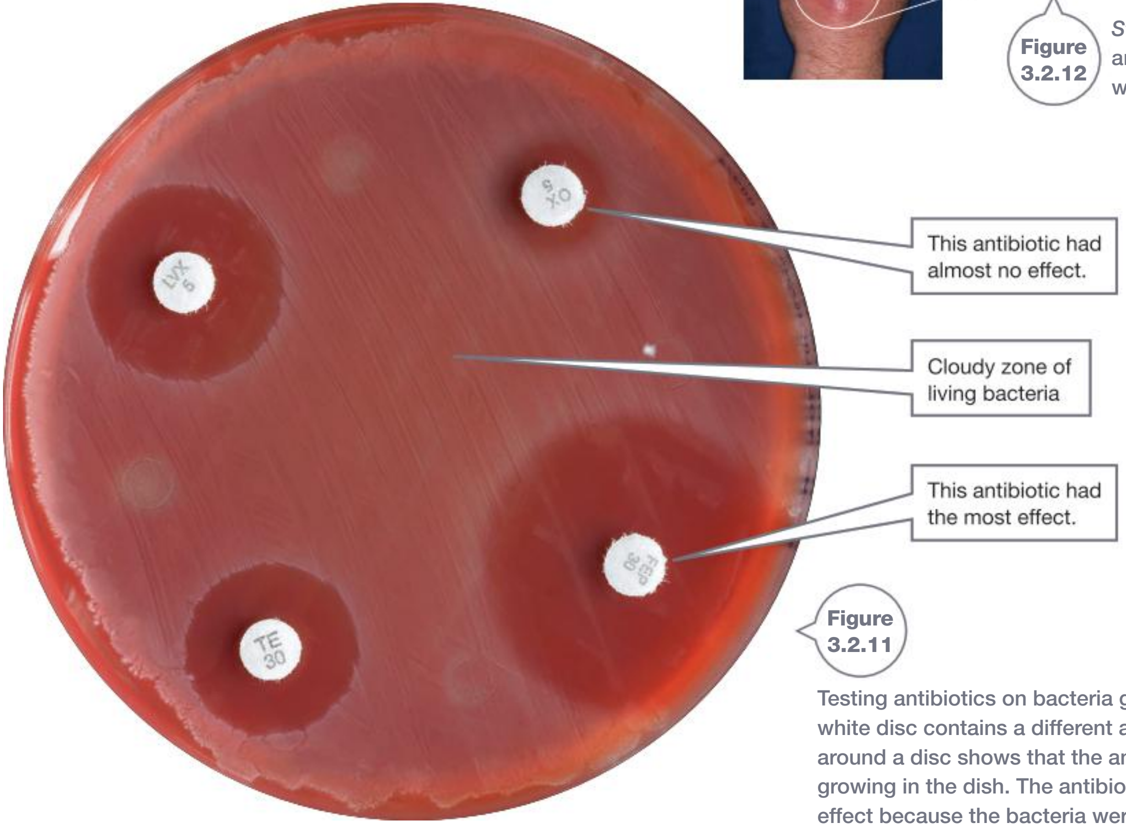


Figure 3.2.11 Testing antibiotics on bacteria growing in a dish. Each white disc contains a different antibiotic. The clear zone around a disc shows that the antibiotic killed the bacteria growing in the dish. The antibiotic at the top right had no effect because the bacteria were resistant to it.

3.2 Unit review

Remembering

1 **Name** the process proposed by Charles Darwin that explained how a species can change over many generations.

2 **List** four different selective agents.

3 **List** five examples of variation in humans.

Understanding

4 **Modify** the following statements to make them correct.
- **a** Natural selection is the process where an individual is acted upon by its environment and produces more offspring.
- **b** A selective agent acts on a population and improves the survival of some individuals more than others.

5 **Modify** the following definition of natural selection to make it correct.

Natural selection is the change in proportion of a particular phenotype of a species over many generations, due to environmental selection of a particular genotype.

6 **Explain** what is meant by *variation*.

7 **Define** resistance to insecticides or antibiotics.

8 **Explain** how light-coloured peppered moths gradually died out in the cities where pollution had changed the environment.

9 **Explain** why variation is necessary before natural selection can occur.

Applying

10 Consider the examples of natural selection in insects and bacteria in this unit.
- **a** **Identify** the selective agents in each case.
- **b** **Identify** the inherited variation in each case.

Analysing

11 **Compare** natural selection and artificial selection.

12 In his famous book *On the Origin of Species*, Charles Darwin said: 'This preservation of favourable variations and the rejection of injurious variations, I call Natural Selection.' **Compare** his definition with the one given on page 79.

Evaluating

13 **Analyse** the data in Table 3.2.1 (on page 81) and **justify** the conclusion made by Kettlewell.

14 **Propose** what would happen to populations of dark- and light-coloured mice living on light-coloured soil.

15 **Evaluate** whether humans have been and are still subject to natural selection.

16 **Evaluate** whether an individual can become adapted during its lifetime.

17 Spraying crops with pesticides has caused the development of pesticide-resistant insects. This is given as an example of natural selection at work despite humans being involved in the spraying.
- **a** **Identify** the agent for natural selection in this case.
- **b** **Assess** whether the example would be better classified as an example of artificial selection.
- **c** **Justify** your answer.

Creating

18 **Construct** a story based on natural selection that could explain how one of the following developed by natural selection: warning colouration in poisonous insects, venom in snakes, wings on dinosaurs.

19 Several early science fiction movies showed humans several million years in the future. They showed us with a huge brain and a head about twice as big. **Construct** an argument opposing this point of view.

Inquiring

1 Research Charles Darwin and discuss his contribution to the understanding of evolution by natural selection. If possible, read the first few pages of Chapter 4 of his book, *On the Origin of Species*. It is available free online.

2 Research and discuss the evidence of evolutionary change in Australian snakes and other predators due to the spread of the cane toad in Australia, and evidence that the toad has evolved to spread faster.

3 Research the famous Australian scientist Howard Florey and explain his contribution to fighting infectious diseases.

4 Research Batesian and Mullerian mimicry in butterflies and moths. Explain the difference between them by using examples such as the monarch or wanderer butterfly.

3.2 Practical activities

1 Natural selection modelled

Purpose
To use a model to investigate natural selection and the effect of camouflage.

Materials
- 2 different-coloured A3 sheets of paper
- 2 sets of 20 toothpicks of two different colours, to match the sheets of paper
- stopwatch
- tweezers
- cup
- bubble wrap or muslin material

Procedure

Part A
1. Work with a partner. One person is the experimenter and the other is the subject. The subject copies the table in the results section into their workbook.
2. The experimenter mixes up the coloured toothpicks and spreads them evenly over one of the sheets of paper while the subject is copying the table. Place a cup 50 cm away from the edge of the paper.
3. The subject stands up. They will have 20 seconds to use the tweezers to pick up as many of the toothpicks as they can, one at a time. Pick them off the paper and put them in the cup at the side of the paper. The experimenter will say when to start and when to stop.
4. When the time is up, the experimenter must count the number of each colour of toothpick the subject picked up. Write the results in your table and on the board.
5. Repeat the experiment with the other coloured sheet of paper.

Part B
6. Repeat the experiment but the subject must put bubble wrap or muslin material over their eyes to reduce their ability to see clearly.

Extension
7. Design and conduct a different method of testing out the effect of camouflage on natural selection, but outside the classroom. Make use of natural objects such as leaves, twigs and flowers.

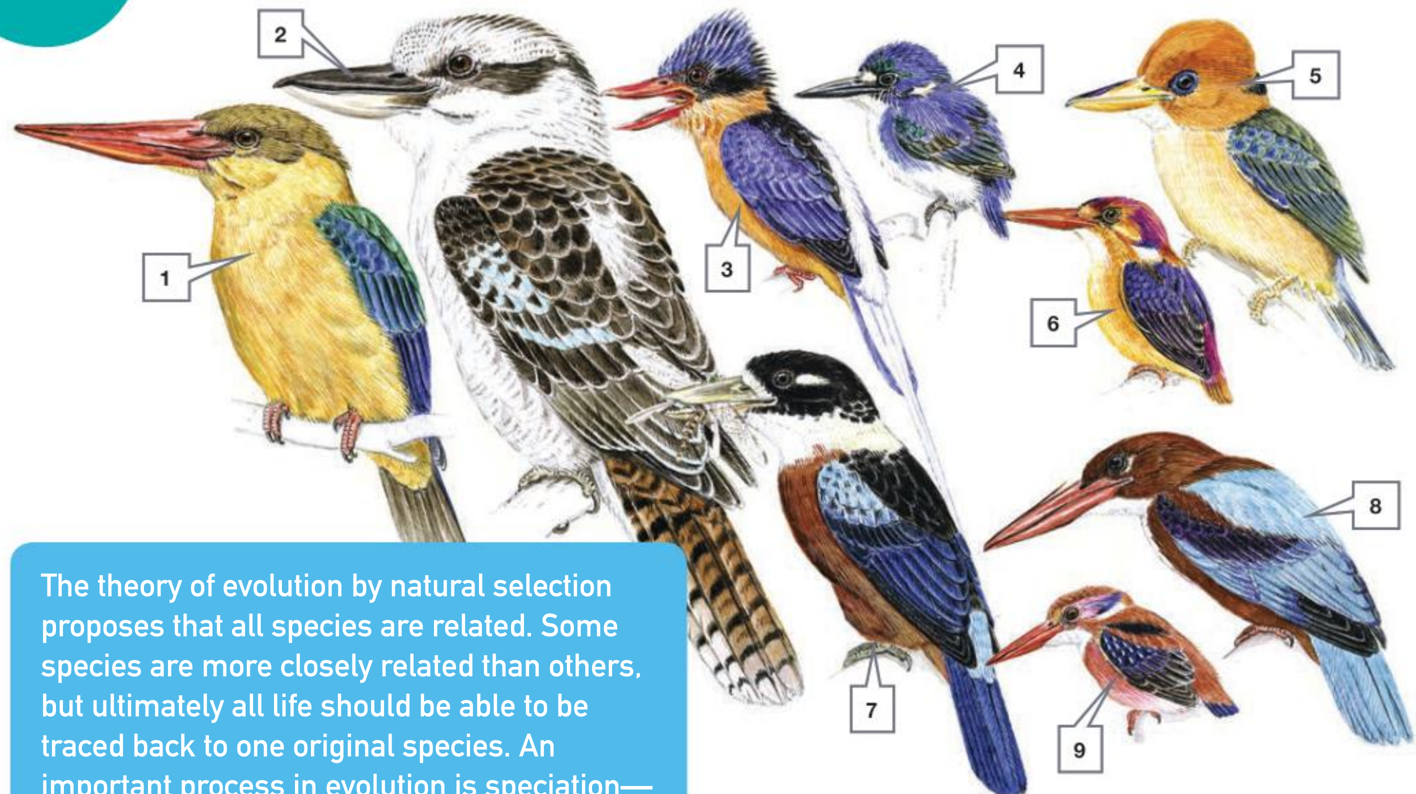
Results
1. Complete the following table.

	Toothpick		Percentage different colour from paper
	Colour A	Colour B	
Good vision			
Paper colour A			
Paper colour B			
Poor vision			
Paper colour A			
Paper colour B			

2. Your teacher should put a class results table on the board. Enter your results and calculate a class average for each set.
3. Copy the class results into your workbook.
4. If you carried out the extension, report your results.

Discussion
1. In part A, **identify** which was picked up more often: toothpicks the same colour as the background paper, or toothpicks a different colour from the paper.
2. In part B, **identify** which was picked up more often: toothpicks the same colour as the background paper, or toothpicks a different colour from the paper.
3. **Compare** the effect of good vision and poor vision on the results.
4. **Discuss** how this experiment models the effect of camouflage on natural selection.
5. **Evaluate** whether this experiment was effective in modelling the effect of camouflage on natural selection.
6. If you carried out the Extension, **draw** a conclusion based on your results.

3.3 Speciation and evolution



The theory of evolution by natural selection proposes that all species are related. Some species are more closely related than others, but ultimately all life should be able to be traced back to one original species. An important process in evolution is speciation—the formation of new species. These nine species from the kingfisher family show that some are more closely related than others. All these species descended from a single ancestral kingfisher.

Evolution

Charles Darwin proposed that natural selection could result in the formation of new species. In his book *On the Origin of Species*, he called this 'modification by descent' rather than evolution. The term evolution was applied to his work by other scientists.

The theory of evolution states that similar species must be closely related to each other. For example, the kingfishers labelled 6 and 9 above are in the same genus *Ceyx* and so they are closely related to each other. Kingfisher 4 is from another genus (*Alcedo*) but is classified in the same sub-family as kingfishers 6 and 9. So kingfisher 4 is related to kingfishers 6 and 9 too. These three species are commonly called river kingfishers and their similarities suggest that they had a common ancestor at some time in the past. The other six species of kingfishers are more distantly related to the river kingfishers. This suggests that these six species separated into a different breeding line at a different time.

The earliest hints of Darwin's theory can be found in his first book *The Voyage of the Beagle*, written in 1845. This book describes his epic journey around the world between 1831 and 1836. On this voyage, Darwin studied many different species in many different environments, including the Andes Mountains, the coast of Australia and the Galapagos Islands. It was on these islands that he studied differences in the beak shapes of finches. Some of his results are shown in Figure 3.3.1. Each of the fifteen finch species seemed to have come from a common ancestor but had beaks that were different. It was as if the different beaks had been selected for the different food sources (such as seeds, honey and insects) found on the different islands.

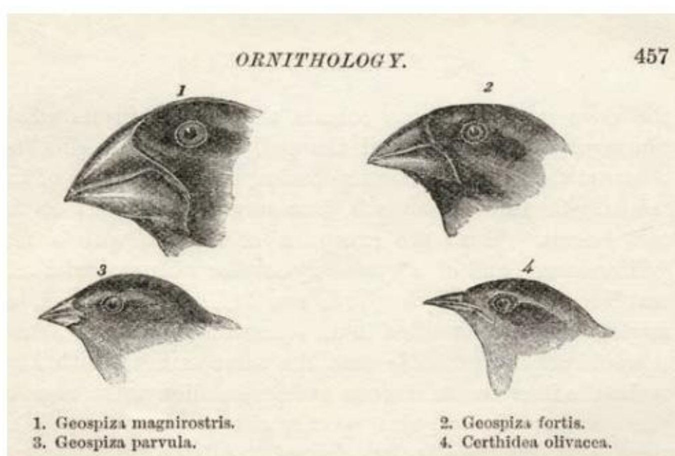


Figure 3.3.1 This illustration from Darwin's book *The Voyage of the Beagle* shows the finch beaks that started him thinking about species being able to change.

What is a species?

It is impossible to determine whether two organisms are the same species from their anatomy. In the past, the test for a **species** was to see if two organisms could interbreed to produce fertile offspring under natural conditions. They were only considered to be the same species if they could produce fertile offspring. An example is the mule. A mule is produced by crossing a horse and a donkey. The mule produced is always sterile and so the horse and donkey are different species.

This interbreeding test can still be used to classify living organisms at the species level. However, these days biologists study DNA and also identify the similarities in the amino acid arrangement in the proteins they make. Since proteins are made by genes, identical proteins must mean identical genes (or at least genes that are very similar). Fossil DNA and proteins are also being analysed to help define relationships. There are now laboratories that specialise in analysing DNA samples from ancient bones.

INQUIRY science 4 fun

Types of eucalypt

Yes

Collect this …

- several flowers of at least three different eucalypts

Do this …

Look for differences between the flowers.

Record this …

Describe what you observed.
Explain any similarities and differences.

Speciation

Speciation is the process by which one species splits into two or more separate species. Speciation is responsible for the formation of any new species that appear in the fossil record.

Speciation has resulted in the high level of biodiversity on Earth. **Biodiversity** refers to the number and range of different species that exist, either on the whole Earth or in any of Earth's ecosystems.

The process of speciation occurs in three basic steps:

- variation
- isolation
- selection.

Step 1. Variation

There must be variation in the population or speciation cannot occur. This is because natural selection is involved, and selection can only act on variation that is already present in the population.

Step 2. Isolation

The formation of new species requires **isolation**. This means that different groups of the population are prevented by some mechanism from interbreeding. Isolation prevents gene flow throughout the population, stopping any differences in one population from reaching the other population. For example, any new genes that arise by mutation in one isolated population cannot spread to the other isolated population. An example of one way in which speciation can occur is shown in Figure 3.3.2.

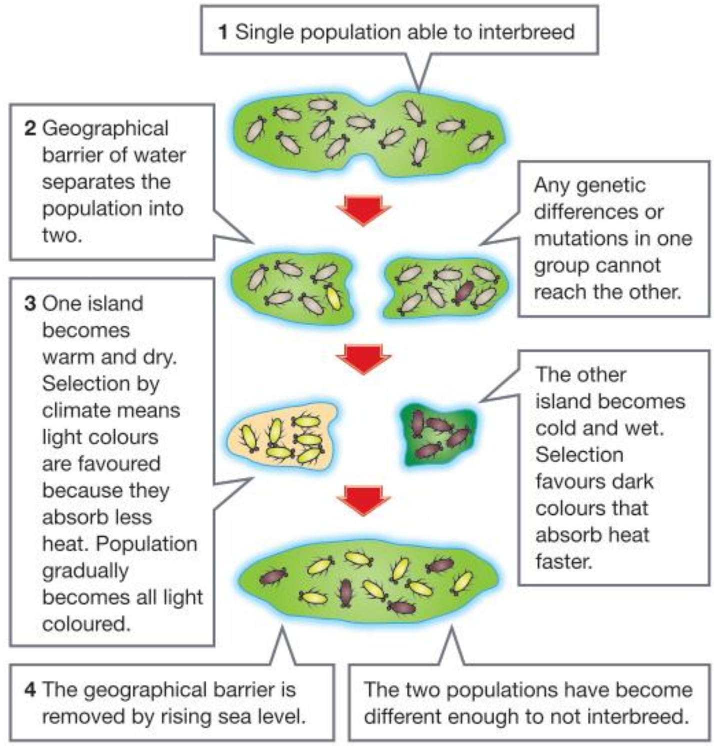


Figure 3.3.2 Speciation is the formation of new species from a common ancestor.

Isolation into separate populations occurs in several ways, for example by a geographical or climatic barrier. Geographical barriers are oceans, rivers, mountain ranges and gorges. Climatic barriers include rainfall, temperature, salinity, ocean currents and sunlight.

Step 3. Selection

Once isolated by barriers, natural selection affects the genotype and causes changes that prevent the groups breeding even if they came back together again at some time in the future. There are many possible changes. A few examples are:

- courtship behaviour—animals may develop different breeding songs, displays and rituals
- breeding seasons—animals may breed at a different time of year
- sterility— animals may breed but the offspring are sterile (like mules)
- chemical barriers—sperm may be killed by the chemistry of the female.

Evidence for evolution

The theory of evolution by natural selection is supported by a great deal of evidence.

Fossils

Early fossils are of fairly simple organisms and later ones are increasingly complex. This makes sense in terms of genetics because new alleles and genes develop from existing genes by mutation. It seems unlikely that complex organisms (with many different genes) would develop first and become simpler (with fewer genes).

The fossil record also shows that there is an increasing number of species that have lived on Earth. Many of these species became extinct along the way, such as the dinosaurs, the diprotodons and marsupial lions. The increasing number of species (increased biodiversity) supports the theory of evolution because that is what you would expect if species continually split into two or more other species over time.

Fossils showing **transitional forms** have also been found. For example, there are transitional forms that show that a group of small dinosaurs had feathers. *Archaeopteryx* and *Anchiornis* (Figure 3.3.3) are examples. Their fossils suggest that one group was in the process of changing from dinosaurs to birds. Transitional forms are hard to classify because they have features of two different groups. In the case of feathered dinosaurs, they have the features of both reptiles (class Reptilia) and birds (class Aves).

Lobe-finned fish are another transitional fossil group that are part fish and part amphibian. They suggest a way in which life moved from the sea and onto the land.

Comparative anatomy

Comparative anatomy compares the structures of organisms of both living species and fossils. Homologous structures fit into this category. Homologous structures such as pentadactyl limbs provide strong evidence for evolution from a single vertebrate ancestor (Figure 3.3.4).

1 p92
3.5

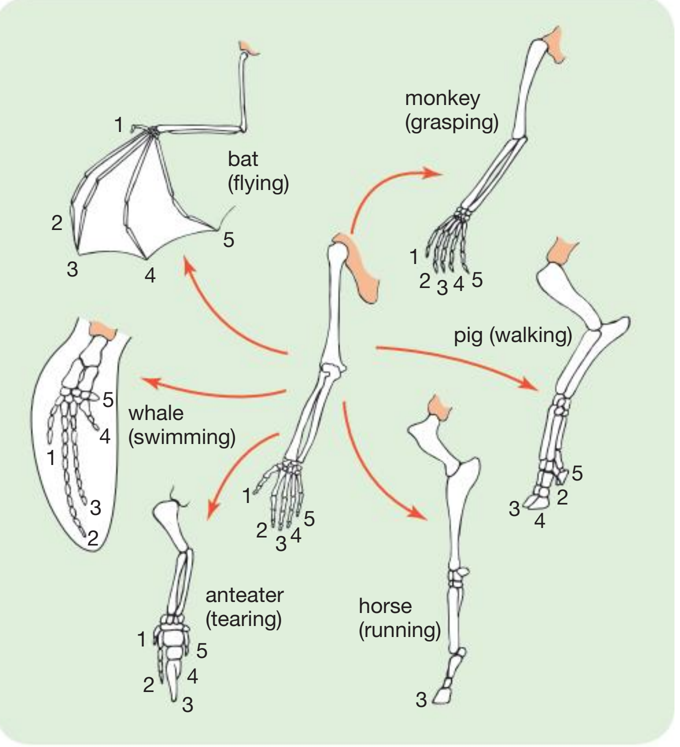


Figure 3.3.4 The pentadactyl limb of vertebrates is a homologous structure that provides evidence for evolution.

Figure 3.3.3 An artist's impression of the feathered dinosaur *Anchiornis*. Studies of fossilised feathers enabled scientists to decide what colour the feathers would have been in life.

DNA and protein structure

All living cells have the same basic DNA structure and use the same genetic code. Proteins produced from genes all come from the same set of amino acids.

Comparing sections of DNA in different species has shown that even organisms that seem to be very different, such as bacteria and humans, have large sections of identical DNA. For example, one of our genes for cell energy release, makes the enzyme cytochrome c. This gene has over 50% of its code identical to the gene in some fungi, and 70% identical to the gene in moths.

Organisms that seem to be fairly similar, on the basis of comparative anatomy, show more genes in common than organisms that are less alike. For example, 96% of the genes in humans and chimpanzees are identical. This is strong evidence supporting evolution: you would expect that two species and their common ancestor would have much of their DNA the same. Fossil DNA can also be compared with that of living species.

Protein amino acid sequences can also be used to compare how closely related species are. This is mostly done with living species, but proteins from fossils can be analysed as well.

Proteins are made out of amino acids like beads on a chain. The sequence of these amino acids is controlled by genes. Cytochrome c is a protein found in all living organisms. Comparing how many of the amino acids are in the same positions on the protein chain can provide some idea of how closely related two species are. For example, humans and monkeys only have one position on the chain where they differ in the amino acid. Humans and moths have 31 positions where they are different. However, studying only one protein like this is unlikely to give a definite answer about how closely two species are related. Many more proteins need to be studied to make such judgements. You can see some of these comparisons in Figure 3.3.5 and Table 3.3.1.

Table 3.3.1 Number of positions with differences in the amino acid present in cytochrome c protein

	Human	Monkey	Kangaroo	Chicken	Turtle	Tuna	Moth
Human	0	1	10	13	15	21	31
Monkey	1	0	11	12	14	21	30
Kangaroo	10	11	0	12	11	18	28
Chicken	13	12	12	0	8	17	28
Turtle	15	14	11	8	0	18	28
Tuna	21	21	18	17	18	0	32
Moth	31	30	28	28	28	32	0

Distribution of current species

Scientists call a map of all the places where a species occurs the **distribution** of the species. When studying distributions, it is very obvious that many unique species occur on isolated islands. With evolution, you would expect to find unusual species on particular islands because isolation is necessary before speciation can occur.

The surface of the Earth is made of tectonic plates. These tectonic plates slowly and continually move. On these tectonic plates are the continents, such as Australia, Africa and Antarctica. As the tectonic plates move, so do the continents. One of the pieces of evidence that convinced scientists that continents moved was the distribution of fossils of particular species.

Moving continents helps explain why Australia has most of the world's marsupial mammals and the only two monotremes. These are the platypus and echidna (Figure 3.3.6). Evidence from plate tectonics shows Australia has been isolated from all other landmasses from about 40 million years ago, providing plenty of time for the evolution of these major groups of mammals.

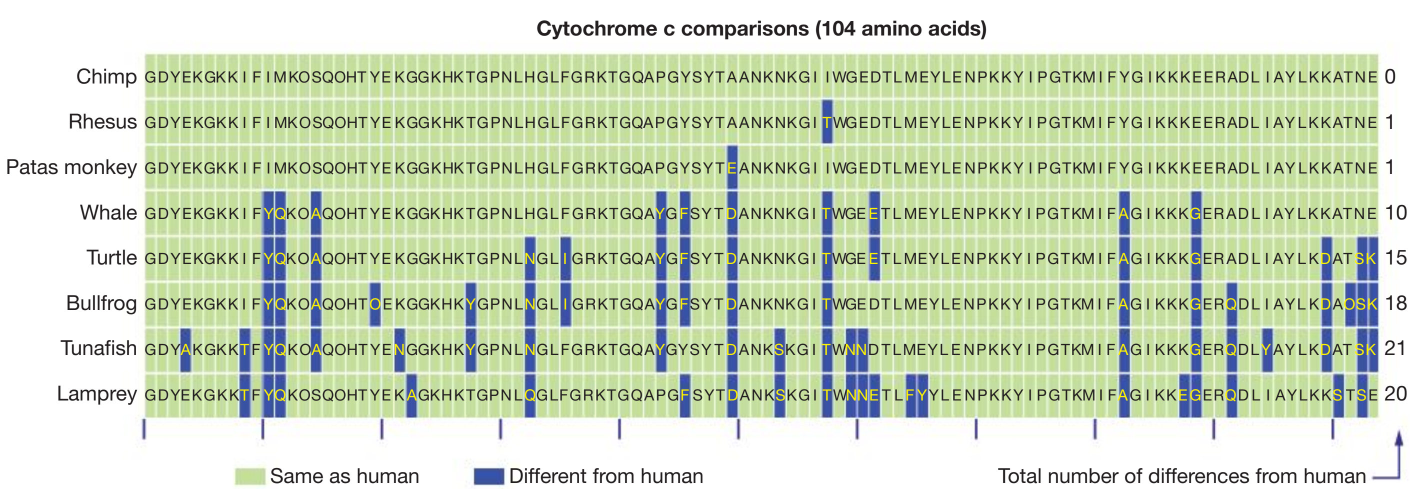


Figure 3.3.5 The amino acid sequences in cytochrome c are shown here for eight different vertebrates. The letters stand for different amino acids.

Figure 3.3.6 The platypus and echidna are the only living monotremes. They evolved in Australia at about the time when it separated from Antarctica and became an isolated continent.

Embryology

Embryology is the study of the development, structure, and function of embryos (Figure 3.3.7). Comparisons of vertebrate embryos show striking similarities in the early stages of their development. For example, there is a time during the embryonic development of fish, lizards and humans when there are branchial arches. These are arch-shaped structures in the throat region. Many other similar structures are also present, such as a 'tail'.

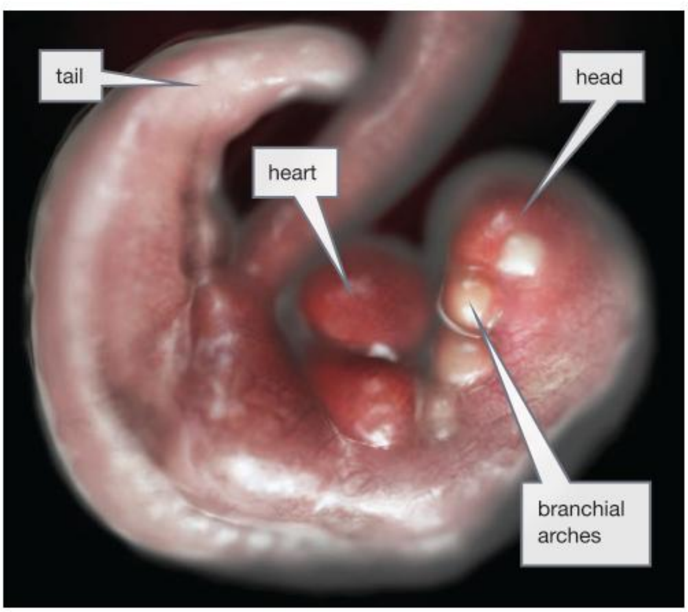


Figure 3.3.7 Human embryo at 4 weeks, showing the branchial arches typical of vertebrate embryos

In humans, the parathyroid glands (endocrine glands in your neck) develop from the branchial arches. Two of the arches grow into the bones in your middle ear. In reptiles, their lower jaws grow from one of the arches. In fish, a gene called Gcm-2 controls the development of the branchial arches into gills. If the gene mutates (or if scientists prevent it working) in embryonic development, the gills fail to develop. In chick embryos, the Gcm-2 gene turns two of the arches into the parathyroid gland. If scientists prevent the gene from working, the parathyroid gland fails to develop. So vertebrate embryos have structures that appear to be homologous on the basis of anatomy, and studying genes shows the same gene has produced different effects in two different species. Somehow the Gcm-2 gene has changed in its effect on the branchial arches from one species to another.

So the development of mammals, reptiles, birds and fish are linked to the branchial arteries. Biologists long ago proposed that fish evolved into amphibians, which evolved into reptiles, which evolved into birds. Evidence from studying embryos including branchial arches supports this idea.

The evidence in brief

In summary, the evidence for evolution is:

- fossils—there is increasing complexity in species, changes over geological time in a lineage and transitional forms
- comparative anatomy—homologous structures can be identified at many different levels of classification, such as the limb bones in classes of vertebrates
- DNA—species that have similar anatomy have been shown to have many common genes
- protein structure—closely related species have more similarities in amino acid sequences in particular proteins
- distribution of species—isolated islands have unusually high proportions of unique species; continents now separated by oceans and containing identical fossil species were once connected in the past
- embryology—embryos with similar anatomy share some of the same genes for development of the embryo. These same genes can exert different effects in different species.

SCIENCE AS A HUMAN ENDEAVOUR

Nature and development of science

DNA profiling and evolution

Figure 3.3.8 Part of an autoradiogram

The genome of a species is the entire genetic information of that species. It is only in the last decade or so that scientists have been able to determine the genome of a species.

Genomics is the study of the genome structure and function. Comparing the genomes of different species has given biologists a better understanding of evolution and the classification of organisms.

Genomics uses many techniques, one of which is DNA profiling, also known as DNA fingerprinting. The process of DNA fingerprinting is very complex, but a simplified version is shown in Figure 3.3.9.

In evolutionary studies, DNA profiling enables scientists to obtain a DNA fingerprint showing fragments of DNA that have been cut at the same place. Then the DNA fingerprints of different species are compared. From the results, common sequences of DNA including genes can be isolated and compared and evolutionary relationships between species can be tested. These evolutionary studies are in their early stages, but genomics has already shown the following.

- Different species possess similar genes associated with the same traits.
- Similar species must be closely related to each other because they share many similar genes.
- Genes are not the whole story in inheritance; other factors such as gene regulators (DNA sections that control genes) are also important and these affect evolution.
- Distantly related species often share stretches of DNA that do not appear to code for any protein. The function of these DNA sections is currently being studied.
- DNA is not the only evidence that is needed to decide evolutionary relationships; studies of anatomy, behaviour and development are also helpful.

1 The process begins with a blood or cell sample from which the DNA is extracted.

2 The DNA is cut into fragments using a restriction enzyme. The fragments are then separated into bands using a technique called electrophoresis.

3 The DNA band pattern is transferred to a nylon membrane.

4 A radioactive DNA probe is introduced. The DNA probe binds to specific DNA sequences on the nylon membrane.

5 The excess probe material is washed away, leaving the unique DNA band pattern.

6 The radioactive DNA pattern is transferred to X-ray film. When developed, the resultant visible pattern is the DNA fingerprint known as an autoradiogram (Figure 3.3.8).

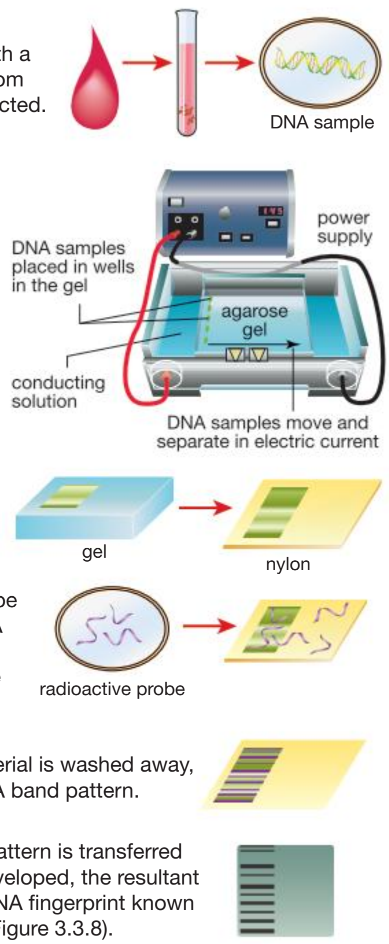


Figure 3.3.9 The steps involved in DNA fingerprinting

3.3 Unit review

Remembering

1 **Name** the term now used for the process that Charles Darwin called 'modification by descent'.

2 **List** three ways of determining if two organisms are the same species.

3 **List** the three main steps in the process of speciation.

4 **List** four reasons why two very similar animals might not be able to mate.

5 **Specify** homologous structures in fish and bird embryos that have been shown to be affected by the gene called Gcm-2.

Understanding

6 **Explain** three methods used to determine if two organisms are in the same species or not.

7 **Explain** what is meant by genetic isolation.

8 It has long been known that horses and donkeys are different species. **Explain** the evidence that shows this.

9 **Discuss** how fossils support the theory of evolution.

10 **Explain** why a barrier is necessary before speciation can occur.

11 **Explain** how the Gcm-2 gene observed in fish and bird embryos supports the theory that birds are related to fish.

Applying

12 **Use** the model of speciation to **explain** why isolated islands often have a high proportion of species not found elsewhere, even on neighbouring islands.

13 Some early lobe-finned fish are difficult to classify into fish or amphibians, because they have features of both. **Demonstrate** how such difficulties support the theory of evolution,

14 **Use** the concept of speciation to **demonstrate** how biodiversity developed on Earth.

Analysing

15 **Distinguish** between:

- **a** evolution and natural selection
- **b** speciation and natural selection
- **c** evolution and speciation.

Evaluating

16 There is no difference in the sequence of amino acids on the cytochrome c molecules of humans and apes. However, monkeys and humans have one difference, while humans and kangaroos have ten differences.

- **a** Based on this, **identify** the more recent common ancestor of humans: apes, monkeys or kangaroos.
- **b** **Justify** your answer.

17 Scientists studying vertebrates in the 1800s and 1900s proposed that they had a common fish ancestor. They proposed that lobe-finned fish evolved into amphibians, which evolved into reptiles, while mammals and birds both evolved from separate branches of the reptiles. Refer to Table 3.3.1 on page 88 and **evaluate** whether this more recent evidence supports the proposal of the early biologists.

Creating

18 **Construct** a series of steps by which two different species of mice could develop from one species after the formation of a deep canyon.

19 **Construct** a diagram showing a series of steps by which two different species of frogs could develop after the formation of the desert of the Nullarbor Plain. Both species came from one species that was originally spread from Western Australia to Victoria (Figure 3.3.10).

Figure 3.3.10 The Nullarbor Plain separating the original distribution of a frog species (in blue) into two groups.

Inquiring

1 Research the story of the giant Galapagos tortoise and what it tells us about evolution.

2 Research how flowering plants evolved at a time when Gondwana was breaking up and how this affected which plant families ended up in different countries.

3 Research the FOXP2 gene in mammals (including early humans) and what it can tell scientists about evolutionary relationships.

3.3 Practical activities

1 Family relationships

Purpose

To compare the structure of flowers from different genera in the family Myrtaceae.

Materials

- specimens from genera in the family key shown right
- hand lens or stereomicroscope
- Stanley trimmer for cutting through fruits
- forceps
- Petri dish
- books with illustrations or photos of members of the Myrtaceae family
- access to the internet

SAFETY

Be careful handling blades.

Wash your hands after handling plant material.

Procedure

1. Your task is to use the key shown right to identify the name of the genus to which each of the plants belongs. This will involve cutting into some flowers and fruits. Your teacher will show you how to do this, or will display cut sections for you to observe. You will be using the hand lens or microscope to observe flower parts. You will need to know the names of the parts of a flower to do this activity.
2. Collect one specimen from the selection at the front of the room. Note down its number. You must write down each of the choices you make for the specimen as you proceed through the key. Finally, write down the name of the genus for the sample.
3. Use the books or internet to see if your specimen looks like the images shown for that genus. If you appear to be incorrect, go back over your choices to see if you made an error.
4. Repeat steps 2 and 3 for as many other specimens as you can in the time you have.

Discussion

1. **Explain** what is meant by a family, genus and species.
2. **Propose** some characteristics of flower structure that members of this family share.
3. **Assess** whether any of these genera seem to have more in common with some genera than with others.
4. **Explain** why classifying a plant into this family on the basis of its flower structure also suggests that it is related to the other members of this group through inheritance.
5. **Explain** why the genera in this family would have some genes the same.

Key to some genera in family Myrtaceae

1a	Ovary with between 3 and 10 sections.	Go to 2.
1b	Ovary with 1 section.	Go to 8.
2a	Stamens separate.	Go to 3.
2b	Stamens in 3–5 bundles, joined for part of length of stamen.	Go to 7.
3a	Flowers with no stalk. Stamens no longer than petals.	Go to 4.
3b	Stamens longer than petals, in two rows.	Go to 5.
3c	Stamens longer than petals, in single row.	*Kunzea*
4a	Leaves in pairs and opposite each other.	*Baeckea*
4b	Leaves alternating.	*Leptospermum*
5a	Flowers with no stalk, in a cylindrical column. Fruit woody. Shrubs.	*Callistemon*
5b	Trees with flowers at ends of branches and each with a stalk.	Go to 6.
6a	Flower with petals. Trees.	*Angophora*
6b	Flower bud covered by a cap which falls off when flower opens. Trees.	*Eucalyptus*
7a	Flowers with no stalk and in cylindrical heads or ball shaped heads. Stamens in five bundles joined at the base for less than ¼ length of the stamen.	*Melaleuca*
7b	Flowers with stalks growing from leaf base. Trees.	*Tristania*
7c	Stamens joined over ¾ length. 3–4 stamens per bundle. Small shrubs.	*Beaufortia*
8a	Flowers waxy and in open groups of 2–4 each with stalks at tip of branches. Shrubs less than 2 m.	*Chamelaucium*
8b	Flowers in terminal heads often covered by petal-like coloured bracts.	*Darwinia*

3.4 Human evolution

The name of our species, *Homo sapiens*, means 'wise man'. According to the fossils so far discovered, we have been around for about 200 000 years. Fossils indicate that other species of human-like animals have existed too. Biologists and palaeontologists have a good idea about how humans came to be here, but more fossil evidence is needed to trace our origins.

Primates

Humans are classified into the class Mammalia, order Primates, family Hominidae, genus ***Homo***. **Primates** include the lemurs, tarsiers, monkeys, apes, gibbons and humans. There is no one specific feature that puts an animal into this order. However, most of them have 'grasping' hands, nails rather than claws and forward-facing eyes. You can see a typical primate in Figure 3.4.1.

Figure 3.4.1

A lemur shows the typical primate features of forward-facing eyes, nails and grasping hands.

INQUIRY science 4 fun

Mammals

Yes

Do this …

1. If you have a cat or dog at home, carefully observe its face and describe where its eyes are.
2. Observe the paws and describe where the toes are and what is on the toes.
3. Compare these with your own features.

Record this …

Describe what you observed.

Explain why these features might be similar or different.

The living animals most like humans are gorillas and chimpanzees, which live only in Africa. On the basis of our similar anatomy, Charles Darwin predicted that the best place to find fossils of human origins would be in Africa, because the ancestors of apes and humans should be found there. Darwin's prediction was supported when many fossils were found in Africa that were classified into the family Hominidae.

SciFile

Dud genes

Not all genes you inherit actually function. For example, all humans inherit the GULOP gene, which would allow us to make vitamin C if it functioned. But it is defective and has many mutations within it. Some distant cousins of humans, the more 'primitive' primates such as lorises, galagos and pottos, still have a working GULOP gene. No higher primates have a GULOP gene that works.

Humans and apes

Our species is classified into the family **Hominidae**, along with chimpanzees and gorillas. However, humans and these two apes have differences mainly in the way they stand and walk. Humans are placed in a level of classification called a sub-tribe.

The key features that place a species in the human sub-tribe involve walking upright on two legs. These features are in the skull, vertebral column, pelvis, femur, knees and feet. There are other characteristic features as well, such as the shape of the jaw and the hand structure. Figure 3.4.2 shows these comparisons.

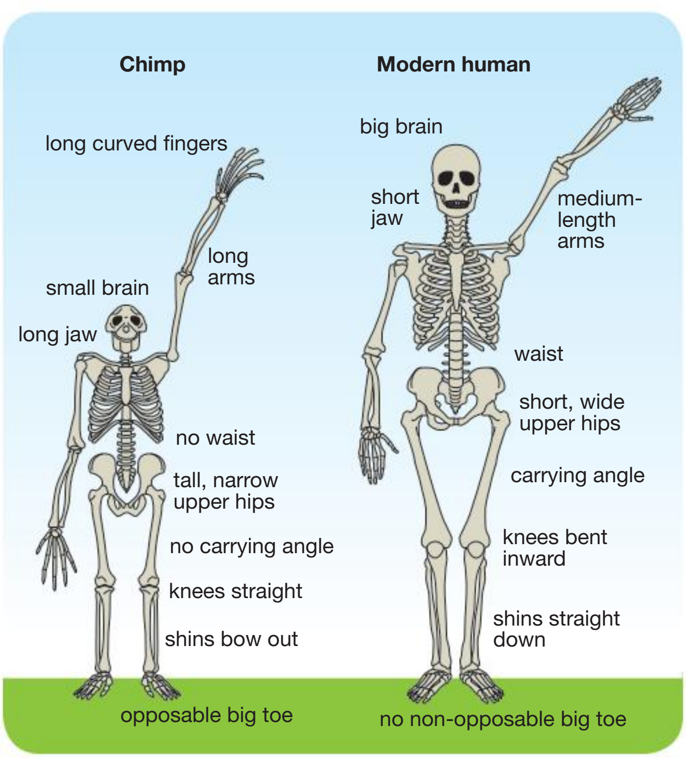


Figure 3.4.2 Some of the distinguishing features of humans and apes

3.6 1 p98 2 p99

Australopithecines

One early group that most anthropologists are fairly sure is ancestral to our genus *Homo* is the genus ***Australopithecus***. This group contains at least six species, who are often referred to as 'ape-men'. Species belonging to *Australopithecines* lived in Africa about 3.7 million to 1.8 million years ago. Among them is probably the group that were ancestors to our genus ***Homo***, but more fossils are needed of early *Homo* to better identify this link. The most likely candidate for the ancestor of the genus *Homo* is *Australopithecus afarensis* (see Figure 3.4.3).

Figure 3.4.3 *Australopithecus afarensis* is the earliest known likely ancestor of humans. The fossilised footprints shown here are about 3.7 million years old.

Australopithecus afarensis lived in East Africa between about 3.7 million and 2.5 million years ago. They were about 1.3 metres tall and weighed about 30 kg. Their brain, at 410 cm^3, was about the size of a chimpanzee's, but they had a much smaller body weight. *Australopithecus afarensis* walked upright on two legs as shown by the shape of their pelvis and the carrying angle of the femurs. The carrying angle is the inward slope of each femur towards the knee. A carrying angle means that the knees are closer together than the hips, making upright walking more efficient. This upright walking on two legs placed them on the path towards being human. At present, scientists are searching for more fossils of species that existed around this time to help decide which *Australopithecus*, if any, may have given rise to genus *Homo*.

Early genus *Homo*

The earliest known member of our genus *Homo* dates from about 2.4 million to 1.4 million years ago. This is a species called *Homo habilis* (Figure 3.4.4). A comparison of *Homo habilis* with *Homo ergaster* and modern *Homo sapiens* suggests that *Homo ergaster* is a much more likely candidate as an ancestor of our species than *Homo habilis*. If both these species lived at the same time, they cannot both be ancestral to our species.

Figure 3.4.4 *Homo habilis* may be ancestral to our species, but more fossils are needed to test this view.

A skull labelled KNM 1470 and given the name *Homo rudolfensis* is a possible candidate to have been on the line from Australopithecines to humans. However, there is only one skull and no other bones. This makes classification of it difficult.

By about 1.9 million years ago, a new species of human had evolved in Africa. It has been called *Homo ergaster* (also known as *Homo erectus*). An example of this species is the amazing specimen labelled KNM WT 15 000, and referred to as the Turkana Boy (Figure 3.4.5). This specimen is about 1.5 million years old. Turkana Boy was about 9–12 years of age when he died. He was 1.6 metres tall and may have reached 1.85 metres as an adult. Almost 90% of his skeleton was recovered. The Turkana Boy had a tall, slender body adapted for walking long distances. He had a more human-like face than *Homo habilis*, with a nose that projected outwards and a larger space for the brain at 880 cm^3. His brain would have probably reached around 910 cm^3 when he reached adulthood.

Figure 3.4.5 *Homo ergaster* migrated out of Africa around 1.9 million years ago. This is the Turkana Boy fossil. Most scientists call the fossils of this species found outside Africa *Homo erectus*.

Another fossil group that may be part of the line to modern humans is *Homo heidelbergensis* (Figure 3.4.6). This group may have evolved from *Homo ergaster* and also migrated out of Africa into Europe. There it seems to have evolved into *Homo neanderthalensis*. *Homo heidelbergensis* may have evolved in Africa into *Homo sapiens*. *Homo sapiens* migrated out of Africa and around the whole Earth, replacing all other forms of *Homo* that existed elsewhere, such as *Homo neanderthalensis*.

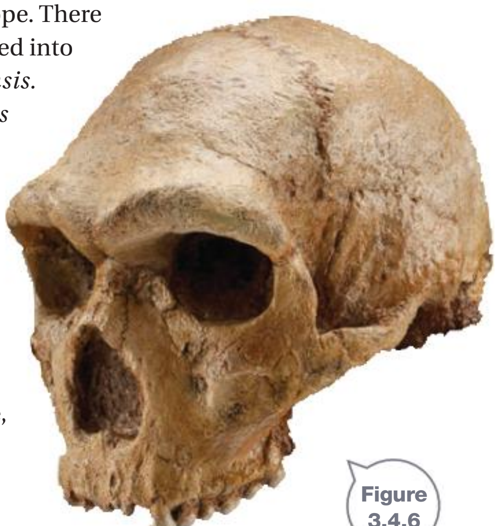


Figure 3.4.6 *Homo heidelbergensis*. European populations of this early human species were the ancestors of the Neanderthals. African populations probably gave rise to our own species.

Out of Africa

At the present time, the most widely accepted view among scientists of the origins of our species is the Recent African Origin model. This is also known as the **Out of Africa model**. This model proposes that a common ancestor of all modern humans evolved in East Africa between 200 000 and 100 000 years ago. Around 60 000 years ago, a small subgroup left Africa and ended up colonising the whole Earth. By about 15 000 years ago, all the continental landmasses (apart from Antarctica) were colonised by our species.

The Out of Africa model is supported by evidence from mitochondrial DNA testing and Y chromosome testing of modern humans. **Mitochondrial DNA (mtDNA)** is DNA contained within the cell mitochondria. This mtDNA is only passed from a mother to her children. As Figure 3.4.7 shows, mitochondria separate into each gamete (sex cell) during meiosis (division of the nuclear DNA) in the ovary. This mtDNA is not shuffled around between cells like the chromosomes are. The only changes that occur in mtDNA are mutations. These mutations are used to track the migration routes of our ancestors. Using mtDNA analysis and Y chromosome analysis, scientists have concluded that all human beings can trace their ancestry back to a small group who lived in Africa less than about 60 000 years ago (Figure 3.4.8).

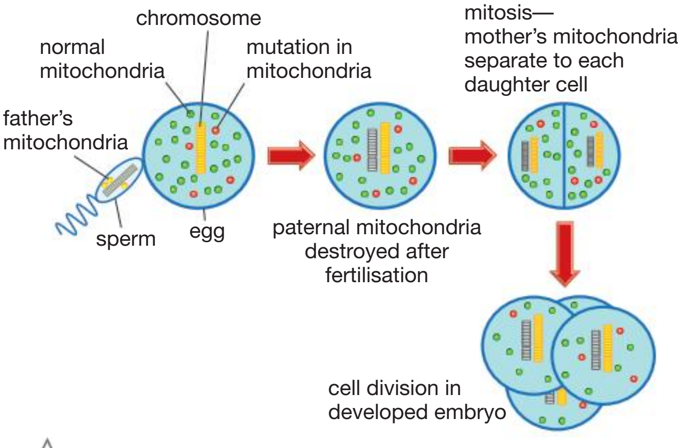


Figure 3.4.7 Mitochondrial DNA stays in the cytoplasm and generally does not affect the genes in the nucleus. The mtDNA is copied to each egg and to each cell when it divides in mitosis.

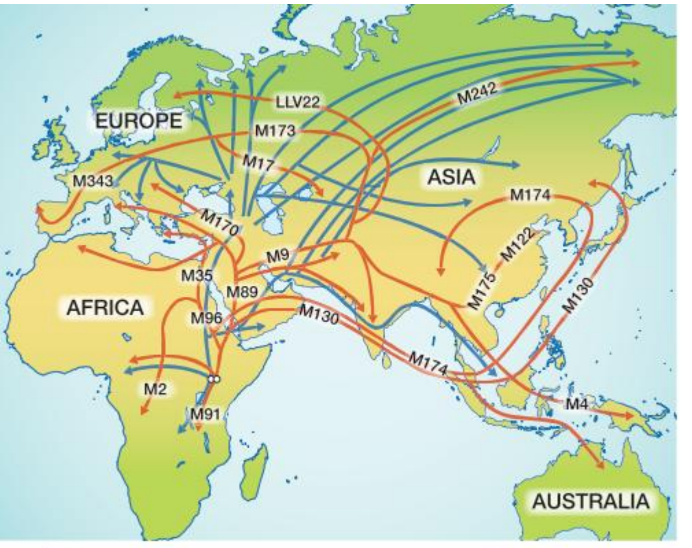


Figure 3.4.8 Migration routes out of Africa using Y chromosome analysis (red lines) and mtDNA analysis (blue lines) traced in the Genographic Project. The letters M and the numbers represent mutant genes. For example, M91 occurred about 60 000 years ago in Africa.

Neanderthal DNA

Mitochondrial DNA extracted from Neanderthal bones show that they were quite different from *Homo sapiens*, but more like us than chimpanzees. The scientists concluded that *Homo sapiens* and *Homo neanderthalensis* became separate species approximately 400 000 years ago. Recent studies of ancient nuclear DNA from a Neanderthal bone suggest that there was some interbreeding with *Homo sapiens*.

SciFile

Signs in the skulls

When the skulls of all the different likely members of the human family are compared, there appear to be some striking changes that have occurred during their evolution. Figure 3.4.9 shows some of these changes clearly.

The apparent changes are as follows:

- The face becomes 'flatter', meaning more vertical.
- The lower jaw shortens and does not project out as much.
- A chin develops.
- The forehead becomes more vertical.
- The cranium (brain space) enlarges and becomes more rounded.
- The cranial capacity (brain size) increases.

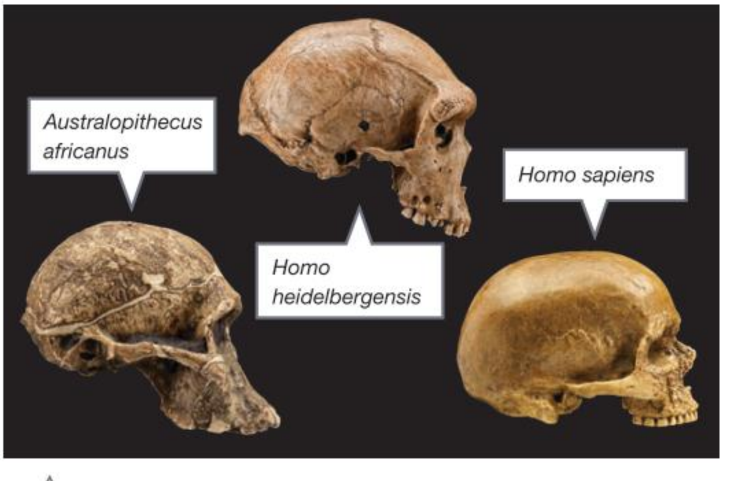


Figure 3.4.9 A range of important fossil skulls in the human family

3.4 Unit review

Remembering

1 **List** terms used to classify modern humans from class to species.

2 **Name** ten primates other than humans.

3 **List** the characteristics of primates.

4 **Name** three species in the family Hominidae.

5 **Name** the two living species most closely related to humans.

Understanding

6 **Describe** the *Australopithecines*.

7 **Outline** the Out of Africa model.

8 **Explain** how mitochondrial DNA (mtDNA) is passed on.

Applying

9 **Identify** the person from whom you received your mtDNA.

10 In 2003, Australian scientists discovered fossils of nine individuals of a tiny species of human on the island of Flores in Indonesia. They classified it as a new species, *Homo floresiensis*. It had a brain volume about one-third the size of that of modern humans, and a height of about 109 cm. **Apply** the Out of Africa hypothesis to **discuss** the possible origins of this species.

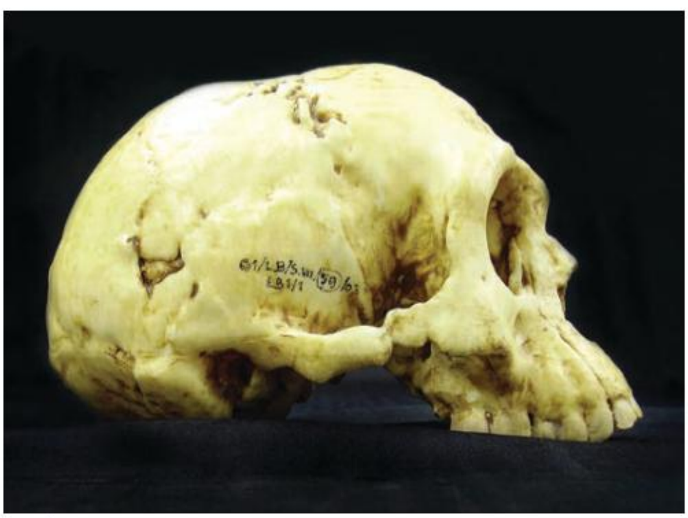


Figure 3.4.10 *Homo floresiensis*

Analysing

11 **Compare** *Homo ergaster* with *Homo sapiens*.

12 **Contrast** the origins of your nuclear DNA and mtDNA.

Evaluating

13 **Justify** why at this time biologists should not make too many judgements about where *Homo rudolfensis* stands in the story of human evolution.

14 **Justify** the Out of Africa model.

15 In 2001, some fascinating fossils were found in Georgia, between the Black Sea and the Caspian Sea. These fossils were classified as a new species named *Homo georgicus*. The almost-complete skull had a cranial capacity of about 600 cm^3, and the body height was about 1.3 metres. The fossils were dated to 1.77 million years ago.

a **Propose** a possible origin for this species

b **Justify** your decision.

Figure 3.4.11 *Homo georgicus*

16 **Deduce** whether upright stance or increased brain size was the first feature that evolved in the lineage (line of descent) that led from apes to humans.

Creating

17 **Construct** an argument that could explain how *Homo habilis* evolved from *Australopithecus afarensis*.

Inquiring

1 Research the species commonly called Neanderthal man, discussing their characteristics and possible origins.

2 Research the mtDNA or Y chromosome evidence for the migration of humans out of Africa, including National Geographic's Genographic Project where you can trace your own ancestral journey out of Africa.

3 Research the DNA analysis of ancient Neanderthal bones and what this tells us about our relationship to *Homo neanderthalensis*.

4 Research the stone tools of the Oldowan, Acheulian, Mousterian and Magdalenian cultures and compare these with Australian Aboriginal stone tools.

3.4 Practical activities

1 Hand adaptations

Purpose

To identify some adaptations of the human hand.

Materials

- human skeleton
- hand X-rays
- ruler
- pencil

Procedure

1. Hold your left hand out in front of you palm face down and fingers spread out. Observe the position of the thumb compared with the fingers. Write a description of the differences.
2. Turn your left hand palm upwards. Touch each of the four fingertips on this hand with your left thumb. Observe carefully how the thumb can move. Describe how your thumb moves across the palm.
3. Grasp a ruler with your left hand the way you would hold a hammer. This is called the power grip. Describe how the thumb assists in holding the ruler.
4. Hold a pencil for writing. This is called the precision grip. Describe the difference in the position of the thumb and fingers in this grip compared with the power grip.
5. The trapezium bone enables you to move your thumb to touch your little finger. Hold your left hand palm upwards, with fingers together and thumb out to the side. Move your thumb across to touch your little finger. Describe which way the thumbnail points before and after moving your thumb.

Discussion

1. **Propose** the reasons for the names *power grip* and *precision grip*.
2. Look at Figure 3.4.12. Use it to locate the position of the trapezium on your own hand. Show your partner where you think this bone is.

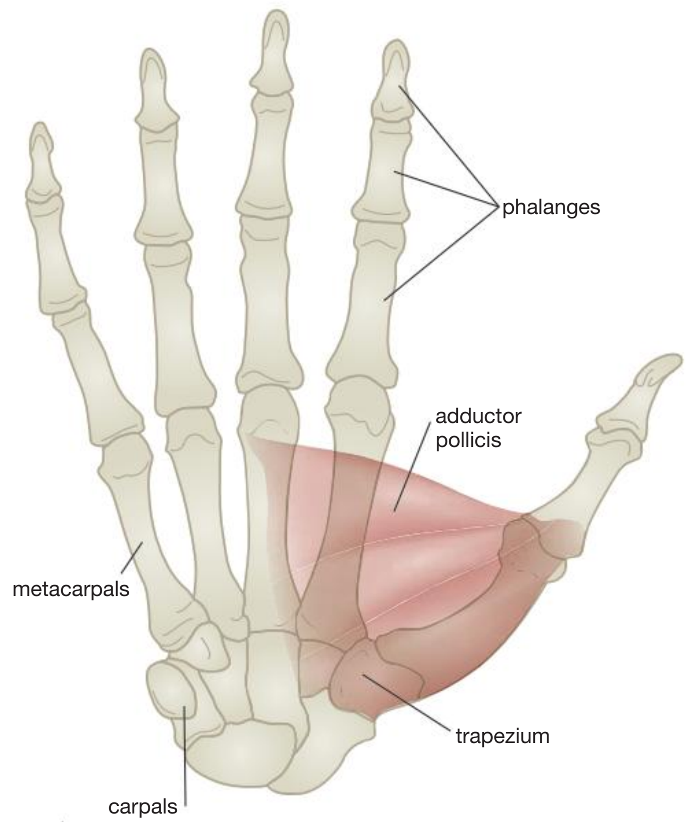


Figure 3.4.12 Bones of the human hand and thumb muscles

3. Using Figure 3.4.12, **identify** the muscles involved in moving the thumb, and what role each has in moving the thumb.
4. **Discuss** the adaptations of the human hand for object manipulation.
5. **Propose** how the human hand may have evolved from the hand of an ape ancestor.

2 Foot adaptations

Purpose

To compare the human hand and foot structure as adaptations of homologous structures.

Materials

- human skeleton
- X-rays of hands and feet
- ruler
- pencil

Procedure

1. Remove your shoe and sock from your left foot. Describe the position of the big toe and other toes.
2. Observe the instep of your foot (or someone else's foot). Describe the shape of the foot from the heel to the toes.
3. Observe a skeleton and X-rays of the foot. Describe how it looks from the side.
4. Observe the heel and the toes of the skeleton and X-rays. Compare the size of the toes and describe the heel.

Discussion

1. **Compare** the position of the thumb with that of the big toe.
2. Using Figure 3.4.13, **propose** how the heel, first metatarsal and big toe could be considered adaptations of the foot for walking.
3. **Discuss** how the same homologous structure could evolve into a hand and a foot.

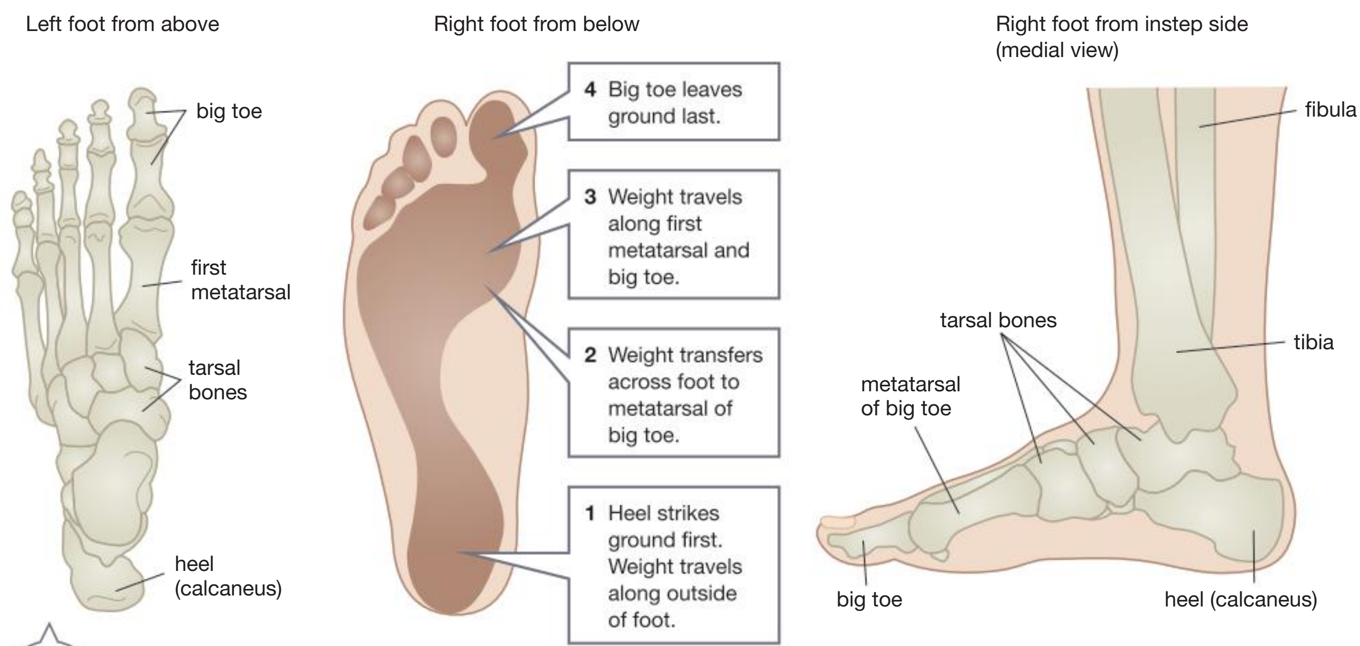


Figure 3.4.13

3 Chapter review

Remembering

1 **Name** the first person to propose the process of natural selection.

2 **List** the steps involved in speciation.

3 **List** the evidence that supports the theory of evolution.

Understanding

4 **Modify** the following statements to make them correct.
  - a Homologous structures have to perform the same function in different species.
  - b Any differences in the position of amino acids in a protein show that species are not related.
  - c Organisms that look similar must have the same genes causing the similarity.
  - d All variation in a species is caused by natural selection.
  - e Natural selection acts on the genes in an organism.

5 **Explain** how fossils support the theory of evolution.

6 Natural selection has been demonstrated in organisms in recent times.
  - a **List** two organisms in which these changes have been obvious.
  - b **Explain** how natural selection caused the change.

7 **Explain** how domesticated animals and plants were altered through artificial (directed) selection.

8 **Explain** the important role of genetic isolation in evolution.

9 **Discuss** some evidence supporting the Out of Africa model.

Applying

10 **Demonstrate** how an adaptive feature, such as coat colour in mice, can change when the 'selection pressure' (natural selection) changes.

11 **Use** the fossil record of birds and dinosaurs to **demonstrate** that transitional forms occur between levels of classification.

12 Humans, lemurs, monkeys, gorillas, chimpanzees and tarsiers are classified into one group. **Identify** three structural features they all share that place them in this group.

Figure 3.5.1 Gorillas, lemurs and chimpanzees are primates.

Analysing

13 **Compare** changes in the vertebrate pentadactyl limb over geological time.

14 **Compare** the importance of variation in both artificial selection and natural selection.

15 **Contrast** homologous and analogous structures.

16 The flying possums of Australia are able to glide from tree to tree because of a thin webbing of skin between their front and back legs that catches the air like a parachute. Despite being very different animals, there are some flying lemurs and squirrels elsewhere in the world that have similar webbing. They too glide from tree to tree. **Classify** the webbing as a homologous or analogous structure.

Evaluating

17 **Propose** a reason why natural selection is more likely to be visible in organisms such as bacteria and insects than in kangaroos and humans.

18 **Justify** the conclusion that species with the same basic structure are related.

19 *Australopithecus* and *Homo* are both classified into the same sub-tribe. **Propose** what features placed *Australopithecus* in the same sub-tribe as us.

20 There is much more variation in domesticated species such as budgerigars than in the wild species. **Propose** why there is less variation in the wild.

Creating

21 **Construct** a story explaining how natural selection resulted in human beings becoming more intelligent over our geological history.

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

natural selection
selective agent
evolution
homologous
speciation
fossils
DNA
primates
comparative anatomy
embryology

3.7

Thinking scientifically

Questions 1 and 2 refer to the following information.

A biologist was studying a population of mice that lived in an area with few trees and scattered low shrubs separated from each other by large areas of bare soil. He found that the mice had two genes that controlled their coat colour. One tended to give the coat a dark-brown colour, while the other produced a lighter yellowish brown colour.

The area contained three different soil types: dark red clay, pale yellow sand and light grey sand. Studies of the proportion of mice with the different coat colour were done and are shown in the table. The area was a very dry semi-desert climate. The mice were preyed upon by hawks that hunted mainly in the morning and late afternoon.

Site	Soil colour	Per cent of mice with brown coat	Per cent of mice with yellowish coat
1	Red	82.0	18.0
2	Light grey	52.0	48.0
3	Pale yellow	41.0	59.0

Q1 Which of the following is a fair interpretation of the data?

A There are more brown-coated mice than yellow-coated mice in the population.

B Brown coats are more suited to red clay than they are to light-grey sand.

C Yellowish coats are more suited to the light-grey sand.

D Brown-coated mice are moving from pale-yellow sand and light-grey sand to the red clay.

Q2 Considering the information in the table, which of the following conclusions is likely?

A Hawks always prefer to eat mice with a yellowish coat colour.

B The climate is selecting for lighter coloured mice because they will absorb less heat.

C The coat colour provides the mice with camouflage protection from the hawks.

D Lighter colour soil selects for the yellowish coat colour.

Q3 Domestic dogs were originally bred from ancestors of the wolf. There are now hundreds of different dog breeds with characteristics varying from tiny chihuahuas to the massive Irish wolfhounds. Natural selection acts to allow survival of offspring most suited to their environment. The environment of the wolf is forests of the Northern Hemisphere. The environment of domestic dogs is the homes of people around the world, where they are cared for and fed by their owners.

Consider the following suggestions. Which most likely explains why there are many different breeds of domestic dog and only one species of wolf, which is fairly alike over the whole Northern Hemisphere?

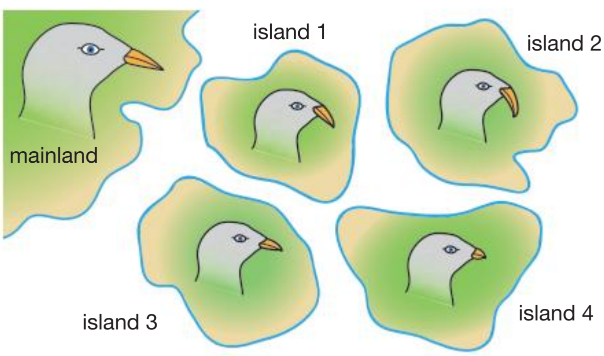
A Not all variations would be suited for survival in the wolf's environment.

B Wolves are artificially selected.

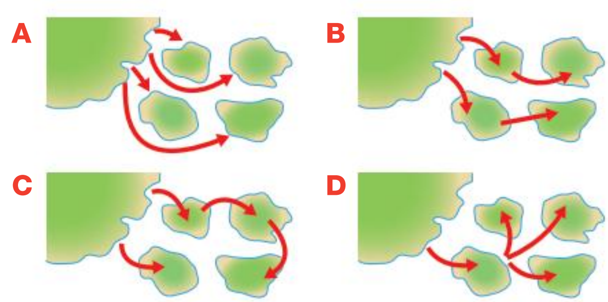
C Domestic dogs are not being selected by the environment.

D Natural selection acting on the wolf made it evolve into many different types of dog.

Q4 Consider the following diagram.



Which of the following is the most likely evolutionary pathway to form the four species of birds on the islands?



Q5 Bacteria divide asexually approximately once every 20 minutes in ideal conditions. Fruit flies reproduce sexually in a life cycle of about 11 days. Why might an experimenter choose bacteria rather than fruit flies in an experiment on natural selection?

A Asexual reproduction cannot produce any genetic change so bacteria are useful as a control in experiments

B Variation, isolation and selection can not occur in bacteria so there will be no speciation

C There will not be any variation in the bacteria for natural selection to act on

D A short generation time means any evolution in the species should occur faster

Glossary

Unit 3.1

Analogous: structures that appear similar or have the same function but are controlled by different genes

Artificial selection: the process by which people choose to breed particular organisms with desirable features; also known as selective breeding or directed selection

Artificial selection

Cross-breeding: selective breeding by combining a desirable feature of one individual with another in the offspring

Evolution: change in the characteristics of a species over many generations

Generation: the time between the birth of an individual and when they produce their own offspring

Homologous: structures that are controlled by some of the same inherited genes

Inbreeding: selective breeding in which closely related individuals are allowed to breed

Unit 3.2

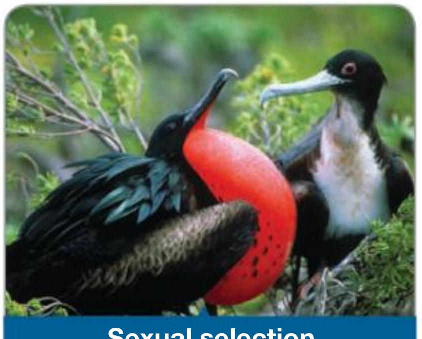
Antibiotics: chemicals made by organisms such as fungi to defend them against bacteria

Natural selection: the process where an environmental factor acts on a population and results in some organisms having more offspring than others

Resistance: inherited ability of a species to withstand chemicals such as pesticides

Selective agent: the environmental factor that acts on the population during natural selection

Sexual selection: a special case of natural selection where the environmental factor is the selection of a mate



Sexual selection

Variation: differences in characteristics due to different genes

Unit 3.3

Biodiversity: the number and range of different species that exist on Earth or in an ecosystem

Distribution: a map of all the places where a species occurs

Embryology: the study of the embryos of different species

Embryology

Isolation: keeping interbreeding groups apart by some barrier or mechanism

Species: group of organisms that can interbreed to produce fertile offspring under natural conditions

Speciation: the process by which one species splits into two or more separate species

Transitional form: fossils that have features of two or more different groups

Unit 3.4

***Australopithecus*:** a genus in the family Hominidae that is probably ancestral to our genus *Homo*

Australopithecus

Hominidae: the family to which humans and the extinct genus *Australopithecus* belong

***Homo*:** the genus to which human beings, and several other extinct species, belong

Mitochondrial DNA (mtDNA): DNA contained within the cell mitochondria and passed from mother to sons and daughters

Out of Africa model: model (hypothesis) proposing a common ancestor of all modern humans evolved in Africa and then migrated out to colonise the whole Earth

Primates: order of animals with 'grasping' hands, nails rather than claws and forward-facing eyes

SCIENCE TAKES YOU PLACES

Look who is using science

AGRONOMIST

My name is Dugald Spenceley. I studied agricultural science and am now a business manager with Syngenta Crop Protection in Australia. The focus of our business is agronomy—the study of crop production.

I work with the company's sales and marketing teams and help to develop the strategies we use to sell our products. This requires me to have a good understanding of what is happening in the market and the suitability of our products for a variety of crops under different growing conditions.

Studying agricultural science has enabled me to work in different fields, such as land management, agronomy, marketing and business management. My science background has helped me to understand the relationships that exist in the farming environment and how my company can best use our products to increase crop production. Crop production is becoming more and more important to ensure that we are able to feed an ever-growing global population.

TECHNICAL OFFICER

I am Helen Gore and I work as a palaeontology technical officer in the Department of Earth and Planetary Sciences at a state museum.

Every day my work brings a new challenge. For example, I often prepare fossils for research. Some days I'll be picking tiny ancient sharks' teeth from sedimentary rock deposits so that the species can be identified and the geological age of the rock determined. Other days, I'll be stabilising (repairing) an extremely fragile fossil.

I also act as a curator (manager) of the museum's fossil collection, which now has more than a million specimens. The collection gives us great insight into the Earth's evolutionary history over the last 3000 million years. We often lend fossil material to scientists throughout the world for research. An important part of the work is preparing fossils for safe transport, and tracking loans to ensure they are returned to the collection.

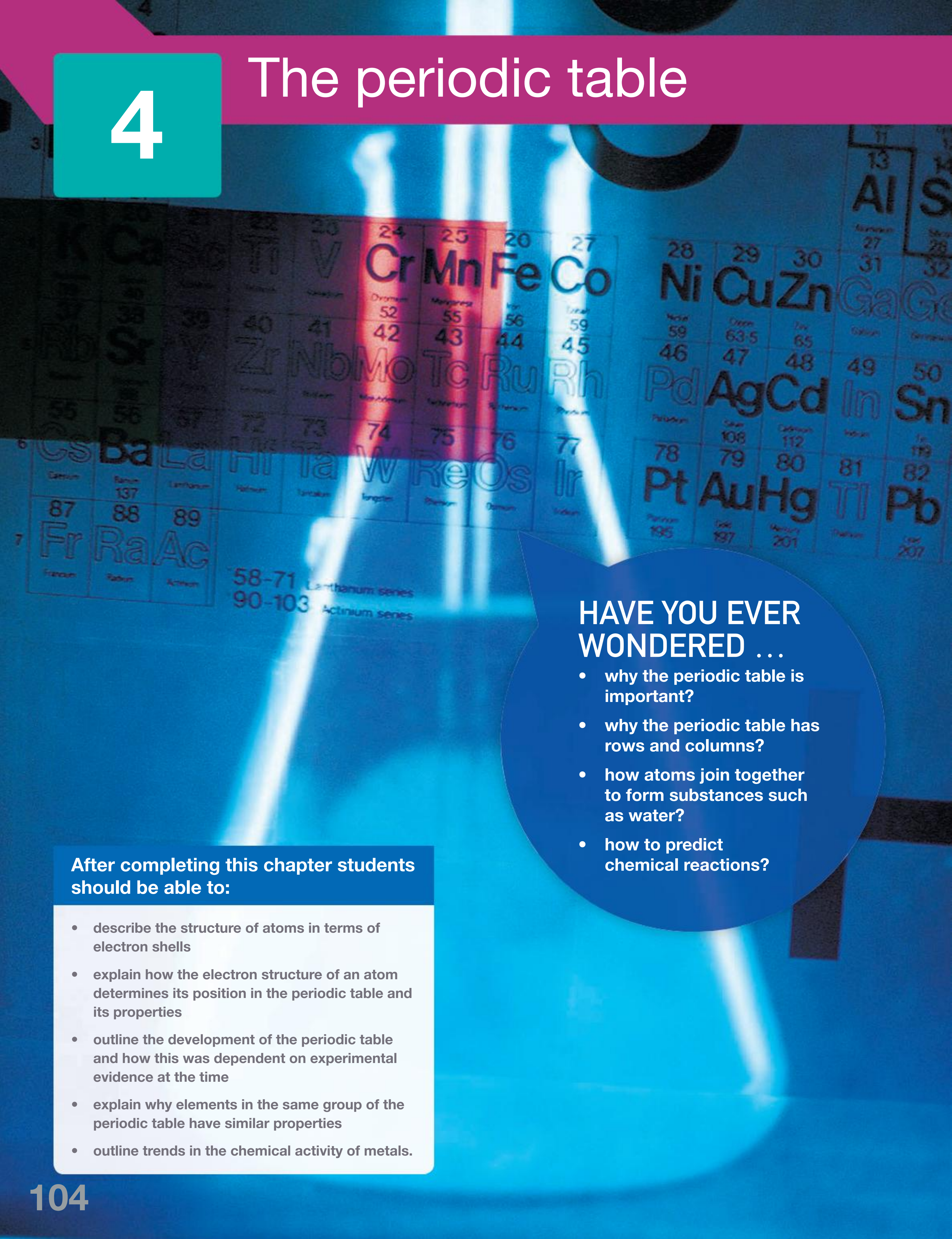
No two days at the museum are the same, and it's particularly exciting when a new fossil species, previously unknown to science, is discovered.

PLANT BREEDER

I am Dr Warwick Stiller, a plant breeder with CSIRO Plant Industry. My work involves developing new varieties of cotton that have higher yields, better disease resistance and higher fibre quality and use less water.

I use conventional breeding methods as well as genetically modified technologies. Some of the more interesting work is identifying useful traits in some of Australia's native cotton species and other wild species that could be transferred into the cotton varieties that we grow.

Being a plant breeder means that I get to make a real impact on farmers' livelihood and the prosperity of rural Australia, as well as enjoying a diverse range of tasks from out in the field to the laboratory.



4 The periodic table

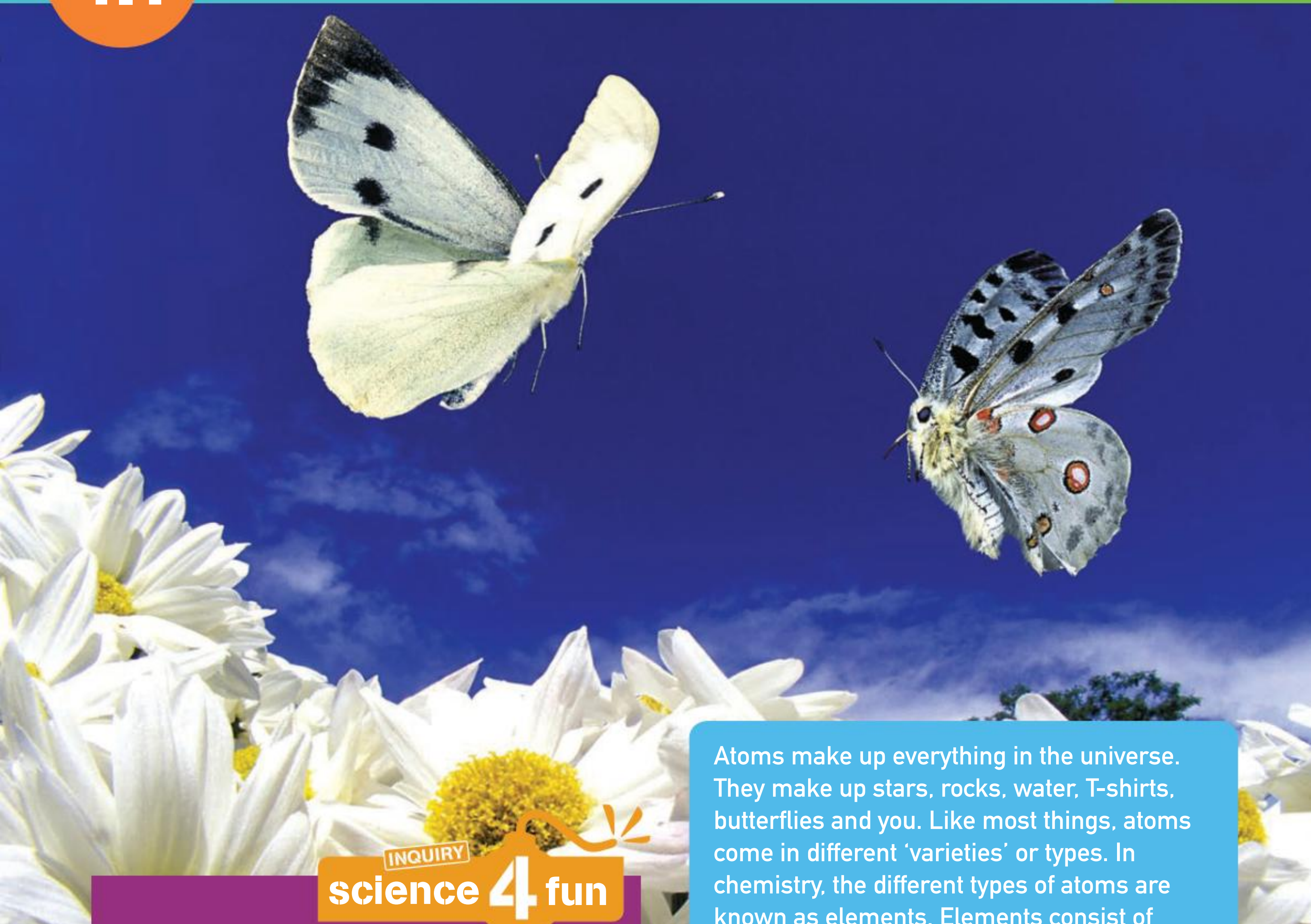
HAVE YOU EVER WONDERED ...

- why the periodic table is important?
- why the periodic table has rows and columns?
- how atoms join together to form substances such as water?
- how to predict chemical reactions?

After completing this chapter students should be able to:

- describe the structure of atoms in terms of electron shells
- explain how the electron structure of an atom determines its position in the periodic table and its properties
- outline the development of the periodic table and how this was dependent on experimental evidence at the time
- explain why elements in the same group of the periodic table have similar properties
- outline trends in the chemical activity of metals.

4.1 Atoms and elements



Atoms make up everything in the universe. They make up stars, rocks, water, T-shirts, butterflies and you. Like most things, atoms come in different 'varieties' or types. In chemistry, the different types of atoms are known as elements. Elements consist of atoms with the same number of protons. Elements can be thought of as the building blocks from which substances are made.

INQUIRY science 4 fun

Element bingo

No

Collect this ...

- 1 bingo card from your teacher
- 1 pencil, pen or highlighter
- access to a periodic table

Do this ...

1. Your teacher will call out clues that will allow you to identify elements of the periodic table.
2. If you have the symbol of that element, then highlight or circle it.
3. When you have a complete row, column, diagonal or card, call out 'Bingo!'

Record this ...

Describe how this activity helps you learn the symbols of the elements.
Explain why this might occur.

Atoms

Atoms are the particles that make up all the substances in the universe. Atoms are so small that you can't see them with normal microscopes. Only a powerful scanning tunnelling microscope (STM) allows them to be seen. A typical STM image is shown in Figure 4.1.1 on page 106. However, even an STM is unable to show the smaller protons, neutrons and electrons that make up atoms. Although these particles are 'invisible', scientists have gathered evidence from which they have deduced that the particles exist and how they are arranged in the atom. This type of evidence is known as **indirect evidence** and does not involve direct observation of the particles themselves.

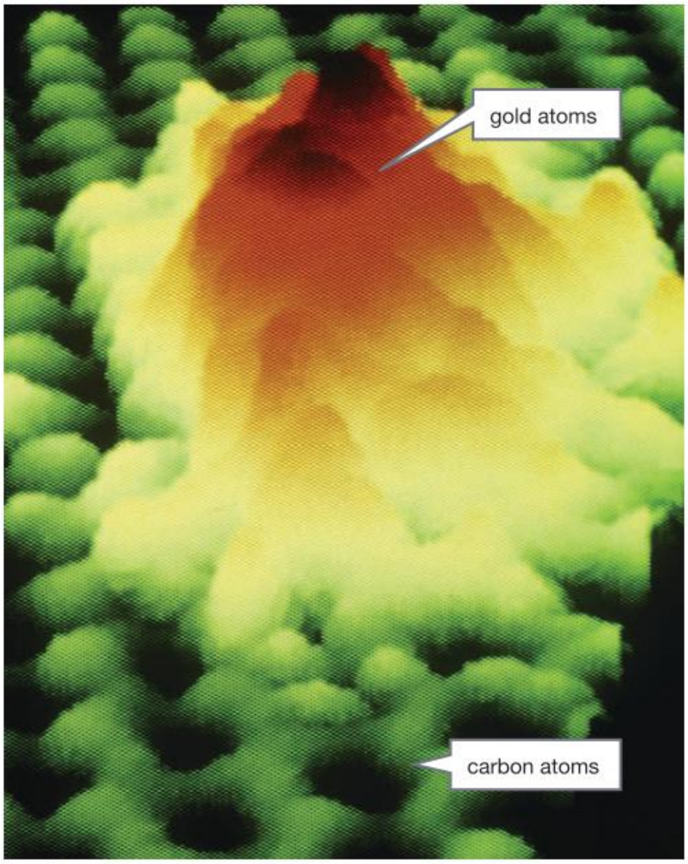


Figure 4.1.1 An STM image of some gold atoms (yellow and brown) on a graphite layer made up of carbon atoms (green)

The nucleus

At the centre of each atom is its **nucleus**, a tight, dense bundle of protons and neutrons. Neutrons are slightly heavier than protons and both are roughly 1800 times heavier than electrons. For this reason, almost all of an atom's mass is in its nucleus. Protons carry a positive charge (+) while neutrons are neutral, having no charge. The positive charges of all those protons in the nucleus give the nucleus a positive charge too.

Electron shells

The electrons spin around in the space around the nucleus. This is shown in Figure 4.1.2. Electrons are negatively charged (–) and are attracted to the positive nucleus. This attraction keeps them from wandering too far from the nucleus but is not enough to pull them in completely.

Atoms are electrically neutral and so the number of electrons is always the same as the number of protons. That is:

Number of electrons in an atom = number of protons

Electrons don't just spin anywhere but spin around the nucleus in regions known as **electron shells** or **energy levels**. The first electron shell is the closest to the nucleus and so the attraction between the nucleus and first-shell electrons is the strongest. This is the lowest energy level for electrons. Electrons in the outermost shell have the highest energy.

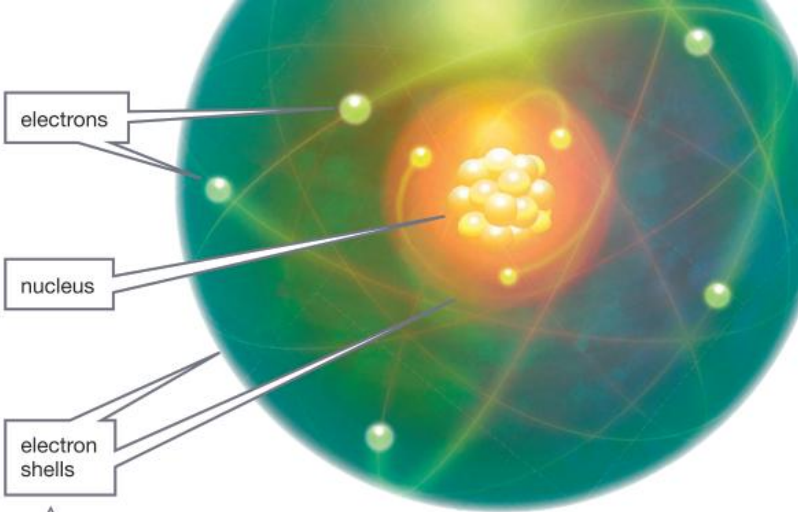


Figure 4.1.2 An atom has a heavy core called the nucleus. Around this are fast-moving electrons, arranged in shells.

The first shell is relatively small and can only hold a maximum of two electrons. Being a little further out, the next electron shell is a little bigger. It can hold eight electrons. The next two shells are bigger again and so are capable of holding even more electrons. The maximum number of electrons that a shell can hold is given by the formula $2n^2$, where n is the number of the shell. This is shown in Table 4.1.1.

Table 4.1.1 Maximum number of electrons held in each shell

Shell	Maximum number of electrons (= $2n^2$)
$n = 1$ (innermost)	2
$n = 2$	8
$n = 3$	18
$n = 4$	32

Electron configuration

Electrons are attracted to the nucleus and this attraction is strongest close to the nucleus. Hence, electrons fill the first shell, then the second shell and so on. When filled in this way, the atom is in its lowest energy state. This is called its **ground state**.

Electron configuration shows how the electrons are arranged in the shells of an atom when it is in its ground state. For example, a sodium atom has 11 electrons. Its electron configuration is 2,8,1. Two electrons are in shell 1, eight are in shell 2 and the remaining electron is in shell 3. Shell 4 is empty. You can see this arrangement in Figure 4.1.3.

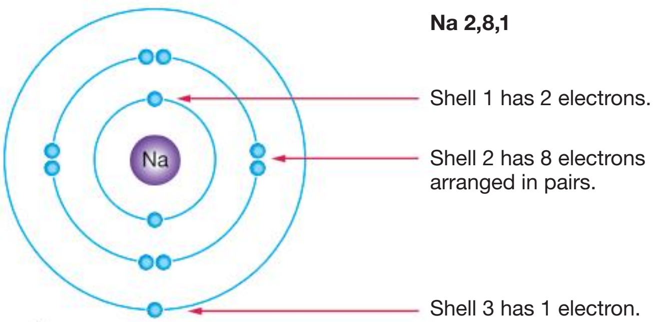


Figure 4.1.3 Sodium's electrons are arranged in its shells according to the electron configuration of 2,8,1. Note that electrons pair up once there are four of them in a shell.

SciFile

Fireworks

The explosive heat of fireworks causes electrons in the atoms to jump from one shell to another. As the electrons return to their ground state, energy is released as light. Different metallic elements release different amounts of energy so each give the fireworks a different colour. This occurs because there are different numbers of protons in atoms of different elements and therefore the attraction of the protons for electrons in the shells is different. So the energy difference between the shells varies.

1 p111

4.1

Elements

The number of protons in the nucleus determines what **element** the atom belongs to.

There are 118 different elements. Twenty-six of these are not found naturally on Earth but are synthetic, having been made in the laboratory. The periodic table in Figure 4.1.8 on page 109 shows all of the known elements. Elements can be thought of as the building blocks from which all substances are made.

The chemical formula of a compound tells you what elements make it up and in what proportions. For example, a molecule of water (H_2O) is made of two atoms of the element hydrogen and one atom of the element oxygen. The formula for the ionic lattice structure of common salt (sodium chloride, NaCl) indicates that there are equal numbers of ions of the element sodium and the element chlorine.

Atomic number

The number of protons in the nucleus of an atom is known as its **atomic number**.

Atomic number = number of protons

Each element has a characteristic and identifying atomic number. For example, all carbon atoms have six protons and so all have an atomic number of 6. All oxygen atoms have eight protons (atomic number of 8), while all uranium atoms have 92 protons (atomic number 92). This makes uranium atoms some of the heaviest known and helps explain why they are unstable and radioactive (Figure 4.1.4). In contrast, a hydrogen atom has only a single proton in its nucleus. Its atomic number is 1, making hydrogen the smallest of all the atoms and the lightest of all the elements. This fact was used in airships like the one in Figure 4.1.5.

Figure 4.1.4 Uranium is the heaviest natural element. Its extreme size makes its nuclei unstable. When these nuclei break apart, massive amounts of energy are released, as is evident in this 1958 atomic bomb test.

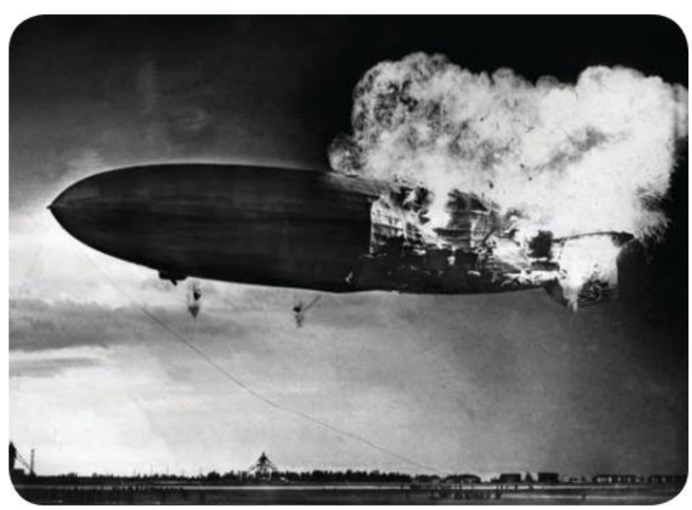


Figure 4.1.5 Hydrogen is lighter than air and so was used in many early airships. Unfortunately, hydrogen is also very explosive, which led to the 1937 Hindenburg disaster shown here.

2 p112

Element symbols

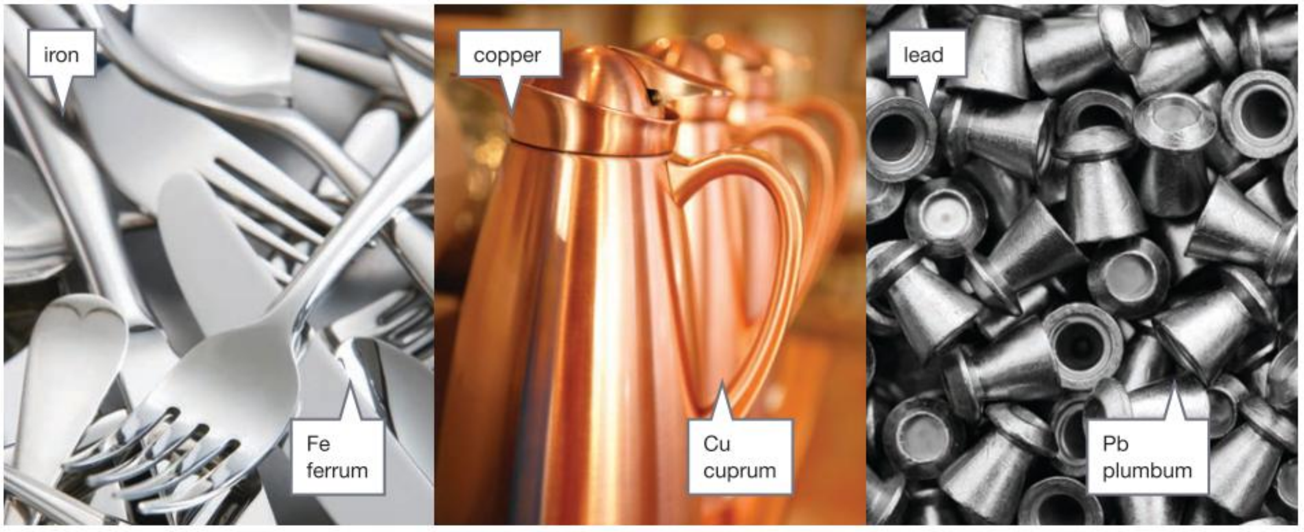
The symbols of most elements use the first letter of their names or two 'logical' letters from them. This makes their symbols relatively easy to predict. Table 4.1.2 shows some of them.

However, a handful of metallic elements have symbols that seem illogical. This is because their symbols are based on their original Latin or Greek names. These 'illogical' symbols are the ones you need to remember. Three of these elements are shown in Figure 4.1.6.

Table 4.1.2 Examples of element symbols

	Name	Symbol
Uses first letter	Oxygen	O
	Fluorine	F
	Sulfur	S
Uses two 'logical' letters	Chlorine	Cl
	Magnesium	Mg
	Calcium	Ca
Based on their original Latin or Greek name	Sodium	Na
	Gold	Au
	Tin	Sn
Temporary	Ununoctium	Uuo

Figure 4.1.6 The symbols of iron (Fe), copper (Cu) and lead (Pb) are based on their respective Latin names *ferrum*, *cuprum* and *plumbum*.



Don't bother remembering these!

SciFile

A few heavy, synthetic elements are so radioactive that they only stay around for one-thousandth of a second or so. This makes confirmation of their discovery extremely difficult. Until confirmation happens, they are given temporary symbols of three letters. You don't need to remember these.

Figure 4.1.7 In 1996, a particle accelerator like this one was used to discover an element with the atomic number 112. It was given the temporary name ununbium (Uub). In 2009, the existence of the element was finally confirmed. It was then given the name copernicium (Cn) after the famous astronomer Nicolaus Copernicus (1473–1543).

The periodic table

The periodic table is a list of all known elements (and those still awaiting confirmation). As Figure 4.1.8 shows, the table is arranged:

- in order of increasing atomic number
- in rows (called periods) and columns (called groups)
- with the metals to the left of the table, the non-metals to the far right and the metalloids in between.

	Group 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period 1	1 **H** hydrogen																	2 **He** helium
Period 2	3 **Li** lithium	4 **Be** beryllium											5 **B** boron	6 **C** carbon	7 **N** nitrogen	8 **O** oxygen	9 **F** fluorine	10 **Ne** neon
Period 3	11 **Na** sodium	12 **Mg** magnesium											13 **Al** aluminium	14 **Si** silicon	15 **P** phosphorus	16 **S** sulfur	17 **Cl** chlorine	18 **Ar** argon
Period 4	19 **K** potassium	20 **Ca** calcium	21 **Sc** scandium	22 **Ti** titanium	23 **V** vanadium	24 **Cr** chromium	25 **Mn** manganese	26 **Fe** iron	27 **Co** cobalt	28 **Ni** nickel	29 **Cu** copper	30 **Zn** zinc	31 **Ga** gallium	32 **Ge** germanium	33 **As** arsenic	34 **Se** selenium	35 **Br** bromine	36 **Kr** krypton
Period 5	37 **Rb** rubidium	38 **Sr** strontium	39 **Y** yttrium	40 **Zr** zirconium	41 **Nb** niobium	42 **Mo** molybdenum	43 **Tc** technetium	44 **Ru** ruthenium	45 **Rh** rhodium	46 **Pd** palladium	47 **Ag** silver	48 **Cd** cadmium	49 **In** indium	50 **Sn** tin	51 **Sb** antimony	52 **Te** tellurium	53 **I** iodine	54 **Xe** xenon
Period 6	55 **Cs** caesium	56 **Ba** barium	57–71 lanthanides	72 **Hf** hafnium	73 **Ta** tantalum	74 **W** tungsten	75 **Re** rhenium	76 **Os** osmium	77 **Ir** iridium	78 **Pt** platinum	79 **Au** gold	80 **Hg** mercury	81 **Tl** thallium	82 **Pb** lead	83 **Bi** bismuth	84 **Po** polonium	85 **At** astatine	86 **Rn** radon
Period 7	87 **Fr** francium	88 **Ra** radium	89–103 actinides	104 **Rf** rutherfordium	105 **Db** dubnium	106 **Sg** seaborgium	107 **Bh** bohrium	108 **Hs** hassium	109 **Mt** meitnerium	110 **Ds** darmstadium	111 **Rg** roentgenium	112 **Cn** copernicium	113 **Uut** ununtrium	114 **Uuq** ununquadium	115 **Uup** ununpentium	116 **Uuh** ununhexium	117 **Uus** ununseptium	118 **Uuo** ununoctium

Lanthanides	57 **La** lanthanum	58 **Ce** cerium	59 **Pr** praseodymium	60 **Nd** neodymium	61 **Pm** promethium	62 **Sm** samarium	63 **Eu** europium	64 **Gd** gadolinium	65 **Tb** trebium	66 **Dy** dysprosium	67 **Ho** holmium	68 **Er** erbium	69 **Tm** thulium	70 **Yb** ytterbium	71 **Lu** lutetium
Actinides	89 **Ac** actinium	90 **Th** thorium	91 **Pa** protactinium	92 **U** uranium	93 **Np** neptunium	94 **Pu** plutonium	95 **Am** americium	96 **Cm** curium	97 **Bk** berkelium	98 **Cf** californium	99 **Es** einsteinium	100 **Fm** fremium	101 **Md** mendelevium	102 **No** nobelium	103 **Lr** lawrencium

atomic number — 13
symbol — **Al**
name — aluminium

KEY Non-metals | Metals | Metalloids

Figure 4.1.8 The periodic table is a list of all the known elements arranged in order of increasing atomic number.

4.1 Unit review

Remembering

1 **Name** the particles in the:
  a nucleus
  b space around the nucleus.

2 **List** the following in order from smallest to largest: atom, electron, proton, neutron.

3 A particular atom has 8 protons, 8 electrons and 9 neutrons. **State** its atomic number.

4 **State** the element symbols for:
  a oxygen
  b chlorine
  c magnesium
  d iron.

5 **Name** the following elements.
  a F
  b Ca
  c Na
  d Pb

6 **State** the electric charge of each of:
  a a proton
  b an electron
  c a neutron
  d a nucleus
  e an atom.

7 **State** the number of electrons that can fit in each of the first four electron shells.

8 **State** how many electrons are in an atom that has an electron configuration of 2,8,8.

Understanding

9 **Define** the following terms.
  a STM
  b indirect evidence
  c atomic number

10 **Explain** why most of an atom's mass is due to its nucleus.

11 a You are watching a replay of a football match on TV. You cannot see the sky but immediately deduce that it was a day match. **Describe** the indirect evidence that would lead you to this conclusion.
  b Another replay comes on and you know that this match was a night match despite not being able to see the sky or light towers. **Describe** the indirect evidence that now suggests it is night.

Applying

12 **Use** the formula $2n^2$ to **calculate** the maximum number of electrons held by shell 5 ($n = 5$).

13 **Demonstrate** how to write electron configurations by writing them for the following atoms.
  a lithium (with 3 electrons)
  b carbon (with 6 electrons)
  c sodium (with 11 electrons)
  d chlorine (with 17 electrons)

14 **Identify** the type of atoms and the number of each type in a single molecule of:
  a methane, CH_4
  b nitric acid, HNO_3
  c glucose, $C_6H_{12}O_6$
  d ethanoic acid (vinegar), CH_3COOH.

Analysing

15 **Compare** a proton with a neutron by listing their similarities and differences.

16 **Use** the periodic table on page 109 to **contrast** an atom of aluminium with an atom of carbon.

Evaluating

17 **Propose** a meaning for the term *subatomic particle*.

Creating

18 **Construct** simple diagrams showing how the electrons are arranged in shells for the atoms listed in Question 13.

19 **Construct** a way of remembering those element symbols that don't seem to match their names.

Inquiring

1 Curie, Mendeleev, Einstein, Rutherford, Roentgen and Nobel all have elements named after them. Research what important work these scientists did, write a few sentences on their achievements, state which elements were named after them and write their element symbols.

2 Research what the term *isotope* means. List the isotopes of hydrogen, carbon, oxygen, chlorine and uranium.

4.1 Practical activities

1 Firework colours

Purpose

To observe the colours that metal salts produce when heated.

SAFETY

Turn the Bunsen burner to the yellow flame or off when not using it.

Tie long hair back.

Do not allow the icy-pole stick to catch fire.

Do not point the spectroscope directly at the Sun.

Materials

- Bunsen burner, bench mat and matches
- tongs
- wooden icy-pole sticks soaked overnight in distilled water or deionised water and solutions of barium chloride, copper chloride, potassium chloride, sodium chloride and strontium chloride
- spectroscope (optional)

Procedure

1 Use tongs to hold the icy-pole stick soaked in water in the hottest part of a blue Bunsen flame. Hold it there for a few seconds only and remove it before it can catch fire.

2 Observe what colour the stick gives to the flame and record the colour in a table like that shown in the results section.

3 Repeat steps 1 and 2 for the other sticks.

Extension

4 Point a spectroscope towards a bright portion of the sky (not the Sun). Sketch the spectrum you see.

5 Observe each of the coloured flames through the spectroscope (Figure 4.1.9). Record what you see.

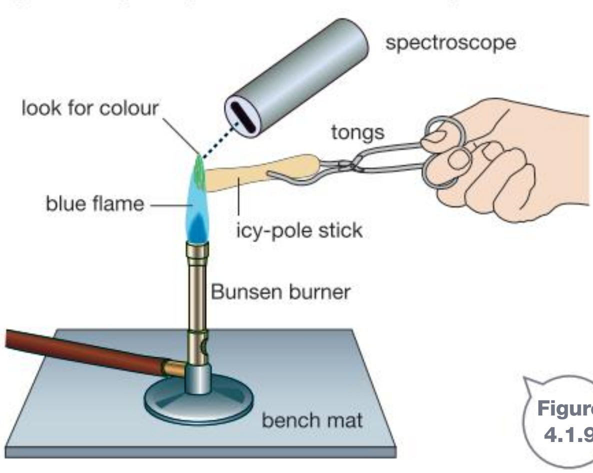


Figure 4.1.9

Results

Copy the following table into your workbook. List all the solutions you tested.

Solution tested	Formula	Colour of flame	Metallic element in solution	Non-metallic element in solution
Distilled water	H_2O		None	H, O
Barium chloride	$BaCl_2$		Ba	Cl, H, O

Discussion

1 Modern fireworks include metal salts to colour them. **Identify** which of the metal salts would make a firework:

a red

b green

c blue-green.

2 As Figure 4.1.10 shows, the grains in fireworks that spray out and give colour are made of starch soaked in the appropriate salt. **Construct** a diagram of a grain that would burn and give the colours:

a blue-green, then purple

b red, then green.

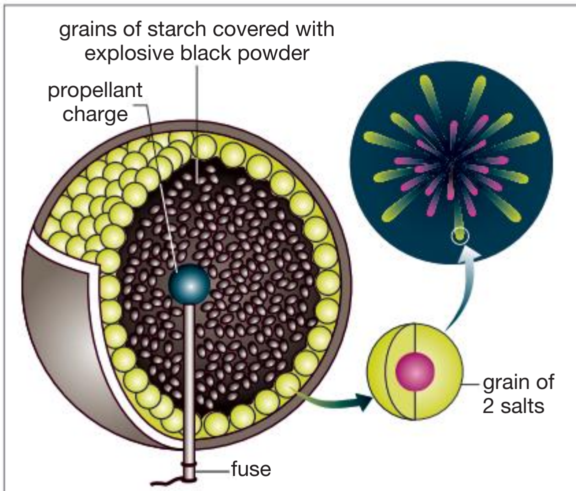


Figure 4.1.10 A firework 'grain'

Firework colours continued on next page

Firework colours continued

3 Firework colours come from electrons changing energy levels. Heat gives electrons energy to jump from one energy level to another. **Describe** where they get this energy from.

4 When the electrons jumped back to their original shells, they released all that energy. **State** the evidence that energy is released.

5 **Identify** the purpose of the stick soaked in water only.

6 **Explain** why distilled water or deionised water was used rather than tap water.

7 The non-metallic element did not add colour to the flame. **Outline** the evidence that supports this statement.

2 Properties of elements

Purpose

To compare the properties of metals and non-metals.

Materials

- samples of sulfur, aluminium, carbon, silicon, tin, zinc, lead, magnesium, iron
- steel wool
- 3 or 4 test-tubes and rack
- power pack or battery (about 2 V)
- wires with alligator clips
- light globe

SAFETY

Turn the Bunsen burner to the yellow flame or off when not using it.

Tie long hair back.

Procedure

1 Use the periodic table in Figure 4.1.8 on page 109 to determine whether the element you are testing is a metal or a non-metal.

2 Record the appearance of each sample in a table as shown in the results section.

3 'Polish' each sample with the steel wool. Record its appearance now.

4 Try and bend the sample. Record whether it bends or crumbles.

5 Place some of the sample in a test-tube with water. Record whether it floats or not and whether any change is obvious. For example, does it dissolve or react?

6 Use a circuit similar to the one in Figure 4.1.11 to test if the sample conducts electricity.

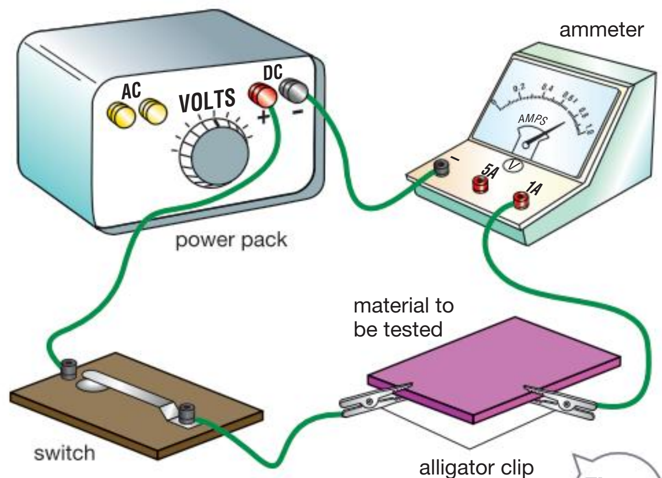


Figure 4.1.11

Results

Construct a table in your workbook like the one below.

Element	Metal or non-metal	Appearance when polished	Bends or crumbles	Float or sinks	Action with water	Electrical conductivity

Discussion

1 Metals share certain physical properties. From your observations, **list** them.

2 **List** the properties that were common in all the non-metals you tested.

4.2 Arranging the elements

The periodic table is a list of all the elements, arranged in order of their atomic numbers. The table's structure allows you to predict the properties of a particular element and what its atoms are likely to do in a chemical reaction.

Columns and rows

The **periodic table** lists all of the known elements in order of increasing atomic number. Having only one proton (atomic number 1), hydrogen is the first element. Ununoctium is the last, with 118 protons (atomic number 118). This list of elements is arranged according to atomic number and in columns depending on the number of electrons in the outer shell.

Periods

The horizontal rows in the periodic table are called **periods**. They are shown in Figure 4.2.1. The period number of an element is the same as the number of shells occupied by the electrons in its atoms.

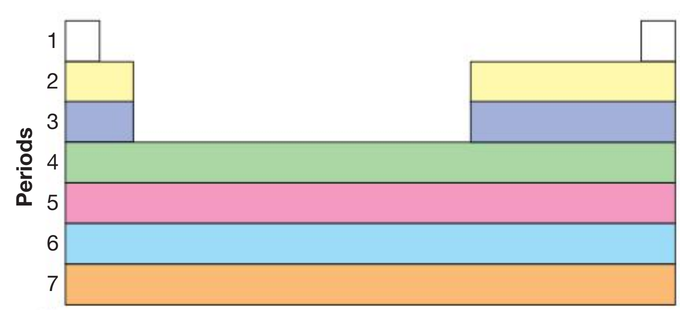


Figure 4.2.1 Periods are the horizontal rows of the periodic table.

Groups

Groups are the vertical columns in the periodic table and are numbered from 1 to 18. An older way of numbering groups was to use the roman numerals I–VIII (Figure 4.2.2). From the group number of an element, you can work out the number of electrons in the outer shell of its atoms.

When using the group numbers 1 to 18, the last digit is usually the number of electrons in the outer shell. So group 12 has two electrons in the outer shell while group 18 has eight.

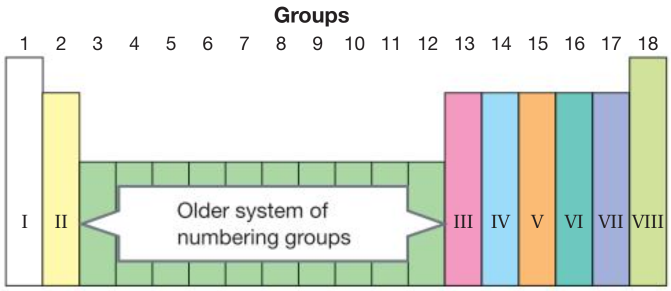


Figure 4.2.2 Groups are the vertical columns of the periodic table.

Placing elements in periods and groups

The electron configuration tells you the period and the group of an element. For example:

- Sodium (element symbol Na) has 11 electrons and an electron configuration of 2,8,1. This configuration shows that sodium atoms have three occupied shells, with one electron in their outer shell. For these reasons, sodium is placed in period 3, group 1.
- Nitrogen (N) has an electron configuration of 2,5. It has two occupied shells and has five outer-shell electrons. It is therefore placed in period 2, group 15.
- Fluorine's (F) electron configuration is 2,7, so it is placed in period 2, group 17.

The connection between electron configuration of the first 18 elements and their position in the periodic table is clear in Table 4.2.1. By arranging the elements this way, the metals are to the left of the periodic table and the non-metals to the right.

Table 4.2.1 Electron configuration of the first 18 elements

Period	Group							
	1	2	13	14	15	16	17	18
1	H 1							He 2
2	Li 2,1	Be 2,2	B 2,3	C 2,4	N 2,5	O 2,6	F 2,7	Ne 2,8
3	Na 2,8,1	Mg 2,8,2	Al 2,8,3	Si 2,8,4	P 2,8,5	S 2,8,6	Cl 2,8,7	Ar 2,8,8

SciFile

The odd one out!

These balloons contain helium atoms. Each helium atom has two electrons occupying a single shell. Helium *should* be in group 2 but is placed in group 18 because of its properties, which are far more like those of group 18 elements than group 2 elements.

4.2

Special blocks

As Figure 4.2.3 shows, the periodic table has three blocks of elements known as the **transition elements**, the **lanthanides** and **actinides**. The placement of elements in these blocks is also based on their electron configuration but is too complex to discuss here.

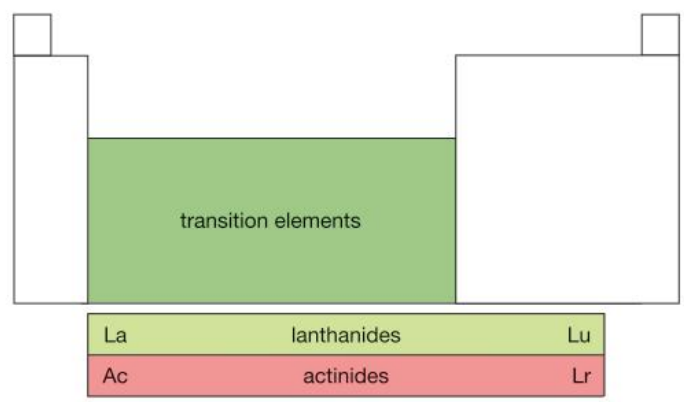


Figure 4.2.3 The transition elements, the lanthanides and actinides, are placed in special blocks. Their placement is also based on electron configuration.

1 p118
2 p119

SCIENCE AS A HUMAN ENDEAVOUR

Nature and development of science

Development of the periodic table

Figure 4.2.4 John Dalton's table of elements and the symbols he gave them

The ancient Greek philosopher Aristotle thought that there were only four elements: earth, water, air and fire. Although scientists now know that these aren't elements, Aristotle's idea began a long search for what substances are made of. As scientific techniques advanced, so did the list of known elements. As more elements were discovered, scientists looked for ways to organise them.

Chemists had long known that certain elements behaved similarly to one another in chemical reactions and in their physical properties. This pattern provided a way of constructing the periodic table that is now used by all chemists worldwide.

The first tables

In 1789, the French chemist Antoine-Laurent de Lavoisier (1743–93) separated the known elements into metals, non-metals and 'earths'. However, his list of 33 elements also included light and a liquid called 'caloric' that was thought to carry heat from hot to cold bodies. Caloric is now known not to exist. Light does exist but is not an element. In 1808, the English chemist John Dalton (1766–1844) went further by giving each of the 36 known elements its own chemical symbol and organising them in order of their mass. You can see his symbols in Figure 4.2.4.

SciFile

Dalton's eyeballs

Dalton was colour blind and suspected that it was because his eyes were filled with blue liquid! He instructed his doctor to dissect his eyes after death to determine if they were. No blue liquid was found but in 1995 the gene that leads to colour-blindness was isolated from his preserved eyes.

Fifty-five elements had been discovered by 1829. Some elements had very similar properties and seemed to be related. For example, chlorine, bromine and iodine (shown in Figure 4.2.5) reacted with other chemicals in a similar way. For this reason, the German chemist Johann Dobereiner (1780–1849) bunched them together into a family of three. Other related elements were also bunched into threes. Dobereiner called his bunches 'triads'. Lithium, sodium and potassium formed a triad, while calcium, strontium and barium formed another.

Figure 4.2.5 The properties of chlorine, bromine and iodine are so similar that Dobereiner placed them in the same triad.

In 1864, the English scientist John Newlands (1837–98) arranged the 60 known elements in order of their mass, forming a table of seven columns. Every eighth element was placed on a new row and so his arrangement was known as the law of octaves (Figure 4.2.6). However, some boxes in his table ended up with more than one element in them.

Figure 4.2.6 Musical notes repeat every eight notes. Newlands organised his elements in a similar way, with a new 'octave' starting every eight elements.

Success

In 1869, the Russian chemist Dmitri Ivanovich Mendeleev (1834–1907) constructed a table of rows and columns like those of his favourite card game, called solitaire or patience. Each element had its own box. He placed them horizontally according to their atomic masses and vertically according to their properties. He believed in the periodicity (repetition) of the properties of the elements and this arrangement placed elements with similar properties in the same columns. He then realised that some atomic masses were wrong and instead placed those elements where their resemblance to other elements suggested they should go. He also left gaps in his table for undiscovered elements and predicted what their properties might be. For example, he predicted that 'eka-silicon' would eventually be discovered. When isolated in 1886, eka-silicon's properties compared remarkably well with Mendeleev's predictions. Eka-silicon is now known as germanium. Table 4.2.2 compares its predicted and measured properties. Similarly, the properties he predicted for eka-aluminium, eka-boron and eka-manganese were close to those of gallium (isolated in 1875), scandium (1879) and technetium (1937) respectively.

Table 4.2.2 Comparing eka-silicon with germanium

Physical property	Eka-silicon: Mendeleev's predictions	Germanium: properties as measured
Colour	Grey	Grey-white
Atomic mass	72	72.61
Melting point (°C)	High	947
Boiling point (°C)	Below 100	84
Density (g/cm^3)	5.5	5.35

SciFile

An eccentric scientist!

Figure 4.2.7 shows Mendeleev's extravagant hair and beard, which he only trimmed once a year. Mendeleev (and his mother) hitch-hiked over 6000 km in 1848 to get to his first day of university in St Petersburg. While there, he spent some of his time perfecting the perfect vodka!

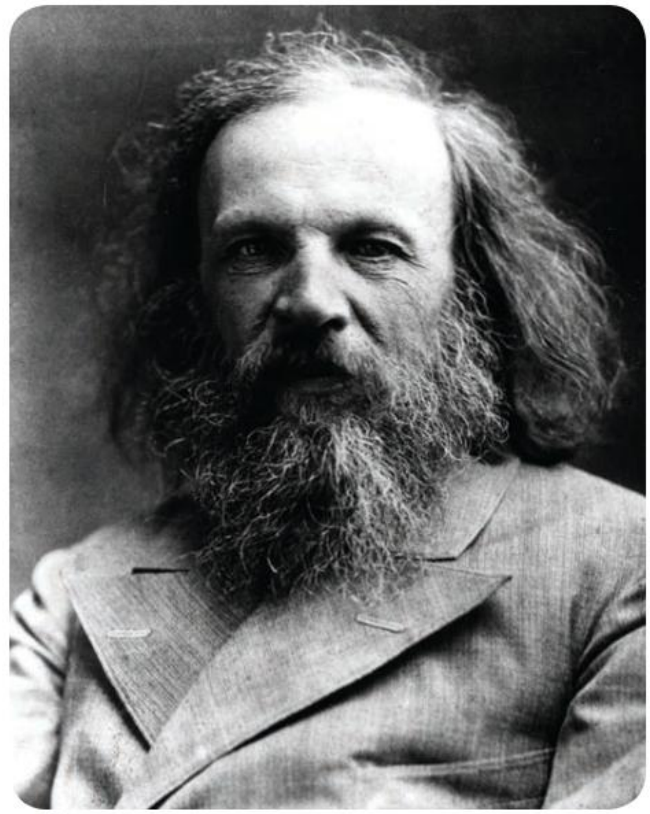


Figure 4.2.7 Dmitri Ivanovich Mendeleev constructed the first modern periodic table.

A similar table to Mendeleev's was constructed in 1868–69 by the German chemist Lothar Meyer (1830–95).

Our modern table

Mendeleev and Meyer arranged the elements in order of increasing atomic mass. To construct his table in 1913, the English physicist Henry Moseley (1887–1915) used atomic numbers instead. An extended version of Moseley's table is still used today.

The discovery of electrons by English scientist J.J. Thomson (1856–1940) in 1897 and the discovery of electron configuration around 1920 eventually led to the periodic table being arranged according to the way electrons were arranged in their shells. Amazingly, this version was identical to the earlier table based on physical and chemical properties! This led scientists to realise that chemistry was largely about electrons and how they behave (particularly the outer-shell electrons).

4.3

4.2 Unit review

Remembering

1 **List** five:
   - a group 15 elements
   - b period 2 elements
   - c common transition elements
   - d lanthanides
   - e actinides.

2 **List** the elements that Dobereiner organised into three triads.

3 **State** how many elements were known in:
   - a 1789
   - b 1808
   - c 1829
   - d 1864
   - e 2011, the year this book was published.

4 **Name** the element that was once called eka-silicon.

Understanding

5 **Outline** how the electron configuration of an element determines its position in the periodic table.

6 **Explain** why Dobereiner organised selected elements into triads.

7 Newland's periodic table ended up having more than one element in some of its boxes. **Explain** why this is not possible.

8 **Explain** why Mendeleev left gaps in his original table.

Applying

9 The electron configurations of different elements are given below. **Identify** in which period and group they should be placed.
   - a 2,3
   - b 2,8,7
   - c 2,8,8,2
   - d 2,8,18,6
   - e 2,8,18,8,2

10 **Use** the periodic table to **identify** the elements whose electron configurations are listed in Question 9.

11 **Use** the periodic table to help you **predict** the electron configuration for:
   - a silicon (Si)
   - b helium (He)
   - c nitrogen (N)
   - d magnesium (Mg).

12 **Identify** the period and group that these atoms would belong to.
   - a Ne
   - b an atom with atomic number 13
   - c an atom with 7 electrons.

13 **Use** the periodic table to **determine** the electron configuration of an atom in:
   - a period 2, group 16
   - b period 3, group 18.

14 **Use** the periodic table to **determine** how many electrons in an atom:
   - a with eight protons
   - b with 18 protons
   - c with an atomic number of 3
   - d with an atomic number of 19
   - e in period 2, group 17
   - f in period 3, group 2
   - g of phosphorus
   - h of potassium.

Analysing

15 **Compare** the elements H, Li and Na by listing the similarities and differences in their electron configurations and placement in the periodic table.

16 **Compare** two properties that Mendeleev predicted for eka-silicon with those of germanium.

Evaluating

17 **Propose** reasons why Dalton's symbols for the elements would be difficult to use today.

Creating

18 **Construct** a scale timeline showing important years in the development of the periodic table.

Inquiring

1 Research Mendeleev, Lavoisier or Dalton and construct a biography outlining their lives, achievements and contributions to the development of the periodic table.

2 Find a version of Mendeleev's original periodic table and compare it with the one used today.

3 Find alternative versions of the periodic table that are used today for different purposes.

4.2 Practical activities

1 Investigating a metallic element

Purpose

To make crystals of the metallic element silver.

Materials

- 250 mL beaker
- hotplate or Bunsen burner, tripod, gauze mat and bench mat
- 1 cm × 4 cm clean zinc strip
- 0.3 g silver nitrate (this could be pre-weighed)
- stirring rod
- 0.5 g agar powder (this could be pre-weighed)
- 40 mL distilled or deionised water
- 100 mL measuring cylinder
- Petri dish
- stereomicroscope (optional)

SAFETY

Silver nitrate stains skin, clothing and benchtops and lead nitrate is poisonous.

Wear safety glasses and gloves at all times when dealing with them.

Turn the Bunsen burner to yellow flame or off when not using it.

Tie long hair back.

Procedure

1. Fold a small piece of paper in two and then open it out.
2. Place the paper onto the electronic balance and measure out 0.5 g of agar onto it.
3. Use the measuring cylinder to measure out 40 mL of distilled or deionised water.
4. Pour the water into the beaker and sprinkle the agar into it as shown in step 1 of Figure 4.2.8.
5. Gently warm the beaker over the hotplate or Bunsen burner, stirring until all of the agar is dissolved.
6. Carefully remove the beaker from the hotplate or Bunsen burner and add 0.3 g of silver nitrate to the beaker. Stir until it is dissolved.
7. Pour the agar solution into a petri dish and gently place the zinc strip in the centre as shown in step 2 of Figure 4.2.8.
8. Place the lid on top of the Petri dish and allow the agar to cool in a dark place (perhaps inside a cupboard). The agar should set into a jelly.
9. Inspect the metal crystals that form over the next few days. If available, use a stereomicroscope for a better view.

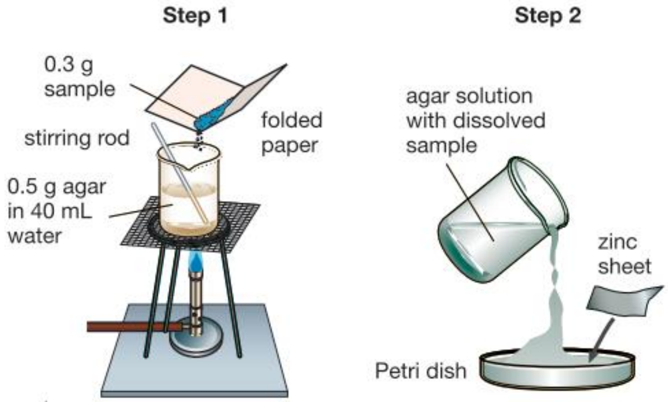


Figure 4.2.8 Making an agar plate

Results

1. Sketch or photograph the pattern produced by the crystals.
2. If you observed the crystals under the stereomicroscope, then draw the shape of an individual crystal.

Discussion

1. **Propose** a reason why the crystals were grown in agar and not a liquid.
2. **Describe** the colour of the agar after the silver nitrate dissolved in it. (This is also what happens if silver nitrate comes into contact with your skin.)
3. **Identify** the atomic number and period for silver.
4. **Identify** which of the following would be the most likely electron configuration of silver.
   - **A** 47
   - **B** 5,11
   - **C** 2,8,18,19
   - **D** 2,8,18,18,1
5. **Name** the special block in which silver is located in the periodic table.

2 Investigating a non-metallic element

Purpose

To determine how much oxygen is in air.

Materials

- non-soapy steel wool (cleaned first with methylated spirits, rinsed in water and dried)
- large (50 mL) test-tube
- plastic container (such as a take-away food container)
- retort stand, bosshead and clamp
- marking pen
- 10 mL measuring cylinder
- access to a calculator

Procedure

1. Add water to the plastic container and place it on the base of the retort stand.
2. Insert a 2–3 cm wad of steel wool in the bottom of the test-tube. Scrunch it up or add a little more so that it stays in place when inverted.
3. Wet the steel wool, then invert the test-tube and clamp so that it as shown in Figure 4.2.9. Make sure that the mouth of the test-tube is well under the surface of the water.
4. Mark where the water level is on the test-tube.
5. Leave the test-tube for at least 2 days. Mark the new water level in the test-tube.
6. Remove the test-tube from the clamp. Leave the steel wool in place and pour water into the test-tube until it reaches the line you marked at the end of the experiment. Empty the water into the measuring cylinder and record its volume in the results table.
7. Pour water into the test-tube until it reaches the line you marked at the start of the experiment. Pour it into an empty measuring cylinder and record its volume (column 2).

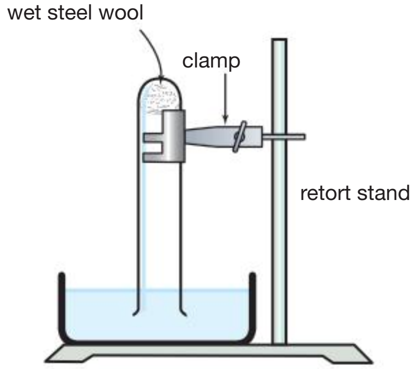


Figure 4.2.9 Inverting the test-tube

Results

1. In your workbook, copy the table below. Record your volumes in columns 1 and 2.
2. Gather the results from another four groups in your class.

Group	Column 1 Volume of air after 2 days (mL)	Column 2 Total volume of air at start (mL)	Column 3 Volume of air 'used up' (mL)	Column 4 Percentage of air 'used up'
1				
2				
3				
4				
5				
Average				

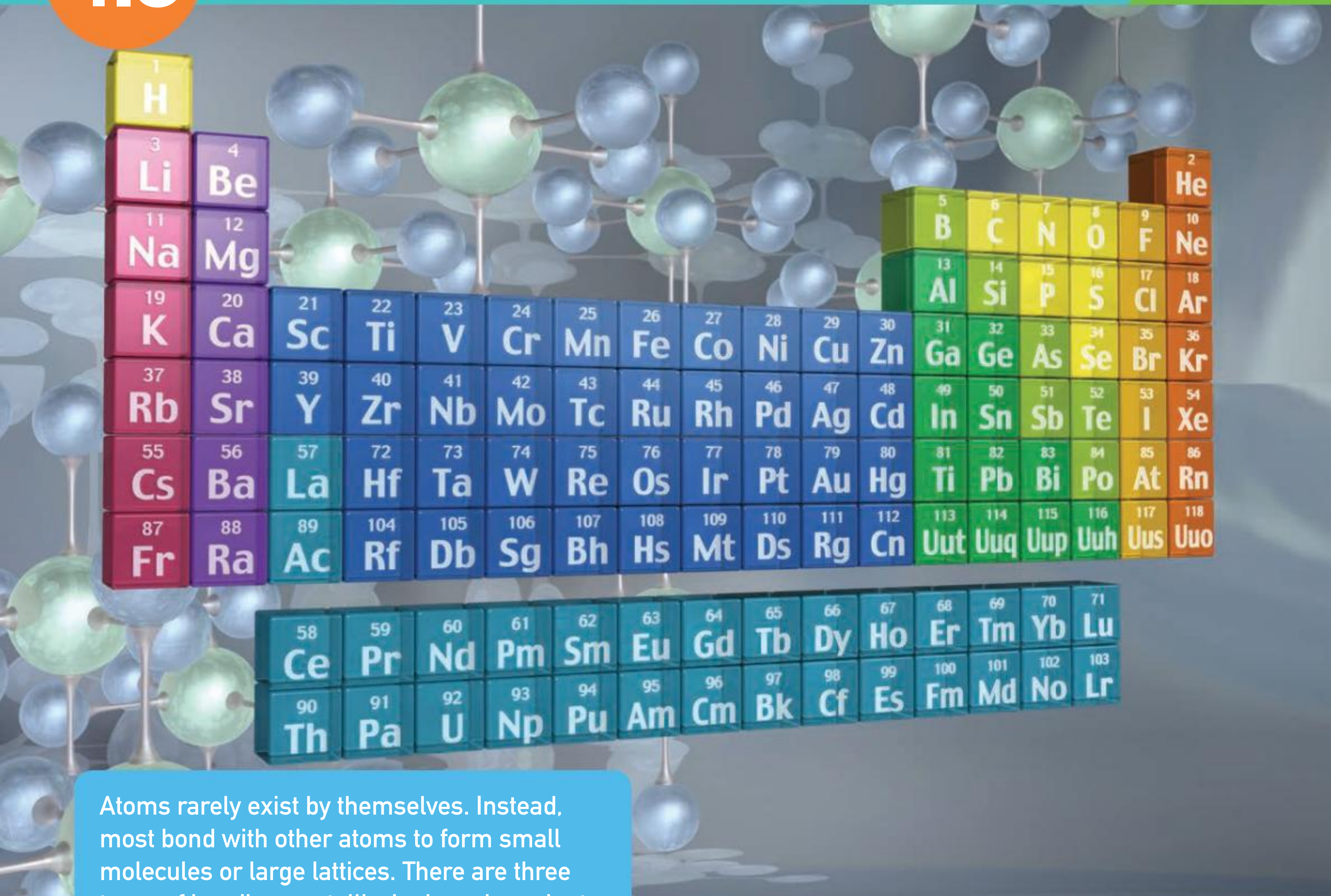
3. Calculate the amount of air 'used up' in the rusting of the steel wool. Calculate this volume by subtracting: column 2 – column 1. Record this volume in column 3.
4. Calculate the percentage of air 'used up' in the experiment.

   $\% \text{ of air used up} = \frac{\text{column 3}}{\text{column 2}} \times 100$
5. Calculate the average of all the groups' measurements.

Discussion

1. **Compare** the results obtained from the different groups.
2. **Identify** the errors in this experiment that will naturally contribute to some variation in the results.
3. **Explain** the advantages of taking multiple measurements in a practical activity.
4. a. Air is about 21% oxygen. **Compare** this percentage with the percentage of air 'used up' in this experiment.
   b. **Assess** whether the two percentages should be the same or not.
   c. **Justify** your answer.
5. For oxygen, **state** its:
   a. atomic number
   b. period and group numbers
   c. electron configuration.

4.3 Bonding



Atoms rarely exist by themselves. Instead, most bond with other atoms to form small molecules or large lattices. There are three types of bonding: metallic, ionic and covalent. The type of bonding that occurs depends on whether the atoms bonding are metals or non-metals.

Atoms that bond and atoms that don't

Most atoms join with other atoms to form small groupings called molecules or large, regular arrangements called lattices. The links between these atoms are called chemical **bonds**.

However, one group of atoms tends not to bond. These are the atoms of elements in group 18, commonly called the **noble** or **inert gases**. The atoms of noble gases are extremely stable and rarely bond with other atoms. Instead, they are **monatomic**, existing as single atoms. This stability is because of their electron configuration. Helium (He) atoms have two electrons filling their outer shells, while neon (Ne) atoms (like those in the tubes of the advertising sign in Figure 4.3.1) have eight electrons filling their outer-shells. Argon (Ar), krypton (Kr), xenon (Xe) and radon (Rn) also have eight electrons in their outer shells.

All other atoms in the periodic table react, gaining, losing or sharing electrons as they do so. This results in particles with full outer shells or outer shells that hold eight electrons. This gives the particles the same electron configuration and stability as a noble gas. This transfer or sharing of electrons is how bonds form.

Bonding types

The types of bonds formed depend on the type of atoms that are bonding.

- Metallic bonding occurs between metal atoms.
- Ionic bonding occurs between metal atoms and non-metal atoms.
- Covalent bonding occurs between atoms of non-metals.

To understand metallic and ionic bonding, you must first understand what ions are.

Ions

Ions are atoms (or groups of atoms) that have become charged because they have had electrons removed from them or because they have removed electrons from other atoms. Atoms are neutral (no charge) because they have equal numbers of protons and electrons. The transfer of electrons destroys this balance.

Number of electrons in an ion ≠ number of protons

This imbalance gives ions a charge.

- Positively charged ions (+) have more protons than electrons. They form when metal atoms lose their outer-shell electrons.
- Negatively charged ions (–) have more electrons than protons. They form when atoms of non-metals gain electrons.

The ions now have the same electron configuration and stability of noble gases.

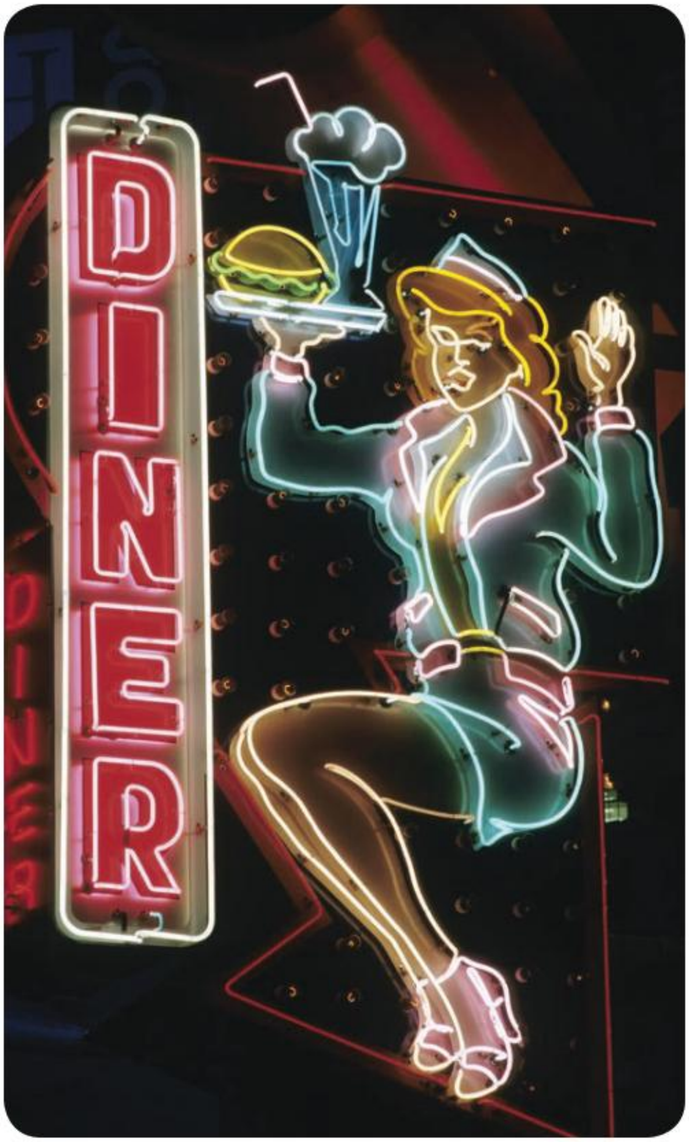


Figure 4.3.1 The neon gas used in this sign is a noble gas. Like all noble gases, neon is stable and so doesn't bond or take part in chemical reactions.

Metallic bonding

Metal atoms have a weak hold on their outer-shell electrons. This gives the outer-shell electrons the freedom to move throughout the metal without being bound to any one atom. Each metal atom becomes a positively charged ion. Opposite charges attract and this electrostatic force provides multidirectional bonding between the positive ions and the 'sea' of loose electrons surrounding them. This bonding holds the metal together and is known as **metallic bonding** (Figure 4.3.2). As Figure 4.3.3 on page 122 shows, metallic bonding explains all the physical properties characteristic of metals.

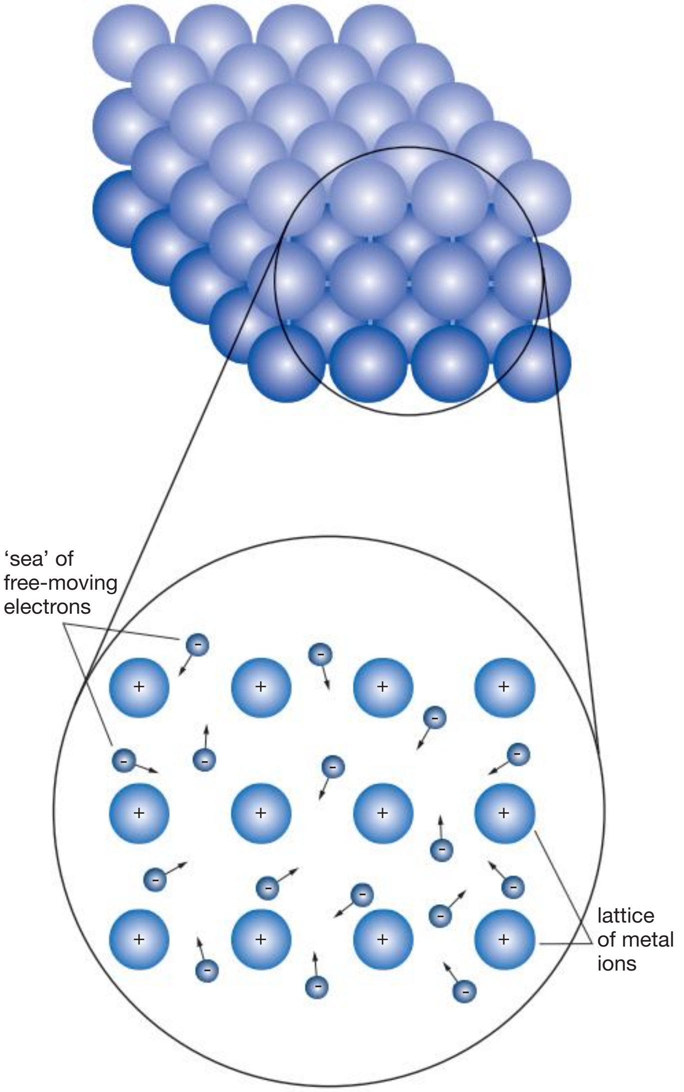


Figure 4.3.2 Metal atoms are bonded to each other because of the attraction between the lattice of positive ions and the electron 'sea' surrounding them.

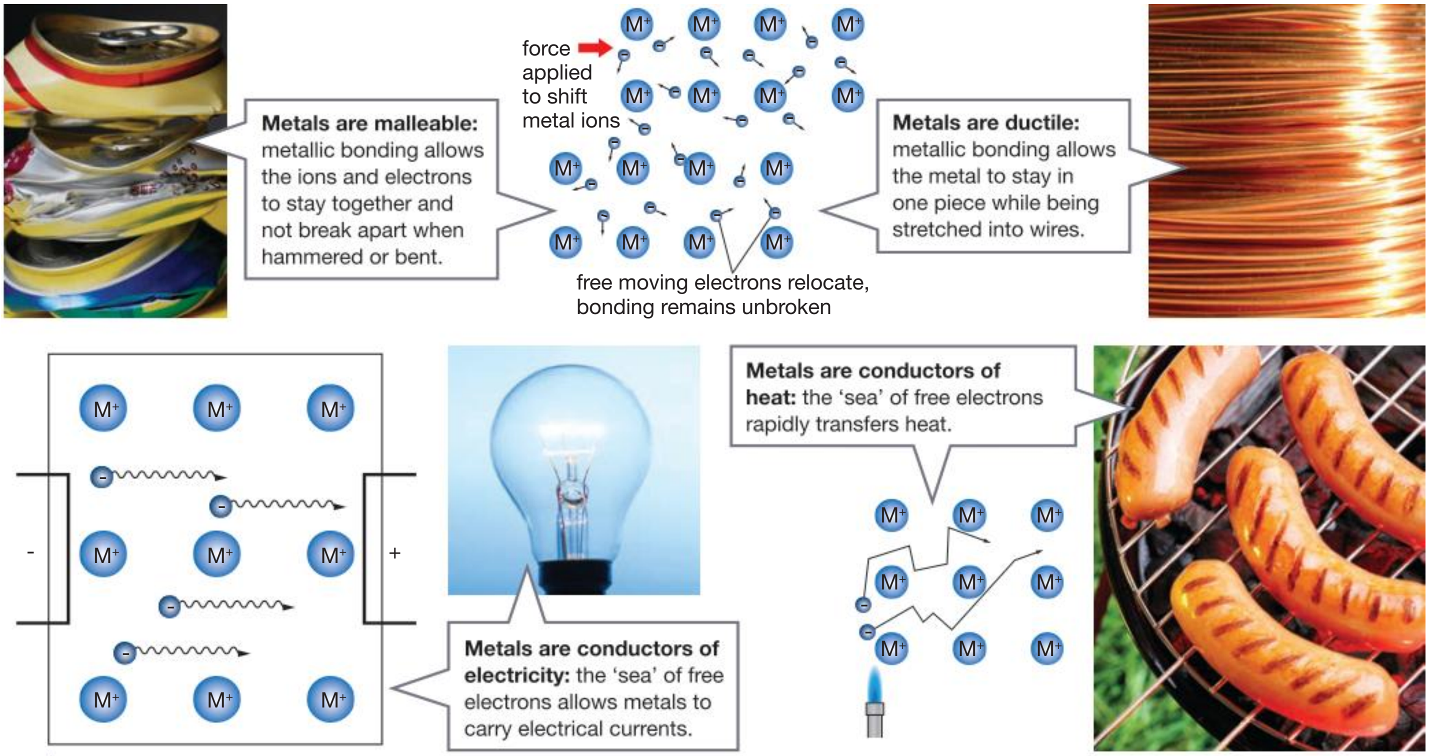


Figure 4.3.3 Each metal ion is attracted to the 'sea' of outer-shell electrons released from all the metal atoms within the lattice. This mutual attraction bonds the metal together.

Ionic bonding

Ionic bonding occurs when metallic elements bond with non-metallic elements. Metal atoms have only a weak hold on their outer-shell electrons. In contrast, non-metallic atoms have a strong hold on their own electrons, and tend to remove outer-shell electrons from any metal atoms nearby. This causes ions to form.

Electrostatic forces pull the positive and negative ions together to form a strong ionic bond. Each ion is surrounded by ions of the opposite charge, building up a three-dimensional structure called a **lattice**. The process is shown in Figure 4.3.4.

The ionic bonding model explains all the important properties of ionic substances, including how they conduct electricity. When solid, ionic substances don't conduct because the ions are bonded within their lattice. When molten or dissolved in water, these ions separate from one another. This allows the ions to conduct an electric current. This current can then light up a globe as in Figure 4.3.5.

Figure 4.3.5 Ionic substances only conduct electricity when molten or dissolved in water.

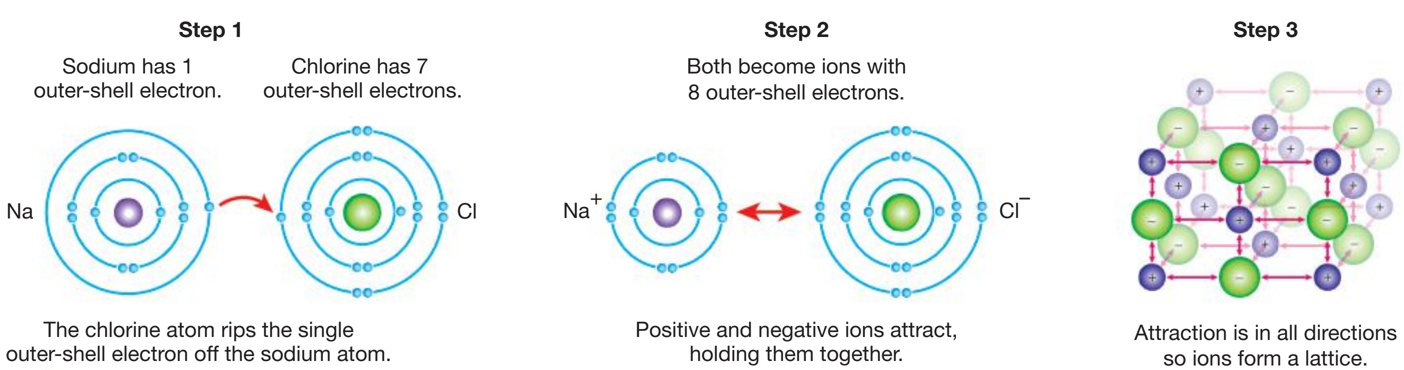


Figure 4.3.4 Ionic bonding holds table salt (sodium chloride, NaCl) together.

Predicting charges of positive ions

Positive ions form when a metal atom loses its outer-shell electrons to obtain the electron configuration of a noble gas. For the metals in groups 1, 2, 13 and 14, their charge is the same as the last digit in the group number.

For example, sodium is in group 1 and so it loses its single outer electron when it becomes an ion. This gives it a single positive charge (+1). Its symbol is Na^+. Likewise, calcium is in group 2 and forms Ca^{2+} ions, while tin is in group 14 and forms Sn^{4+} ions. Other examples of metal atoms forming ions are shown in Table 4.3.1.

Table 4.3.1 Predicting charges of metal ions

Element	Group number	Electron configuration	Loses	Charge formed	Ion formed
Lithium Li	1	2,1	1 electron	+1	Lithium ion Li^+
Beryllium Be	2	2,2	2 electrons	+2	Beryllium ion Be^{2+}
Sodium Na	1	2,8,1	1 electron	+1	Sodium ion Na^+
Magnesium Mg	2	2,8,2	2 electrons	+2	Magnesium ion Mg^{2+}
Aluminium Al	13	2,8,3	3 electrons	+3	Aluminium ion Al^{3+}

The metal atoms of groups 3–12 generally form ions with a charge of +1 or +2. Some, like copper and iron, form multiple charges; for example, Cu^+ and Cu^{2+}, Fe^{2+} and Fe^{3+}. Unfortunately, these charges cannot be predicted and so you just need to remember them.

Predicting charges of negative ions

Negative ions form when atoms of non-metals remove electrons from metal atoms. The number of electrons they remove is always enough to form an outer shell of 8 electrons.

For example, sulfur is in group 16 and so it gains an additional two electrons, giving it a charge of –2. The ion's new symbol is S^{2-} and is now called sulfide.

Other examples of non-metals forming ions are shown in Table 4.3.2. Figure 4.3.6 summarises the charges formed by various positive and negative ions.

Table 4.3.2 Predicting charges of non-metal ions

Element	Group number	Electron configuration	Gains	Charge formed	Ion formed
Carbon C	14	2,4	4 electrons	–4	Carbide ion C^{4-}
Nitrogen N	15	2,5	3 electrons	–3	Nitride ion N^{3-}
Oxygen O	16	2,6	2 electrons	–2	Oxide ion O^{2-}
Fluorine F	17	2,7	1 electron	–1	Fluoride ion F^-
Phosphorus P	15	2,8,5	3 electrons	–3	Phosphide ion P^{3-}
Sulfur S	16	2,8,6	2 electrons	–2	Sulfide ion S^{2-}
Chlorine Cl	17	2,8,7	1 electron	–1	Chloride ion Cl^-

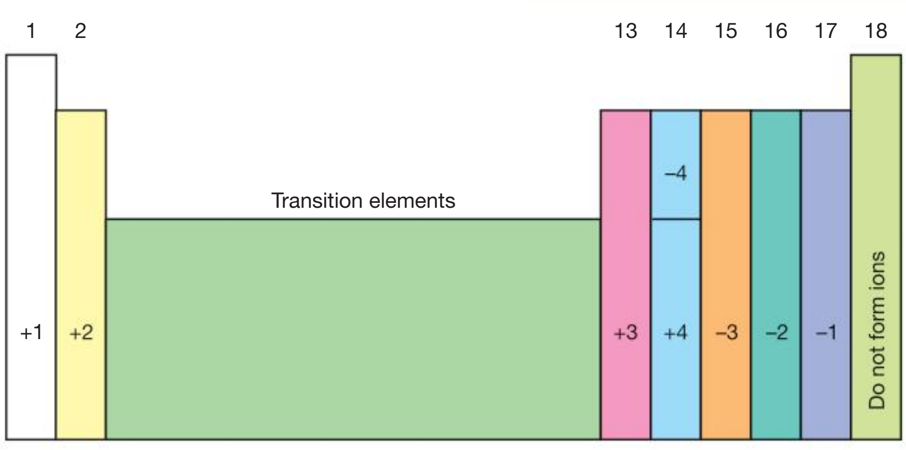


Figure 4.3.6 The group number of an element can be used to predict the charges of any ions formed.

Covalent bonding

Covalent bonding happens when non-metallic atoms bond with each other. Non-metals have the ability to remove electrons from metals but they can't do this to other non-metals. Instead, they share some of their outer-shell electrons. Covalent bonds happen when two non-metals share one or more pairs of outer-shell electrons. If one pair is shared, then one electron from each atom forms the bond. The shared grip on these electrons holds the two atoms together. It's a little like what is happening in Figure 4.3.7.

Figure 4.3.7

Covalent bonding is a bit like two people struggling for the same chair. When both are of the same strength, neither will be able to take the chair off the other. Instead both will continue to hold the chair, indirectly joining them together.

Non-metals only share enough electrons to fill their outer shell or to have eight electrons in it. For example, three additional electrons would fill the outer-shell of nitrogen (electron configuration 2,5). Therefore, a nitrogen atom must pair up three of its electrons with three electrons from other non-metallic atoms. This results in three covalent bonds. Figure 4.3.8 shows that nitrogen can form these three bonds in different ways.

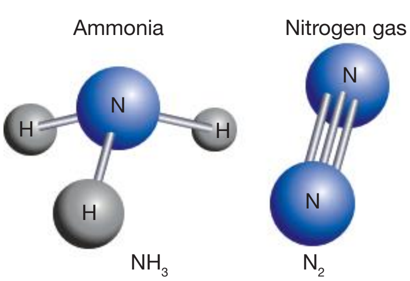


Figure 4.3.8

Nitrogen needs three extra electrons and so forms three single covalent bonds or a triple covalent bond.

Covalent bonding usually results in the formation of discrete groupings of atoms known as **molecules**. Figure 4.3.9 shows just two of the molecules in which oxygen is bonded covalently.

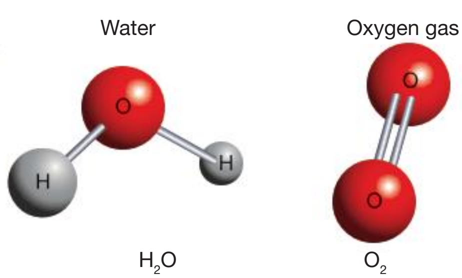


Figure 4.3.9

Oxygen needs two extra electrons and so forms two single covalent bonds or a double covalent bond.

Although carbon forms the basic backbone of millions of different types of molecules, it can also use covalent bonding to form extended lattices of graphite and diamond, shown in Figure 4.3.10.

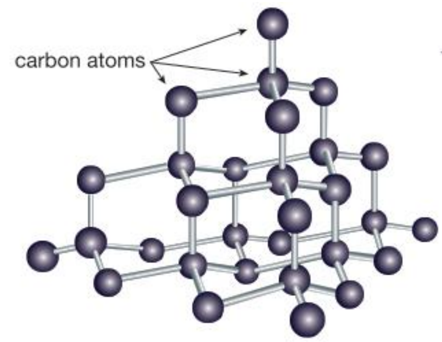


Figure 4.3.10

Carbon's ability to form four covalent bonds allows it to form the incredibly strong structure of diamond.

p128

INQUIRY science 4 fun

A rough diamond

What does the structure of diamond look like?

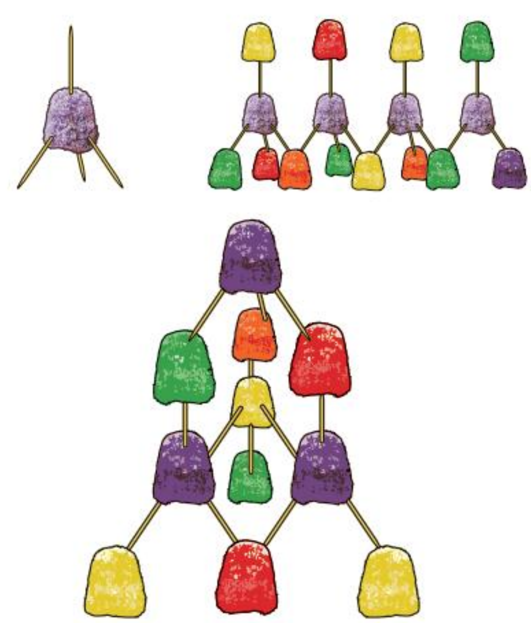
Yes

Collect this ...

- lollies such as fruit pastilles or raspberries
- toothpicks
- heavy book

Do this ...

1. Insert four toothpicks into a lolly so that they form a tetrahedron or triangular pyramid like that shown below.
2. Attach more lollies and toothpicks until you have diamond!
3. Once built, place the book on top of your structure and push lightly down.



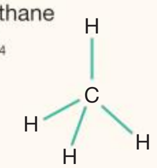
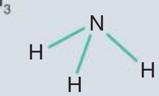
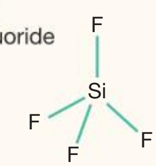
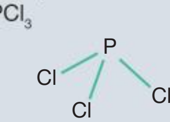
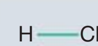
Record this ...

Describe how strong your structure was.
Explain why you think this happened.

Predicting the number of covalent bonds

Non-metals form covalent bonds in order to obtain the same electron configuration as a noble gas. Therefore, the number of covalent bonds formed is equal to the number of electrons they need. This is shown in Table 4.3.3.

Table 4.3.3 Predicting number of covalent bonds

Element	Group number	Electron configuration	Number of electrons needed	Number of covalent bonds formed	Example
Carbon C	14	2,4	4	4	Methane CH_4 
Nitrogen N	15	2,5	3	3	Ammonia NH_3 
Oxygen O	16	2,6	2	2	Oxygen gas O_2 
Fluorine F	17	2,7	1	1	Fluorine gas F_2 
Silicon Si	14	2,8,4	4	4	Silicon tetrafluoride SiF_4 
Phosphorus P	15	2,8,5	3	3	Phosphorus trichloride PCl_3 
Sulfur S	16	2,8,6	2	2	Sulfur monoxide SO 
Chlorine Cl	17	2,8,7	1	1	Hydrogen chloride (hydrochloric acid) HCl 

4.3 Unit review

Remembering

1 **State** whether the following elements have a high or low attraction for outer-shell electrons.
  a metals
  b non-metals

2 **Recall** the different types of bonding by matching them with the correct combination of elements.

a	metallic	i	metal/non-metal
b	ionic	ii	non-metal/non-metal
c	covalent	iii	metal/metal

3 **Recall** the different types of bonding by matching them with the term that best identifies them:

a	metallic	i	shared electrons
b	ionic	ii	electron sea
c	covalent	iii	charged atoms

4 Below are eight fragments of sentences. Arrange them to form two complete sentences that **recall** the formation of ions.

Metal atoms ...
Non-metal atoms ...

... gain electrons ...
... lose electrons ...

... to form positive ions, ...
... to form negative ions, ...

... which have more protons than electrons.
... which have more electrons than protons.

5 **Name** the ions formed from the following atoms.
  a sodium
  b chlorine
  c oxygen

6 **Name** two forms of carbon that are lattice structures.

Understanding

7 **Define** the term *monatomic*.

8 **Explain** why the noble gases tend not to form bonds.

9 **Explain** why metals are good electrical conductors.

10 **Define** the terms:
  a malleable
  b ductile.

11 **Outline** how sodium and chlorine atoms eventually form a lattice of sodium chloride

12 **Explain** why molten and dissolved sodium chloride conduct electricity but solid sodium chloride doesn't.

13 **Explain** why sodium chloride is neutral with no overall charge despite it being constructed of charged ions.

14 **Explain** why ionic substances form lattices instead of molecules.

Applying

15 **Use** the metallic bonding model to **explain** why metals don't tend to break when bent.

16 **Use** the structure of diamond to **explain** why it is so strong.

17 **Use** the following electron configurations to **predict** the likely charges of ions formed from the following atoms.
  a Mg (2,8,2)
  b fluorine (2,7)
  c lithium (2,1)
  d phosphorus (2,8,5)

18 **Use** the periodic table to **predict** the likely charges of ions formed by atoms of the following elements.
  a Br
  b Sr
  c Se
  d Fr

19 **Identify** the missing information to complete the following table.

Number of protons	Number of neutrons	Number of electrons	Overall charge	Atom or ion?	Symbol
8	6	10			
10	10	10			
13	15	10			
	18	18	–1		
19	20		+1		K^+

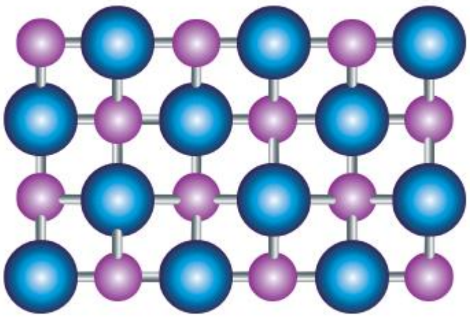
20 **Use** the ionic bonding model to **explain** why ionic substances conduct electricity when molten but not when solid.

21 **Use** the periodic table and group number to **predict** the number of covalent bonds formed by the following non-metals.
  a O
  b N
  c Cl
  d Si

Analysing

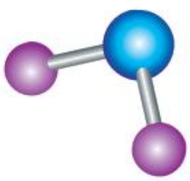
22 **Classify** the following diagrams as representing an atom, a molecule or a lattice.

a



b

c

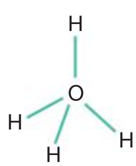


23 Molecules of hydrogen, oxygen and nitrogen all have two atoms in them. Their formulas are H_2, O_2 and N_2. **Compare** the bonding in these molecules by listing their similarities and differences.

Evaluating

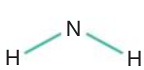
24 **Assess** whether the following molecules are likely or not by counting the number of bonds in them.

a

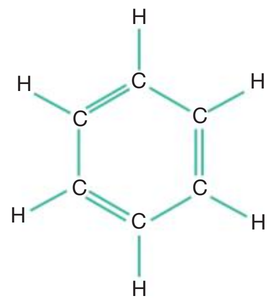


b

c



d



e

25 You don't need to worry about the number of neutrons when calculating the charge of an ion. **Propose** a reason why.

Inquiring

1. Research the noble gases, their uses and their discovery.
2. Within the shells are subshells named s, p, d and f. They explain the existence of the transition elements, lanthanides and actinides. Find diagrams of what these subshells look like.
3. Research the bonding that takes place in graphite and use it to explain why graphite is an electrical conductor.

Figure 4.3.11 These three electrodes are made up of graphite and have just been removed from an electric arc furnace used to make steel.

4.3 Practical activities

1 Model building

Purpose

To construct models of molecules and lattices.

Materials

- chemistry atomic model kit

Procedure

1 Use the model kit to construct lattices of the following. Then test the structure as suggested.

Diamond, C

- Use identical pieces that have four 'pegs' arranged in a tetrahedron.
- Test how rigid the structure is by lightly squashing it.

Graphite, C

- Use identical pieces that have three 'pegs' arranged as a three-point star.
- Test how easy it is to slide one layer over another.

Sodium chloride, NaCl

- Use two colours and pieces that have six 'pegs'.
- Test how rigid the structure is by lightly squashing it.

2 Use the model kit to construct molecules of the following.

Water, H_2O

- For the O atom, use a piece with four 'pegs', but only use two of them.
- For the H atoms, use a piece with one 'peg' only.

Ammonia, NH_3

- For the N atom, use a piece with four 'pegs', but only use three of them.
- For the H atoms, use a piece with one 'peg' only.

Methane, CH_4

- For the C atom, use a piece with four 'pegs'.
- For the H atoms, use a piece with one 'peg' only.

Extension

3 Use the model kit to design and construct different molecules. Make sure you use every peg or hole in every piece you use.

4 Write the chemical formula for each of the molecules you construct.

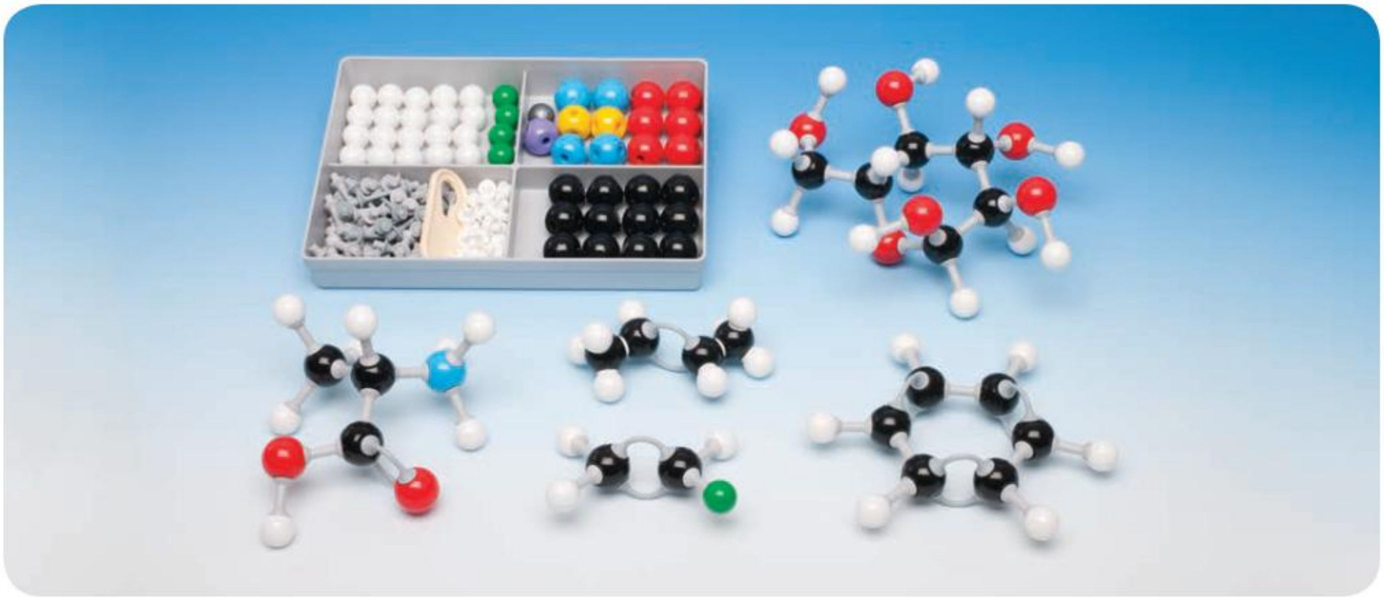
Discussion

1 **Describe** how the lattice structure of diamond makes it incredibly strong.

2 Use the periodic table to **propose** another element that could be expected to form a similarly shaped and strong lattice as diamond.

3 Atoms bond to obtain the same electron configuration as a noble gas. To do this they form bonds and electron pairs. **State** how many electron pairs should be around most atoms in the molecules you constructed.

4 The pieces chosen to represent hydrogen only had one 'peg' and not the four suggested for other pieces in the molecules. Use electron configuration to **explain** why.



4.4 Family groupings

Look at your family carefully and you'll probably notice some similarities. It might be hair colour, nose or shape of their chins. There will also be many differences. The elements in each group of the periodic table have family resemblances too in the way they look and the way they react.

Similar but different

The elements of any particular group in the periodic table all have the same number of outer-shell electrons. For this reason, they tend to form ions of the same charge or have the same number of covalent bonds when forming a molecule. This causes most compounds constructed from them to be similar.

For example, every element in group 2 is a solid metal. When bonding with a non-metal, each forms an ion carrying a charge of +2. For this reason, they all form similar ionic compounds with chlorine, with the same 1:2 ratio of metal to chlorine. This is shown in their formulas $MgCl_2$, $CaCl_2$, $SrCl_2$ and $BaCl_2$.

Likewise, each of the elements of group 17 form the same number of covalent bonds and therefore form similar molecules, such as HF, HCl, HBr and HI.

However, the elements in each group are not the same. This is because every new period represents a new shell being added to the atom. Therefore, the outer electrons are a little further out from the nucleus and held less tightly. Hence, a gradual change in physical and chemical properties is observed as you move down through the atoms in each group.

Predicting chemical equations

Elements of the same group tend to react in very similar ways and so a balanced chemical equation for one element can be used to predict the reactions for other elements in the group. For example, the balanced formula equation for the reaction of fluorine with hydrogen sulfide is:

$$F_2 + H_2S \rightarrow S + 2HF$$

The other group 17 elements will react in similar ways and so it can be expected that their balanced formula equations will be similar too. Hence, you can predict that their reactions will most likely be:

$$Cl_2 + H_2S \rightarrow S + 2HCl$$
$$Br_2 + H_2S \rightarrow S + 2HBr$$
$$I_2 + H_2S \rightarrow S + 2HI$$

Groups 1 and 2—alkali metals and alkaline earths

The group 1 elements shown in Figure 4.4.1 are known as the **alkali metals**. The group 2 elements are known as the **alkaline earths**. All the alkali metals:

- form +1 ions
- are far too reactive to be found naturally in their pure forms
- have typical metallic properties
- display similar extreme chemical behaviour.

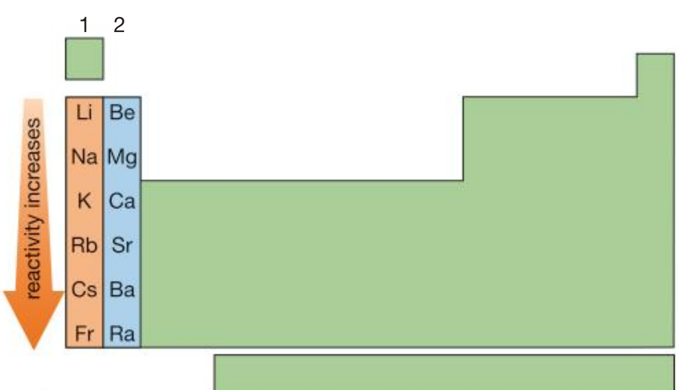


Figure 4.4.1 The alkali metals are group 1 and alkaline earths are group 2.

Lithium, sodium and potassium are light enough to float on water and are so soft that they can be cut with a knife. They all react with chlorine gas (and the other group 17 elements) and produce similar white salts. For example, lithium reacts with chlorine gas to form lithium chloride. This can be written as the balanced formula equation:

$$2Li + Cl_2 \rightarrow 2LiCl$$

From this equation, you can predict the equations for the other alkali metals and other group 17 elements. These equations are:

$$2Na + Cl_2 \rightarrow 2NaCl$$
$$2K + Br_2 \rightarrow 2KBr$$
$$2Li + F_2 \rightarrow 2LiF$$

All alkali metals react violently with water, producing an alkaline or basic solution and hydrogen gas, which sometimes ignites due to the heat produced. This is what has happened in Figure 4.4.2. For sodium, the balanced formula equation is:

$$2Na + 2H_2O \rightarrow 2NaOH + H_2$$

The other alkali metals will do much the same:

$$2Li + 2H_2O \rightarrow 2LiOH + H_2$$
$$2K + 2H_2O \rightarrow 2KOH + H_2$$

Figure 4.4.2 An accident in which sodium was accidentally dropped into water. Reactions of this type become even more violent as you move down group 1.

Trends in chemical activity of metals

Metal atoms have a weak hold on their outer-shell electrons. As you move down a group, extra shells are added and so this hold gets even weaker. This makes the metal more unstable and more reactive. Lithium atoms are the smallest in group 1 and lithium metal fizzes when put in water. Sodium atoms are a little bigger and can react explosively with moisture in the air. Reactions with moisture become even more violent as you move down group 1. To avoid this happening accidentally, alkali metals are usually stored in paraffin oil to keep them moisture-free.

1 p135

Group 2 metals all act in a similar, but slightly less reactive, way to group 1.

Group 14

The elements of group 14 display a wide range of properties (Figure 4.4.3). The group begins with the non-metal carbon, moves through the metalloids silicon and germanium and finishes with the metallic elements tin and lead.

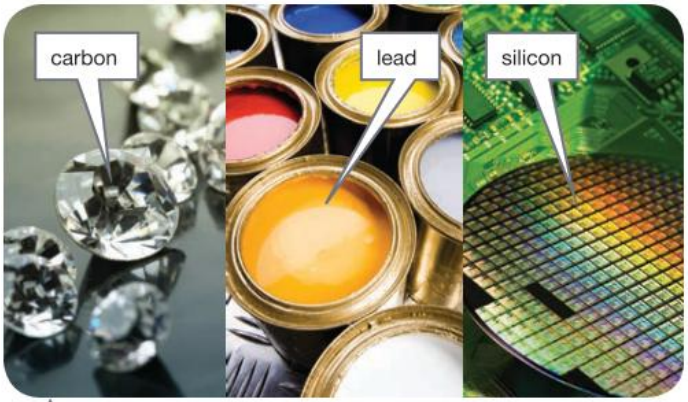


Figure 4.4.3 Group 14 elements

Pure carbon exists in several different forms or **allotropes**, the most common being amorphous carbon (charcoal), diamond, graphite and buckyballs. The molecular structures of the four allotropes of carbon are all different.

Carbon is also in molecules in every living thing on Earth, and anything that was once living such as wood.

A carbon atom forms four covalent bonds when it joins with other carbon atoms or the atoms of other non-metals. This gives carbon the ability to form an amazing range of molecules. Substances that have carbon skeletons like those in Figure 4.4.4 are known as **organic** substances and their molecules are **organic molecules**. Organic molecules make up all living things, fossil fuels and plastics (more correctly known as polymers).

Silicon is found as silicon dioxide and metal silicates. Together they make up 75% of the Earth's crust—sand, clay, asbestos and quartz contain silicon as do many gemstones (like the one in Figure 4.4.5). Silicon is the major component of glass.

Mendeleev predicted the existence of germanium 15 years before its discovery, naming it eka-silicon. Germanium is used as the catalyst in fluorescent lights and its oxides are used in the production of lenses for optical instruments such as microscopes. Both silicon and germanium are semiconductors and are widely used in electronic components.

Tin and lead are metals and have characteristic metallic properties. They are malleable (able to be bent), ductile (able to be stretched into wires), lustrous (shiny when polished) and electrical and thermal conductors.

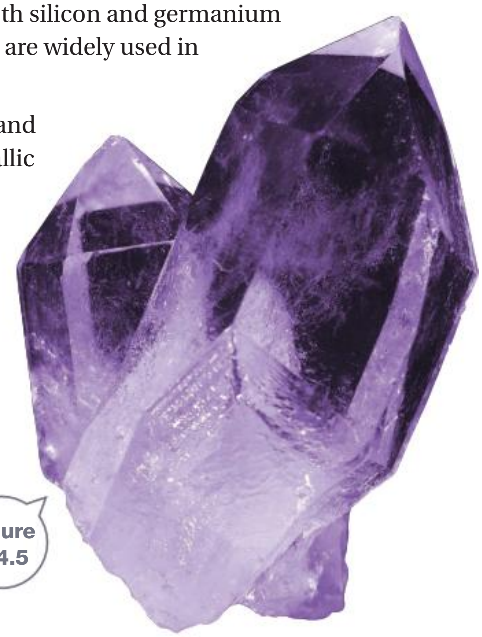


Figure 4.4.5 Silicon dioxide is the main component of many precious and semiprecious gemstones such as this amethyst.

Figure 4.4.4 There are more compounds of carbon than any other element on Earth. Organic compounds form the basis for all life on Earth, all fossil fuels and all plastics.

Group 17—the halogens

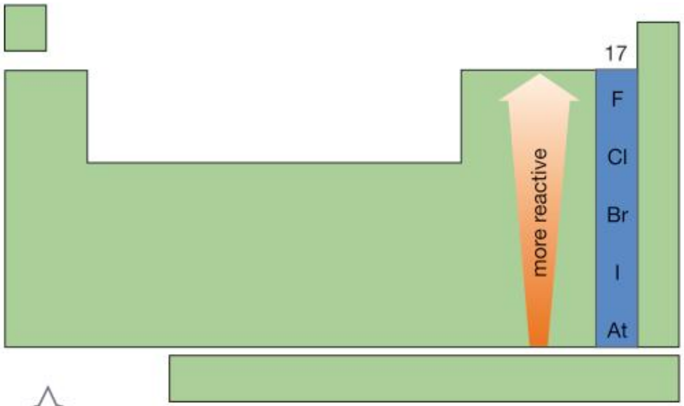


Figure 4.4.6 The halogens

The group 17 elements shown in Figure 4.4.6 are known as the **halogens**. Atoms of halogens:

- form ions with a charge of –1
- are not found in nature in their pure form but are found in various types of salts, including sea salt
- get bigger and become less reactive as you move down the group
- all form molecules, each being made up of two atoms (F_2, Cl_2, Br_2 and I_2). You can see this in Figure 4.4.7
- have coloured and poisonous vapours (Figure 4.4.8).

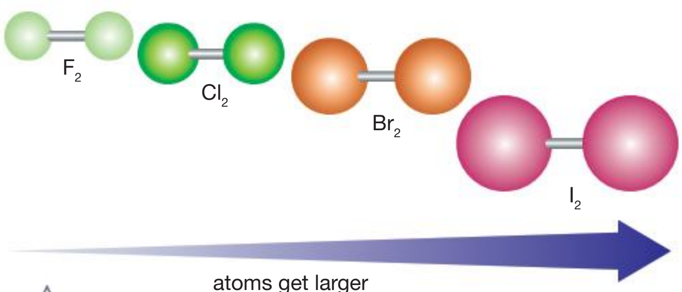


Figure 4.4.7 Although the halogens have similarities, their different sizes result in some differences in their properties.

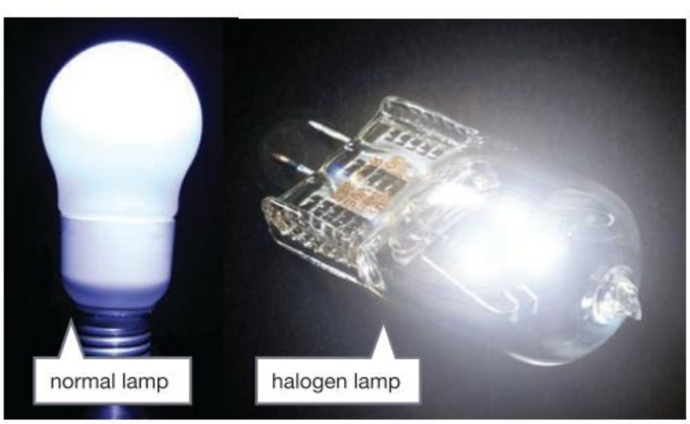


Figure 4.4.8 Halogen lamps are filled with a noble gas with a trace of a halogen such as iodine or bromine. Halogen lights are much brighter than normal globes.

All of the halogens convert hydrogen sulfide (H_2S, known as 'rotten egg' gas) into sulfur (S). These reactions also form very similar gases composed of hydrogen and the halogen, such as hydrogen chloride. These reactions can be written as balanced formula equations:

$$F_2 + H_2S \rightarrow S + 2HF$$

$$Cl_2 + H_2S \rightarrow S + 2HCl$$

As Figure 4.4.9 shows, they also react in a similar way with iron.

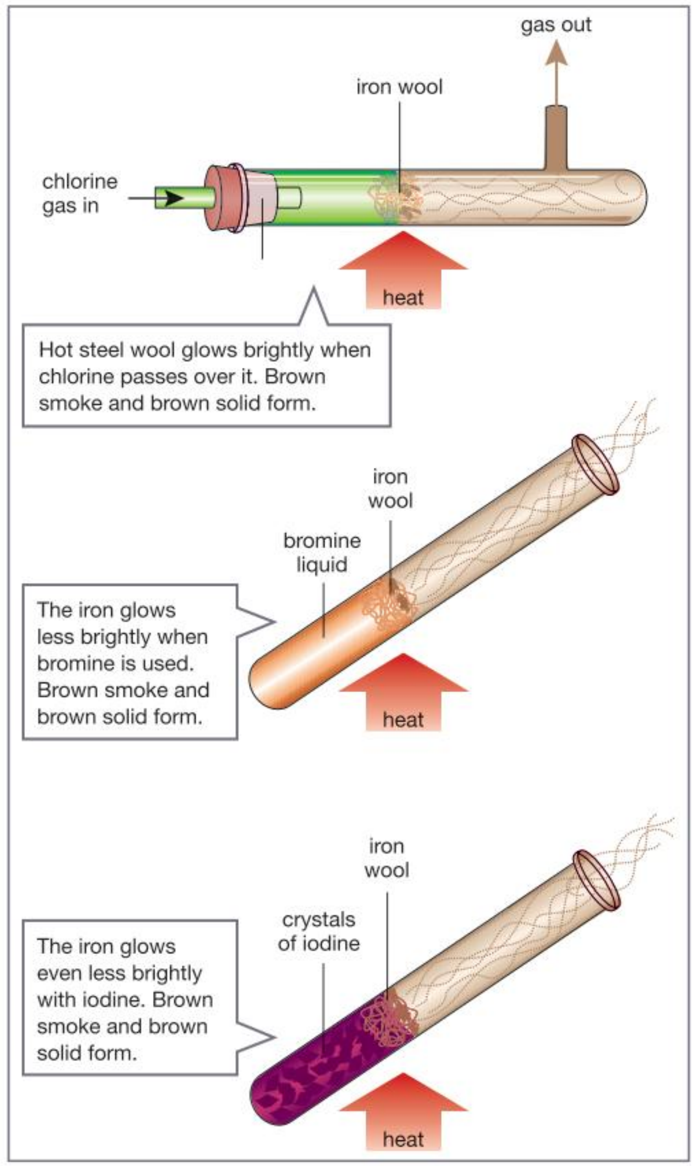


Figure 4.4.9 Each of the halogens reacts with iron in a very similar way, forming very similar products.

3 p137

SciFile

Quiet children!

Bromine forms the bromide ion, the salts of which were used as sedatives in the 19th century. Bromide salts were given to some children by providing them with their own saltshaker at dinner time. That kept them quiet!

Group 18—the noble gases

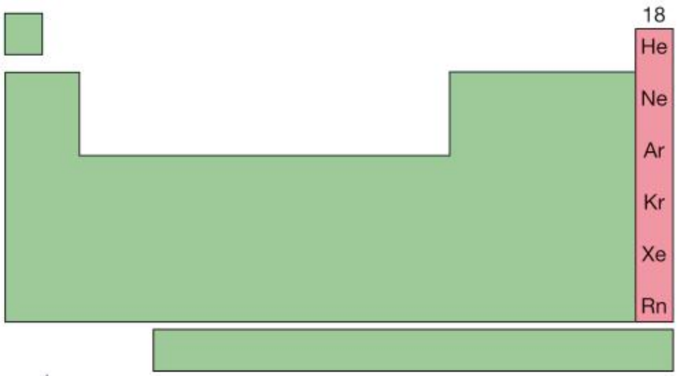


Figure 4.4.10 The noble or inert gases

The noble gases of group 18 (shown in Figure 4.4.10) are colourless and occur naturally in the atmosphere. Distillation is used to separate them from liquid air. They are incredibly stable and react only under rare and extreme circumstances. Helium is safe and light enough to be used for party balloons and for airships (unlike the alternative hydrogen, which is explosive). Balloons of the other noble gases get progressively heavier. This is shown in Figure 4.4.11.

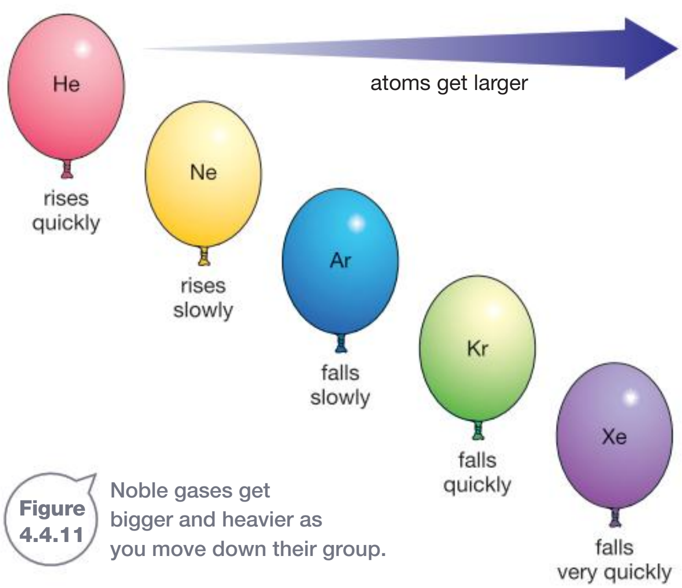


Figure 4.4.11 Noble gases get bigger and heavier as you move down their group.

SciFile

Squeaky voices

Your voice goes high and squeaky when you breathe in helium from a party balloon. Your vocal cords vibrate more quickly in helium because it is lighter than air, making the pitch go higher. Don't try this, though. People have died from breathing in gases such as helium.

The transition metals

The transition elements (groups 3–12) are all metals and include many of our most useful, colourful and valuable ones such as iron, copper, zinc, gold and silver. Their salts and solutions are also colourful—some are shown in Figure 4.4.12. The transition metals have very similar properties. For example, they all tend to be relatively hard with high melting points. Likewise, the period 4 metals iron, cobalt and nickel are all magnetic, despite being in different groups.

SciFile

Scandium, agent Sc-46!

The East German secret police (the Stasi) regularly sprayed opponents of the government (dissidents) with radioactive scandium, $^{46}_{21}Sc$. The unknowing dissidents were then traced with a Geiger counter strapped under the armpits of Stasi agents. Vibrations alerted the agent that their trace was nearby. The Stasi also used radioactive silver bullets that could be safely shot into the tyres of cars they wanted to track.

Figure 4.4.12 These solutions of transition metals show how colourful transition metals can be.

4.4 Unit review

Remembering

1 **State** the group number of the following 'families' of elements.
  - a alkali metals
  - b alkaline earth metals
  - c halogens
  - d noble gases

2 **Name** the alkali metal that would be the:
  - a smallest atom
  - b most reactive.

3 **Name** an element that has similar properties to:
  - a potassium (K)
  - b calcium (Ca)
  - c oxygen (O).

4 **Name** three allotropes of carbon.

5 **State** the chemical formulas for molecules of fluorine and molecules of chlorine.

6 **Name** the separation method that is used to separate noble gases from air.

Understanding

7 **Explain** why helium is used instead of hydrogen in airships.

8 Carbon has a unique ability to form the backbone of many long chain-like molecules. **Describe** the feature of carbon atoms that enables it to do this.

Applying

9 **Use** the electron configuration of oxygen and sulfur to **explain** why they form similar molecules such as H_2O and H_2S.

10 **Use** family resemblances and the balanced formula equations given in this unit to **predict** the reactions of:
  - a sodium (Na) and water (H_2O)
  - b rubidium (Rb) with water (H_2O)
  - c lithium (Li) with iodine (I_2)
  - d sodium (Na) with bromine (Br_2).

11 **Identify** the chemical formulas missing from each of the following balanced formula equations.
  - a $F_2 + H_2S \rightarrow \ldots + 2HF$
  - b $2Na + Br_2 \rightarrow 2\ldots$
  - c $2Na + 2\ldots \rightarrow 2NaOH + H_2$

Analysing

12 The noble gases and halogens are non-metals yet are very different from each other. **Contrast** these two groups.

13 **Compare** the alkali metals with the alkaline earths by listing their similarities and differences.

Evaluating

14 All the noble gases except radon (which is radioactive) could be used in party balloons but helium is the best. **Propose** a reason why.

15 Tin acts like a non-metal below 13°C. In 1913 Captain Robert Scott and two fellow explorers froze to death in Antarctica after they ran out of heating fuel that was stored in tins. **Use** the properties of metals and non-metals to **propose** reasons why they unexpectedly ran out.

Creating

16 The melting and boiling points for each of the halogens are shown below.
  - a **Identify** which halogens would be solid, liquid or gas at the following temperatures.
    - i 20°C
    - ii 100°C
    - iii –199°C
    - iv 150°C
  - b **Use** a spreadsheet or graph paper to **construct** accurate line graphs of the:
    - i melting point versus period number
    - ii boiling point versus period number.

Period number	Group 17 element	Melting point (°C)	Boiling point (°C)
2	Fluorine F	–220	–188
3	Chlorine Cl	–101	–35
4	Bromine Br	–7	59
5	Iodine I	114	185

Inquiring

1 a Research the uses for the alkali metals, alkaline earths, halogens and/or noble gases.
  b Construct a table to summarise your findings.

2 Some metals such as lead and mercury are known as cumulative poisons. Research what this means, the symptoms of cumulative poisoning and how you might come into contact with these metals.

4.4 Practical activities

1 The alkaline earths

Purpose

To investigate the reactivity of group 2, the alkaline earth elements.

SAFETY

Do not handle calcium metal with your bare hands because it reacts with moisture.

Wear safety glasses at all times.

Materials

- 2 test-tubes and rack
- 1 rubber stopper with hole and glass tubing
- 1 rubber stopper with no hole
- 250 mL beaker
- Bunsen burner, tripod, bench mat and matches
- distilled or de-ionised water
- 1 × 5 cm strip of magnesium
- steel wool or emery paper
- phenolphthalein solution
- small sample of calcium
- tweezers

Procedure

Part A

1. Clean the magnesium strip with steel wool or emery paper and then form it into a coil.
2. Place the coil in a test-tube and cover it with distilled water.
3. Watch *very* carefully over the next 5 minutes. Look for bubbles.
4. If nothing happens, heat it gently over a yellow flame (Figure 4.4.13).
5. When finished, add 1 drop of phenolphthalein to the solution. Record the colour.

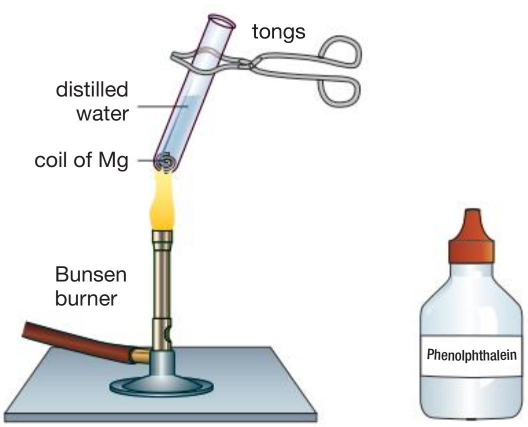


Figure 4.4.13

Part B

1. Put about 5 cm of distilled water into the other test-tube.
2. Using tweezers, add a piece of calcium. Immediately stopper the test-tube with the single-holed rubber stopper and collect any gas generated as shown in Figure 4.4.14.
3. Once the inverted test-tube is filled with gas, remove and stopper it.
4. Light a match, remove the stopper and place the match near the opening of the test-tube filled with gas. Record what happens and use the following guide to identify the gas.
   - If the match pops, then the gas is hydrogen.
   - If the match goes out, then the gas is carbon dioxide.
   - If the match flares up, then the gas is oxygen.
5. Add one drop of phenolphthalein to the test-tube that contained the water and calcium. Record the colour.

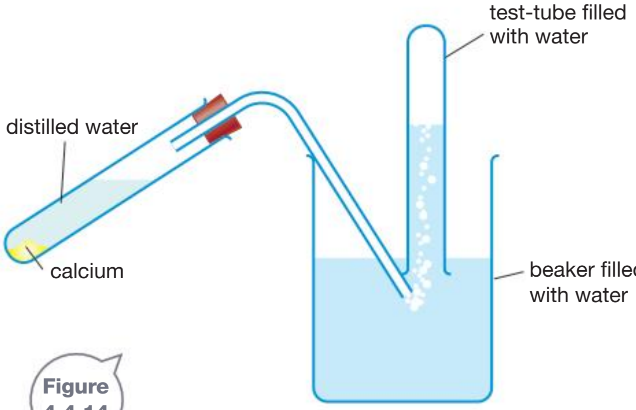


Figure 4.4.14

Discussion

1. From your observation, **state** whether Mg or Ca is more reactive.
2. **Describe** what happens to reactivity as you move down group 2.
3. Group 1 metals are more reactive than group 2 metals. **Propose** a reason why reactions of group 1 metals are rarely performed in class except as teacher demonstrations.

4.4 Practical activities

2 Making casein plastic

Casein was an early plastic that is still used for buttons and some wood glues. It is hardened industrially with formalin.

Purpose

To make a simple plastic and test its properties.

Materials

- full-cream milk
- vinegar
- hotplate or Bunsen burner, bench mat, tripod and gauze mat
- 100 mL measuring cylinder
- 2 × 250 mL beakers
- thermometer
- glass stirring rod
- elastic band
- coarse cloth for straining
- paper towel/filter paper
- assorted moulds (such as bottle caps, moulded chocolate trays)
- fine sandpaper
- tongs

SAFETY

Turn the Bunsen burner to the yellow flame or off when not using it.

Tie long hair back.

Procedure

1 Place 100 mL of milk in one of the beakers. Warm it gently over the hotplate or Bunsen burner until the milk reaches 50°C as shown in Figure 4.4.15. Do not overheat it.

2 Add 10 mL of vinegar and stir it with the stirring rod. Record what happens.

3 The milk should curdle to form white lumps of (casein) and yellowish liquid called whey. Record what it looks and smells like.

4 Secure the piece of cloth tightly over the other beaker and strain through the curds and whey.

5 Carefully remove the cloth and squeeze it to remove as much liquid as you can.

6 Empty the curds (casein) onto the paper towel/filter paper. Pat them dry, then firmly press into moulds. Leave the casein to dry in the sun.

7 After a couple of days, remove the mould and polish the casein with the sandpaper.

8 Use tongs to hold a small amount of the dry casein in a Bunsen flame. Record whether it melts, burns or chars (goes black).

Extension

9 Casein can be used to make a glue that will stick wood together. Search the internet for a procedure that uses casein to make wood glue. Show your teacher your procedure. Once you obtain their permission to proceed, carefully follow your procedure, make your glue and use it to stick two pieces of timber together (for example, two icy-pole sticks).

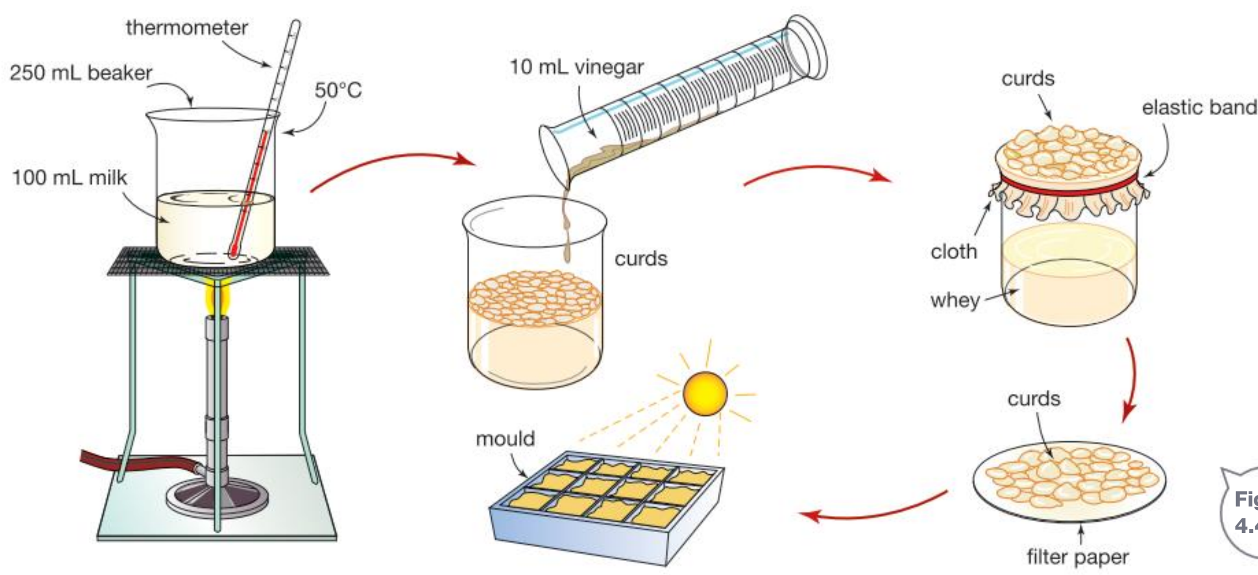


Figure 4.4.15

Results

Record your observations at each step of the practical activity.

Discussion

1 **Propose** a reason for adding the vinegar to the milk in step 2.

2 Plastics can be classified as thermoplastic or thermosetting. Thermoplastics melt when heated while thermosetting plastics burn. **Classify** casein as thermoplastic or thermosetting.

3 Plastics such as casein are organic compounds that contain carbon. **Propose** possible sources of the carbon in this experiment.

3 Halogen precipitates

Precipitates are insoluble solids that sometimes form when solutions are mixed.

Purpose

To compare the precipitates formed when lead combines with different halogens.

Materials

- disposable gloves
- white tile or spotting tray (tray with small indents)
- dropping bottles of saturated solutions of lead nitrate, potassium fluoride (KF), potassium chloride (KCl), potassium bromide (KBr) and potassium iodide (KI)
- marker pen

SAFETY

Lead is toxic. Do not get any of its compounds on you.

Wear disposable gloves and safety glasses at all times.

Wash your hands well after the activity.

Procedure

1 Put your disposable gloves and safety glasses on.

2 Place 3 drops of potassium fluoride solution in one indent of the spotting tray or on one corner of the white tile.

3 Use the marker pen to label this sample with KF.

4 In the each of the other indents or corners, place 3 drops of potassium chloride, potassium bromide or potassium iodide solutions. Label them KCl, KBr or KI respectively.

5 Add 3 drops of lead nitrate to each of the samples as shown in Figure 4.4.16. Record your observations.

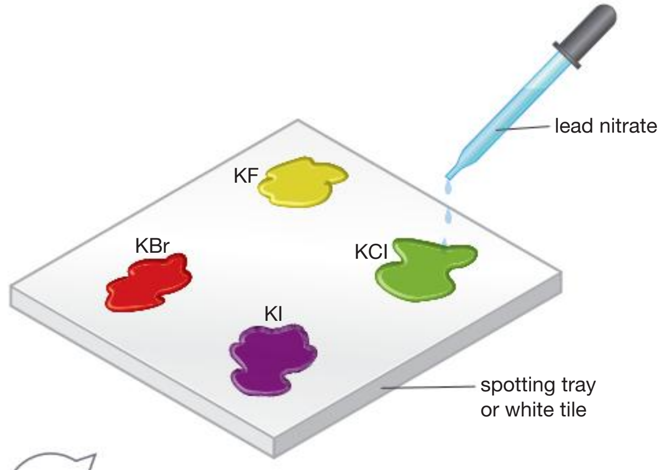


Figure 4.4.16

Results

Construct a table to display your observations.

Discussion

1 The solid formed was a precipitate. **Describe** what a precipitate is.

2 The precipitates formed were lead fluoride, lead chloride, lead bromide and lead iodide. **Compare t**he precipitates formed by listing their similarities and differences.

3 **Describe** the changes in the colour of the precipitates as you moved down group 17 from fluorine to iodine.

4 Chapter review

Remembering

1 **State** how many different elements are currently known.

2 **Name** the following elements.
a F b Ca c Na d Pb

3 **Name** the ions formed from the following atoms.
a sulfur
b aluminium
c phosphorus

4 **List** the symbols for the group 18 elements.

5 **State** the likely charges of the ions that belong in groups 1, 2 and 13–18.

Understanding

6 **Explain** why atoms are neutral, despite containing particles with positive and negative charges.

7 **Define** the following terms.
a malleable b lattice
c allotrope d organic molecule

8 a Helium could be placed in group 2. **Explain** why.
b **Explain** why helium is normally placed in group 18 instead.

9 **Outline** how a sodium ion forms.

10 **Explain** why atoms in the same group have similar properties.

Applying

11 **Identify** the following metals.
a the only metal that is a liquid at 25°C
b those in period 3
c those in group 14

12 **Identify** a non-metallic element that:
a is in group 15
b is in period 2
c has similar properties to chlorine
d would have atoms of a larger diameter than those of oxygen.

13 **Identify** which type of bonding would most likely happen between:
a identical metal atoms
b metal and non-metal atoms
c atoms of non-metals
d Na and O
e N and F
f Mg and Mg.

14 **Use** the group number of the following elements to **predict** the likely charges of the ions formed by:
a sulfur b aluminium
c potassium d nitrogen.

15 **Use** the periodic table to **predict** the number of covalent bonds formed by:
a P b S c Si d Br.

16 Carbon is a group 14 element that forms a compound CH_4. **Use** this information to **predict** the formula of compounds formed from hydrogen and the other four elements of group IV:
a silicon b germanium
c tin d lead.

17 Chlorine reacts with hydrogen sulfide in the reaction:

$$Cl_2 + H_2S \rightarrow S + 2HCl$$

Use this equation to **predict** the balanced formula equation for the reaction of the following halogens with hydrogen sulfide (H_2S).
a bromine (Br_2) b iodine (I_2)

Analysing

18 **Contrast** ionic bonding with covalent bonding.

19 **Analyse** whether the following ions are likely to exist or not.
a Br^{2-} b Sr^{2+} c Se^{3-} d Fr^{-}

Evaluating

20 Plumbing pipes were once made of lead. **Use** the symbols of the periodic table to **propose** where the words 'plumber' and 'plumbing' came from.

Creating

21 **Construct** a simple outline of the periodic table, labelling the direction the groups and periods go, the important 'family' groups and the important other blocks.

22 **Use** the following ten key terms to **construct** a visual summary of the information presented in this chapter.
row
period
group
column
electron configuration
atomic number
protons
electrons
shells
periodic table

4.7

Thinking scientifically

The periodic table below will assist you in answering these questions.

Q1 State which of the following is the correct symbol for sodium.

A So **B** Sm
C Na **D** NA

Q2 State which of the following statements is incorrect.

A Chlorine is in period 3.
B Chlorine is in group 17.
C Chlorine has the atomic number 17.
D Chlorine would react in a similar way to O, N, C and B.

Q3 Every new period represents another electron shell being added to an atom. From this information, identify the statement below that is *definitely* true.

A Helium is the biggest of all the group 18 elements.
B A sulfur atom is bigger than an oxygen atom.
C A sulfur atom is bigger than a phosphorus atom.
D A sodium atom is bigger than a potassium atom.

Q4 Atoms in the same group of a periodic table tend to form similar molecules. Carbon and chlorine form the molecule CCl_4. Use this information and the periodic table to identify which of the following molecules could not occur.

A CN_4 **B** CBr_4
C CF_4 **D** $SiCl_4$

Q5 Atoms in the same group of the periodic table tend to react in a very similar way to each other. The reaction between lithium and chlorine is:

$$2Li + Cl_2 \rightarrow 2LiCl$$

Use this information and the periodic table to identify which of the following reactions could not occur.

A $2Mg + Cl_2 \rightarrow 2MgCl$
B $2Na + Cl_2 \rightarrow 2NaCl$
C $2Na + Br_2 \rightarrow 2NaBr$
D $2K + I_2 \rightarrow 2KI$

Group

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period 1	1 **H** hydrogen																	2 **He** helium
Period 2	3 **Li** lithium	4 **Be** beryllium											5 **B** boron	6 **C** carbon	7 **N** nitrogen	8 **O** oxygen	9 **F** fluorine	10 **Ne** neon
Period 3	11 **Na** sodium	12 **Mg** magnesium											13 **Al** aluminium	14 **Si** silicon	15 **P** phosphorus	16 **S** sulfur	17 **Cl** chlorine	18 **Ar** argon
Period 4	19 **K** potassium	20 **Ca** calcium	21 **Sc** scandium	22 **Ti** titanium	23 **V** vanadium	24 **Cr** chromium	25 **Mn** manganese	26 **Fe** iron	27 **Co** cobalt	28 **Ni** nickel	29 **Cu** copper	30 **Zn** zinc	31 **Ga** gallium	32 **Ge** germanium	33 **As** arsenic	34 **Se** selenium	35 **Br** bromine	36 **Kr** krypton
Period 5	37 **Rb** rubidium	38 **Sr** strontium	39 **Y** yttrium	40 **Zr** zirconium	41 **Nb** niobium	42 **Mo** molybdenum	43 **Tc** technetium	44 **Ru** ruthenium	45 **Rh** rhodium	46 **Pd** palladium	47 **Ag** silver	48 **Cd** cadmium	49 **In** indium	50 **Sn** tin	51 **Sb** antimony	52 **Te** tellurium	53 **I** iodine	54 **Xe** xenon
Period 6	55 **Cs** caesium	56 **Ba** barium	57–71 lanthanides	72 **Hf** hafnium	73 **Ta** tantalum	74 **W** tungsten	75 **Re** rhenium	76 **Os** osmium	77 **Ir** iridium	78 **Pt** platinum	79 **Au** gold	80 **Hg** mercury	81 **Tl** thallium	82 **Pb** lead	83 **Bi** bismuth	84 **Po** polonium	85 **At** astatine	86 **Rn** radon
Period 7	87 **Fr** francium	88 **Ra** radium	89–103 actinides	104 **Rf** rutherfordium	105 **Db** dubnium	106 **Sg** seaborgium	107 **Bh** bohrium	108 **Hs** hassium	109 **Mt** meitnerium	110 **Ds** darmstadium	111 **Rg** roentgenium	112 **Cn** copernicium	113 **Uut** ununtrium	114 **Uuq** ununquadium	115 **Uup** ununpentium	116 **Uuh** ununhexium	117 **Uus** ununseptium	118 **Uuo** ununoctium

Lanthanides	57 **La** lanthanum	58 **Ce** cerium	59 **Pr** praseodymium	60 **Nd** neodymium	61 **Pm** promethium	62 **Sm** samarium	63 **Eu** europium	64 **Gd** gadolinium	65 **Tb** trebium	66 **Dy** dysprosium	67 **Ho** holmium	68 **Er** erbium	69 **Tm** thulium	70 **Yb** ytterbium	71 **Lu** lutetium
Actinides	89 **Ac** actinium	90 **Th** thorium	91 **Pa** protactinium	92 **U** uranium	93 **Np** neptunium	94 **Pu** plutonium	95 **Am** americium	96 **Cm** curium	97 **Bk** berkelium	98 **Cf** californium	99 **Es** einsteinium	100 **Fm** fremium	101 **Md** mendelevium	102 **No** nobelium	103 **Lr** lawrencium

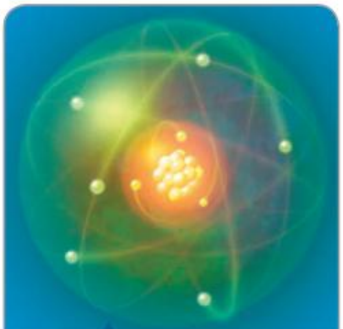
Glossary

Unit 4.1

Atomic number: number of protons in an atom

Atoms: the particles that make up all materials; the smallest part of an element that can take part in a chemical reaction

Electron configuration: arrangement of electrons in electron shells



Electron shells

Electron shells: also known as energy levels, the regions surrounding the nucleus where electrons may be found

Element: a substance composed of atoms with the same atomic number; 118 are known to exist

Energy levels: also known as electron shells, the regions surrounding the nucleus where electrons may be found

Ground state: the lowest energy arrangement of an atom's electrons in energy levels (shells)

Indirect evidence: evidence that does not involve direct observation

Nucleus: heavy core at the centre of the atom, made of protons and neutrons

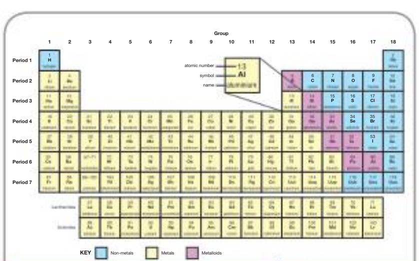
Unit 4.2

Actinides: a special block of metallic elements with atomic numbers 90–103

Groups: vertical columns of the periodic table; group number is equal to the number of electrons in the outer shell of atoms of the elements in that group

Lanthanides: a special block of metallic elements with atomic numbers 58–71

Periodic table: a list of all the known elements, arranged horizontally in order of increasing atomic number and vertically according to the number of electrons in the outer shell



Periodic table

Periods: horizontal rows of the periodic table; period number of an element is equal to the number of electron shells

Transition elements: a special block of metallic elements covering elements from groups 3–12

Unit 4.3

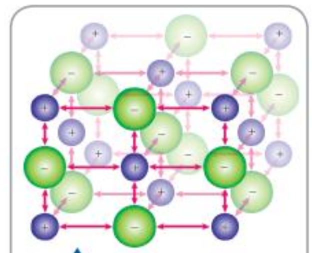
Bonds: links that join atoms together

Covalent bonding: the sharing of electrons between atoms of non-metals

Inert gases: also known as noble gases, group 18 elements known for their stability (lack of reactivity)

Ionic bonding: attraction of positive and negative ions formed from the transfer of electrons from metallic to non-metallic atoms

Ions: 'charged atoms' (or groups of atoms) formed by electrons being transferred from one atom to another



Lattice

Lattices: a regular arrangement of particles. In ionic lattices, the particles are ions; in solid molecular lattices, the particles are molecules; and in diamond and graphite, the particles are atoms

Metallic bonding: a mutual attraction between a lattice of positive metal ions and a sea of delocalised, outer-shell electrons

Molecules: discrete groupings of atoms covalently bonded together

Monatomic: atoms that exist on their own, without bonding with others

Noble gases

Noble gases: also known as inert gases, group 18 elements known for their stability (lack of reactivity)

Unit 4.4

Alkali metals: group 1 elements

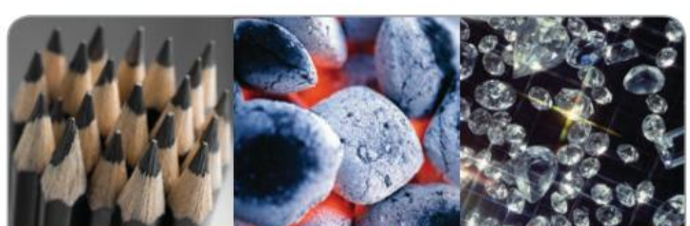
Alkaline earths: group 2 elements

Allotropes: forms of the same element that have different molecular structures and therefore different properties

Halogens: group 17 elements

Organic: compound that is or was part of a living thing; contains carbon

Organic molecules: molecules that have a backbone of carbon



Allotropes

Chemical reactions

5

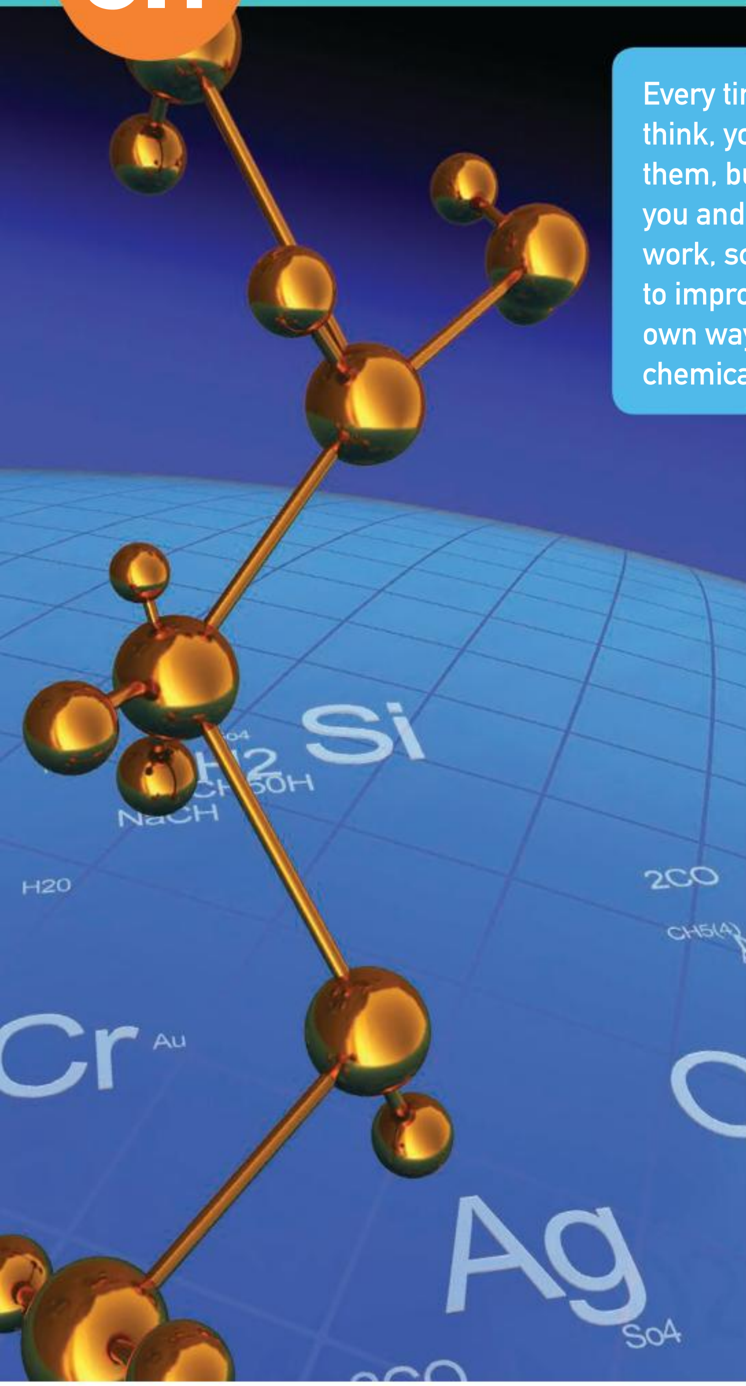
HAVE YOU EVER WONDERED...

- what makes a bullet explode?
- how a candle stays alight?
- where a battery gets its energy from?
- why you put milk in the fridge?

After completing this chapter students should be able to:

- use word and formula equations to represent chemical reactions
- predict the products of different types of simple chemical reactions
- describe how chemistry can be used to produce a range of useful substances such as fuels, metals and pharmaceuticals
- explain the effect of a range of factors including temperature, surface area, concentration, agitation and catalysts on the rate of chemical reactions.

5.1 Chemical equations



Every time you light a candle, bake a cake, take a breath or even think, you start a chemical reaction. You may not always notice them, but chemical reactions are going on constantly around you and inside you. By understanding how chemical reactions work, scientists are able to use and control chemical reactions to improve our quality of life. Chemists have developed their own way of describing and explaining what happens during a chemical reaction. They do this by writing chemical equations.

What is a chemical equation?

Chemical equations are one of the most basic tools for describing what happens during a chemical reaction. A chemical equation can communicate detailed information about any chemical reaction in a single line. The general structure of a chemical equation is:

reactants → products

where the arrow (→) means 'rearrange to form'.

Word and formula equations

Replacing the **reactants** and **products** with their chemical names gives a **word equation**. For example, when calcium carbonate ($CaCO_3$) reacts with sulfuric acid (H_2SO_4), it produces calcium sulfate ($CaSO_4$), water (H_2O) and carbon dioxide gas (CO_2). In this reaction, you have:

Reactants = calcium carbonate, sulfuric acid

Products = calcium sulfate, water, carbon dioxide gas

So the general form of an equation:

reactants → products

becomes the word equation:

calcium carbonate + sulfuric acid → calcium sulfate + carbon dioxide gas + water

This is much simpler than trying to explain the chemical reaction with sentences. However, word equations are still quite long.

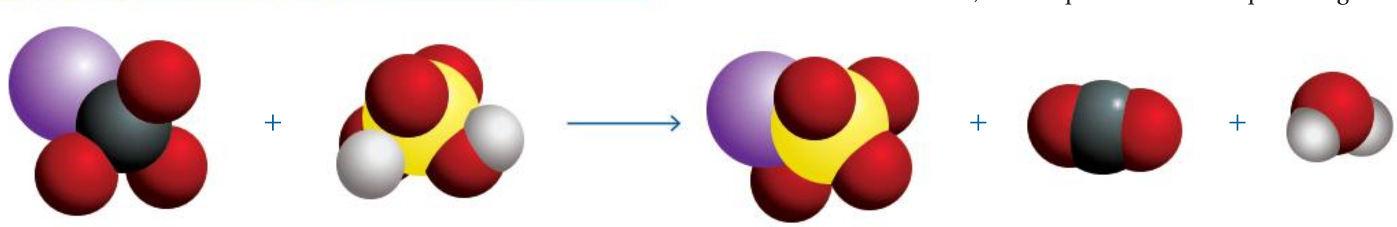


Figure 5.1.1 The atoms from the calcium carbonate combine with the atoms from the sulfuric acid to produce calcium sulfate, hydrogen and carbon dioxide.

Scientists can write the equation much more effectively by replacing the chemical names with their chemical formulas. The chemical equation for the previous example then becomes:

$$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + CO_2 + H_2O$$

This type of chemical equation is known as a **formula equation**. The formula equation is shorter to write and contains more information. It shows exactly what atoms (or ions) are involved in the chemical reaction. Figure 5.1.1 shows how the reactants in the equation above rearrange to form the products.

Showing states

The reactants and products in a chemical reaction can be in one of four states—solid, liquid, gas or **aqueous solution** (dissolved in water). Chemists give these states the symbols:

- (s) for a solid
- (l) for a liquid
- (g) for a gas
- (aq) for an aqueous solution.

The symbols can be added to the formula equations to give even more information about the chemical reaction. In the previous example, calcium carbonate and calcium sulfate are both solids, sulfuric acid is an aqueous solution, water is a liquid and carbon dioxide is a gas. All of this information can be included in the formula equation by writing the symbol for the state next to the formula name:

$$CaCO_3(s) + H_2SO_4(aq) \rightarrow CaSO_4(s) + H_2O(l) + CO_2(g)$$

The states are always written after the formula name in brackets.

Balanced chemical equations

The formula equation for the reaction of calcium carbonate with sulfuric acid is a **balanced equation**. This means that it has the same number of atoms of each element on both sides of the equation. You can easily check this by counting the number of atoms in the reactants and products:

Reactants = $1 \times Ca$, $1 \times C$, $7 \times O$, $2 \times H$, $1 \times S$

Products = $1 \times Ca$, $1 \times C$, $7 \times O$, $2 \times H$, $1 \times S$

Balanced equations are consistent with the **law of conservation of mass**. This law states that:

During a chemical reaction, atoms cannot be created or destroyed.

You cannot create or destroy atoms in a chemical reaction. But you can rearrange them. As a result, the number of atoms in the reactants must equal the number of atoms in the products. Also, the mass of the reactants must equal the mass of the products. This is shown in Figure 5.1.2.

Figure 5.1.2 The total mass of these beakers does not change despite a chemical reaction having taken place. The law of conservation of mass says that the total mass of the reactants and the total mass of the products must be the same.

However, not all formula equations will be balanced when you first write them. For example, when hydrogen gas reacts with oxygen gas, the product is water. The word and formula equations for this reaction are:

hydrogen + oxygen → water

$$H_2(g) + O_2(g) \rightarrow H_2O(l)$$

Counting the number of atoms on both sides of the equation shows that the equation is not balanced.

Reactants = $2 \times H$, $2 \times O$

Products = $2 \times H$, $1 \times O$

This means that if one molecule of hydrogen reacts with one molecule of oxygen, then an oxygen atom is left over. This is shown in Figure 5.1.3.

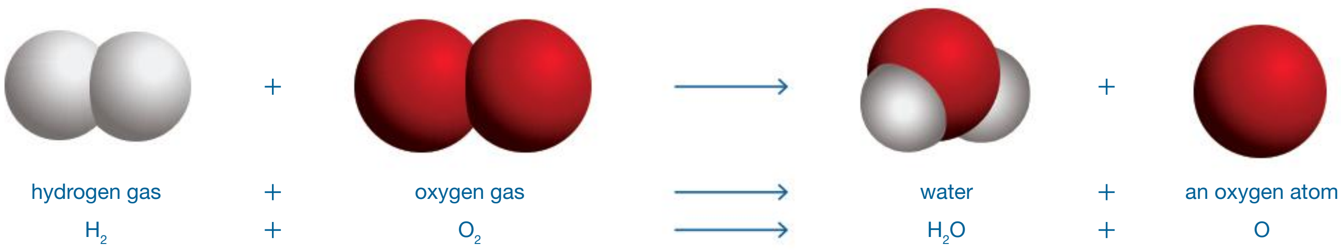


Figure 5.1.3 A single hydrogen molecule will not react with a single oxygen molecule because there would be an extra oxygen atom left over.

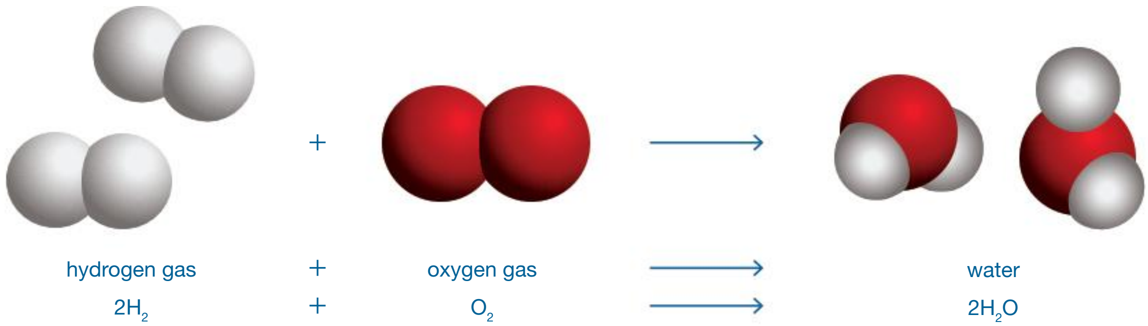


Figure 5.1.4 It takes two hydrogen molecules for each oxygen molecule, and this produces two water molecules.

However, if two hydrogen molecules react with one oxygen molecule, then the atoms can rearrange to produce two complete molecules of water. This is shown in Figure 5.1.4. Chemists represent this reaction as a balanced formula equation by writing:

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$$

Placing a 2 in front of the chemical formula for hydrogen and water indicates that the reaction uses two hydrogen molecules and produces two water molecules. Re-counting the number of atoms in the reactants and products shows that this equation is now balanced.

Reactants = $4 \times H$, $2 \times O$

Products = $4 \times H$, $2 \times O$

Consider another chemical reaction in which calcium metal (Ca) reacts with oxygen gas (O_2) to produce solid calcium oxide (CaO). The reactants in this reaction are calcium and oxygen gas. The only product is calcium oxide. Therefore, the general equation:

reactants → products

becomes the word equation:

calcium + oxygen → calcium oxide

Replacing the chemical names with their formulas gives the formula equation:

$$Ca + O_2 \rightarrow CaO$$

Adding the states to the formula equation gives:

$$Ca(s) + O_2(g) \rightarrow CaO(s)$$

Checking the atoms of each element on both sides shows that the equation is unbalanced:

Reactants = $1 \times Ca$, $2 \times O$

Products = $1 \times Ca$, $1 \times O$

However, it will be balanced if two calcium atoms react with one oxygen molecule to produce two CaO molecules. So the final balanced equation can be written as:

$$2Ca(s) + O_2(g) \rightarrow 2CaO(s)$$

SciFile

Big burners

The fuel tanks that supply fuel to power space rockets into orbit do not use petrol. Some use oxygen and hydrogen that react explosively to produce large amounts of energy.

The equation is:

$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$

This creates the enormous plume of exhaust gases that exit from the rocket motors. The rockets accelerate the massive weight to reach escape velocity of about 11 km/s.

SKILL BUILDER

Balancing equations

Balancing chemical equations can be tricky, but if you follow some simple steps you should arrive at the right answer. Let's look at the reaction between potassium carbonate (K_2CO_3) and nitric acid (HNO_3), which produces potassium nitrate (KNO_3), water (H_2O) and carbon dioxide (CO_2).

1 Write the word equation.

potassium carbonate + nitric acid → potassium nitrate + water + carbon dioxide

2 Write the unbalanced equation by replacing the chemical names with the chemical formulas.

$K_2CO_3 + HNO_3 \rightarrow KNO_3 + H_2O + CO_2$

3 Balance each element one by one.

Potassium (K): There are two on the left and only one on the right, so put a 2 in front of the potassium nitrate (KNO_3). This is sensible because you cannot destroy atoms—if you start with 2, you must end up with 2.

$K_2CO_3 + HNO_3 \rightarrow 2KNO_3 + H_2O + CO_2$

Carbon (C): There is one on the left and one on the right, so you don't need to change anything.

Oxygen (O): There are six on the left (three from the K_2CO_3 and three from the HNO_3). However, there are nine on the right:

- 1 from the H_2O
- 2 from the CO_2
- 6 from the $2KNO_3$

Putting a 2 in front of the HNO_3 solves the problem:

$K_2CO_3 + 2HNO_3 \rightarrow 2KNO_3 + H_2O + CO_2$

Now everything balances. (Note that, when trying to balance by adding numbers, this adds multiple lots of everything in the formula. For example, adding a 2 in front of the K_2CO_3 would also balance the oxygen atoms but it would unbalance the potassium and carbon atoms.)

Hydrogen (H): There are now two on the left and two on the right, so this balances.

Nitrogen (N): There are now two on the left and two on the right, so this balances.

4 Double check the numbers of atoms on both sides of the equation.

Reactants = 2 × K, 1 × C, 9 × O, 2 × H, 2 × N

Products = 2 × K, 1 × C, 9 × O, 2 × H, 2 × N

The equation is now balanced.

1 p148 2 p148 5.1

SciFile

In the limelight

Solid calcium oxide (CaO) is also known as lime or quicklime. When it is heated to 2500°C it begins to glow with an extremely bright light. For this reason, it was used in theatres for lighting before the discovery of electricity and is the origin of the term 'in the limelight'.

SCIENCE AS A HUMAN ENDEAVOUR

Nature and development of science

Moving atoms

Figure 5.1.5 An STM image of silicon atoms that make up the surface of a crystal

During chemical reactions, atoms are rearranged to form different types of chemical compounds. Recently, scientists have discovered how to rearrange atoms one by one, using a special type of microscope know as a scanning tunnelling microscope (STM).

Scanning tunnelling microscopes

Scanning tunnelling microscopes are the only type of microscope that can create images of atoms like those in Figure 5.1.5. To create an image of atoms, the STM scans the surface of a crystal with a very sharp tip. The sharp tip senses the atoms as bumps on the surface. This is similar to the way in which a sight-impaired person senses the bumps of Braille on a page. In this way, the STM can build up an image of the atoms on the surface line by line, as shown in Figure 5.1.6. Scientists use this technique to get a better understanding of atoms and how they make up crystals.

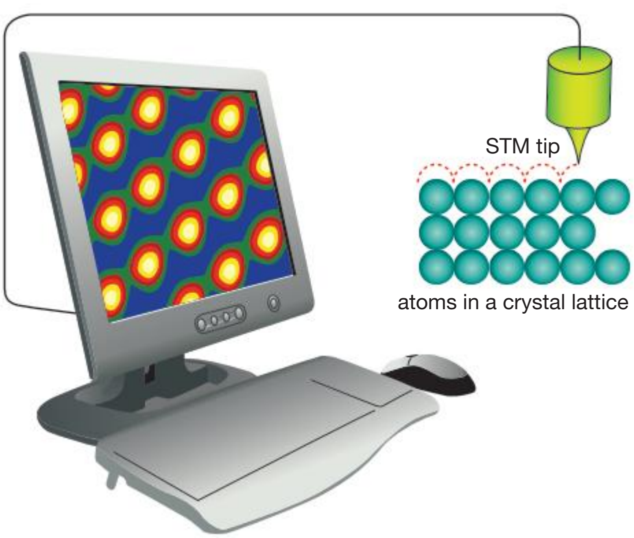


Figure 5.1.6 The STM builds up an image of the surface by sensing the atoms with a very sharp tip.

Moving atoms

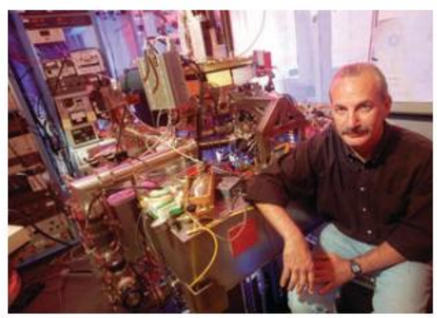


Figure 5.1.7 Professor Donald Eigler was the first person to show that atoms could be moved around with an STM.

In 1989, American nanoscientist Professor Donald Eigler (Figure 5.1.7) showed that the STM could be used to move atoms around one by one. To achieve this, Professor Eigler put iron atoms on a copper surface. He then used the STM tip to push the atoms around the surface and create very precise geometric shapes such as circles, triangles and squares (Figure 5.1.8). Since then, other people have also used the STM to construct designs atom by atom. These include using atoms to write the Japanese characters for the word *atom* as well as the world's smallest stick-figure man.

5.2

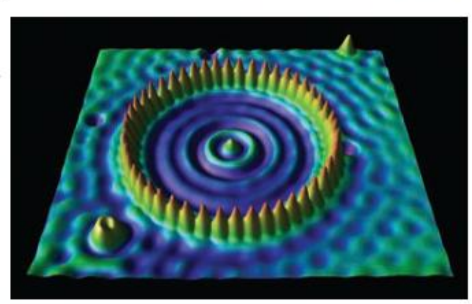


Figure 5.1.8 Using an STM tip, Professor Don Eigler was able to move iron atoms into perfect geometric shapes.

5.1 Unit review

Remembering

1 **State** the general name given to the chemicals that:
- **a** take part in a chemical reaction
- **b** produced by a chemical reaction.

2 **State** what $\rightarrow$ means in chemical equations.

3 **State** the law of conservation of mass.

4 **State** the meaning of the symbols (s), (l), (g) and (aq).

Understanding

5 **Explain** how the law of conservation of mass applies to chemical equations.

6 If a chemical equation contained the formula $2CH_4$, **explain** the meaning of the number 2 and the number 4.

7 **Describe** the difference between NaCl(s) and NaCl(aq).

Applying

8 **a** **Use** word equations to **describe** the following reactions.
b **Identify** the state of the reactants and products.
- **i** When copper is added to dilute nitric acid, copper nitrate, nitrogen monoxide and water are formed.
- **ii** If sulfuric acid is poured onto solid sodium carbonate, bubbles of carbon dioxide are produced, as well as water and sodium sulfate in solution.
- **iii** Magnesium burns easily in oxygen gas, producing magnesium oxide.
- **iv** When sodium metal is placed in water, it reacts to produce sodium hydroxide and hydrogen gas.

9 **Identify** the chemical formula for each of these substances. Include the appropriate state: (aq), (l), (s), (g) at room temperature and pressure.
- **a** carbon dioxide
- **b** dilute sulfuric acid
- **c** hydrogen
- **d** potassium carbonate crystals
- **e** dilute nitric acid
- **f** calcium

10 **Identify** the equation that is *not* balanced.
- **A** $4Al + 3O_2 \rightarrow 2Al_2O_3$
- **B** $Mg + 2HCl \rightarrow MgCl_2 + H_2$
- **C** $2Zn + O_2 \rightarrow 2ZnO$
- **D** $C_5H_{12} + 8O_2 \rightarrow CO_2 + 6H_2O$

Analysing

11 **Calculate** the correct number of reactants and products to balance the following equations.
- **a** $P_4 + O_2 \rightarrow P_2O_5$
- **b** $KClO_3 \rightarrow KCl + O_2$
- **c** $BaO + HNO_3 \rightarrow Ba(NO_3)_2 + H_2O$
- **d** $Pb_3O_4 \rightarrow PbO + O_2$
- **e** $Pb(NO_3)_2 \rightarrow PbO + NO_2 + O_2$

Evaluating

12 Jessica heated some blue copper(II) nitrate crystals in a test-tube. She noticed that brown nitrogen dioxide gas was produced. When a glowing splint was held at the top of the test-tube, it relit, proving that oxygen gas was also produced. A fine black solid, copper(II) oxide, was left in the test-tube.
- **a** **Determine** the reactants and products of the reaction.
- **b** **Deduce** the word equation for this reaction.
- **c** **Deduce** the balanced chemical equation.

13 David added dilute hydrochloric acid to solid calcium carbonate in a beaker. When he weighed the beaker after the bubbling had stopped, he noticed a reduction in mass. **Propose** why his results did not appear to agree with the law of conservation of mass.

Creating

14 Juan burns different masses of magnesium metal (Mg) with oxygen (O_2) to form magnesium oxide (MgO). He measures the mass of the reactants and product before and after, as shown in the table.

Mass of magnesium reacting (g)	Mass of oxygen reacting (g)	Mass of magnesium oxide produced (g)
2.00	0.70	2.70
3.00	1.04	4.04
4.00	1.39	5.39

- **a** **Construct** a word equation for this reaction.
- **b** **Construct** a balanced chemical equation.
- **c** **Modify** the equation to include the states of the reactants and products.
- **d** **Explain** how the above results demonstrate the law of conservation of mass.

Inquiring

1 Investigate the chemical reactions for photosynthesis and respiration. Write the word equations, formula equations and balanced equations for these reactions.

2 Research acid–base reactions. Write the general word equation for acid–base reactions and then three balanced formula equations showing three examples of acid–base reactions.

5.1 Practical activities

1 Reactions with modelling clay

Purpose

To simulate the conservation of mass in chemical reactions using modelling clay models.

Materials

- 3 different colours of modelling clay
- atomic model kit

Procedure

1. Use the atomic model kit to make models of methane (CH_4), oxygen (O_2) and ethane (C_2H_6).
2. Use the modelling clay to create models of the three molecules. Your models should be spheres stuck together to simulate chemical bonds.
3. Without adding, subtracting or splitting any modelling clay atoms, try to simulate how the atoms rearrange according to the unbalanced chemical reaction for burning methane in air:

   methane + oxygen gas → carbon dioxide + water

   $CH_4 + O_2 \rightarrow CO_2 + H_2O$

4. Construct one methane molecule and two oxygen molecules and simulate the balanced chemical reaction:

   methane + oxygen gas → carbon dioxide + water

   $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

5. Perform the same simulation for the combustion of ethane (C_2H_6) in oxygen by first simulating the unbalanced equation:

   ethane + oxygen gas → carbon dioxide + water

   $C_2H_6 + O_2 \rightarrow CO_2 + H_2O$

6. Simulate the balanced equation with the plasticine models:

   ethane + oxygen gas → carbon dioxide + water

   $2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$

Discussion

1. **Describe** what happened when you tried to simulate the unbalanced reactions, listing any excess atoms and those you did not have enough of.
2. **Explain** how a balanced equation gives an accurate description of what is going on during a chemical reaction.

2 Conservation of mass

Purpose

To investigate conservation of mass in a chemical reaction.

Materials

- 20 mL barium nitrate ($BaNO_3$) solution
- 20 mL of sodium sulfate ($NaSO_4$) solution
- 2 × 50 mL beakers
- access to an electronic balance

SAFETY

Barium nitrate solution is toxic, so avoid contact with eyes, skin and mouth. Wear safety glasses, lab coat and gloves.

Procedure

1. Pour approximately 20 mL of barium nitrate into one beaker and approximately 20 mL of sodium sulfate into the other.
2. Measure the weight of each beaker and record your results in the table in the results section.
3. Pour the barium nitrate in beaker 1 into beaker 2.
4. Remeasure the weight of each beaker and record your results.

Results

Copy and complete the following table.

	Beaker 1	Beaker 2	Total
Mass before reaction (g)			
Mass after reaction (g)			

Discussion

1. **Describe** what happened when the two solutions were mixed.
2. The products of this reaction are solid barium sulfate and a sodium nitrate solution. From this information, **construct** a word equation and balanced formula equation for this reaction.
3. **Assess** whether your results agree with the law of conservation of mass. **Explain** your assessment.

5.2 Classifying chemical reactions

There are many different types or classes of chemical reactions. Each type of chemical reaction has something in common. This could be common reactants or products or the way that the chemical reaction takes place. Classifying chemical reactions helps chemists understand how chemical reactions work. By understanding how one chemical reaction works, scientists can understand more about all reactions of the same type.

Decomposition reactions

When a single reactant breaks apart to form several products, the reactant is said to decompose. The general form of a **decomposition reaction** can be written as:

$$XY \rightarrow X + Y$$

An everyday example of a decomposition reaction is the chemical reaction that puts the fizz in soft drinks like the one shown in Figure 5.2.1. Soft drinks contain dissolved carbonic acid (H_2CO_3). When carbonic acid decomposes, it forms water (H_2O) and bubbles of carbon dioxide gas (CO_2). The carbon dioxide gas formed by this reaction remains dissolved in the soft drink until the lid is removed.

The balanced equation for the decomposition of carbonic acid is:

$$\text{carbonic acid} \rightarrow \text{water} + \text{carbon dioxide}$$
$$H_2CO_3(aq) \rightarrow H_2O(l) + CO_2(g)$$

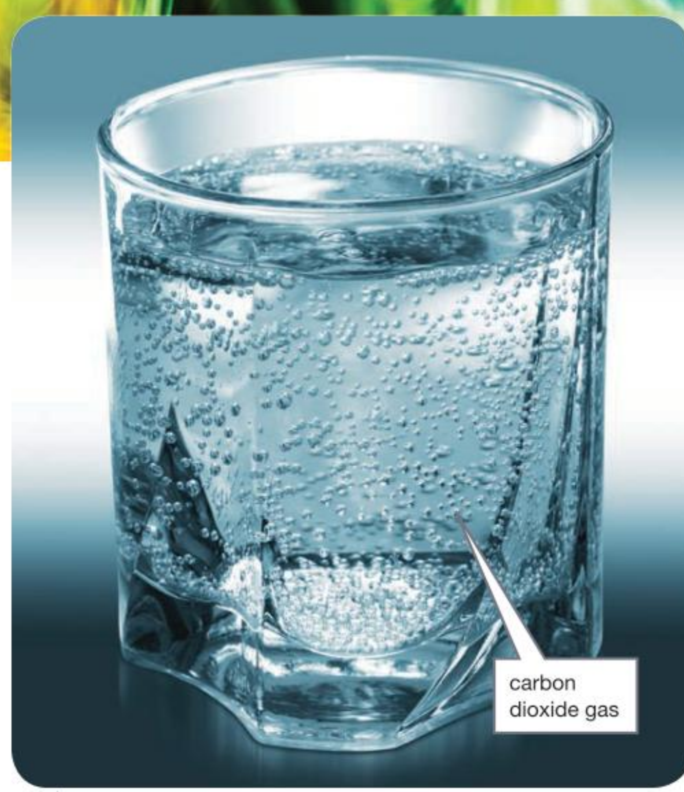


Figure 5.2.1 The decomposition reaction of carbonic acid gives carbonated water its fizz.

INQUIRY
science 4 fun

Raisin lava lamp

Can you create a lava lamp with a decomposition reaction?

Yes

Collect this ...

- clear fizzy drink such as lemonade or tonic water
- raisins
- clear glass or bottle

Do this ...

1. Pour the lemonade into the clear glass or bottle.
2. Add several raisins.

Record this ...

Describe what you saw.

Explain why you think this happened.

Thermal decomposition

Some substances will only decompose when heated to high temperatures. This is known as thermal decomposition. Metal carbonates and metal hydrogen carbonates both undergo thermal decomposition.

Thermal decomposition of sodium azide (NaN_3) is a chemical reaction that saves lives every day by inflating vehicle airbags like the one in Figure 5.2.2. When sodium azide is heated, it decomposes into sodium metal and nitrogen gas. The balanced equation is:

$$\text{sodium azide} \rightarrow \text{sodium} + \text{nitrogen gas}$$
$$2NaN_3(s) \rightarrow 2Na(s) + 3N_2(g)$$

Just 100 grams of sodium azide can produce around 56 litres of nitrogen gas in under 0.03 seconds. This reaction rapidly inflates the airbag in the event of a collision.

Figure 5.2.2 The decomposition of sodium azide (NaN_3) saves lives every day.

1 p159

Combination reactions

Combination reactions occur when two reactants combine to form a single product. The general equation for a combination reaction can be written as:

$$X + Y \rightarrow XY$$

Combination reactions are important in industry. For example, a combination reaction is used to create hydrochloric acid for industry and laboratories. First, hydrogen gas (H_2) and chlorine gas (Cl_2) are combined to form hydrogen chloride gas (HCl) in large chemical plants like the one in Figure 5.2.3.

The balanced equation for the combination of hydrogen and chlorine is:

$$\text{hydrogen gas} + \text{chlorine gas} \rightarrow \text{hydrogen chloride gas}$$
$$H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$$

The hydrogen chloride gas that is produced is then bubbled through de-ionised water to produce hydrochloric acid.

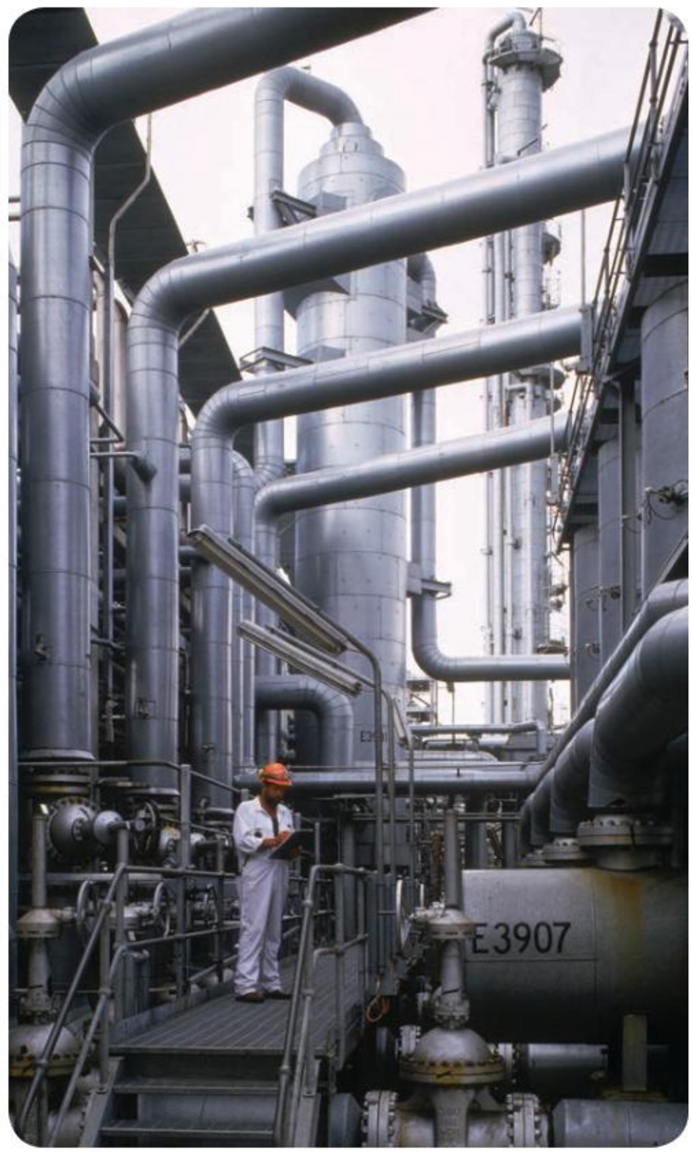


Figure 5.2.3 Hydrochloric acid is manufactured at chemical plants using a combination reaction between hydrogen gas and chlorine gas.

Precipitation reactions

Occasionally when two clear solutions are mixed together, they react to form a solid. The solid is said to precipitate out of the solution. As shown in Figure 5.2.4, most precipitates quickly fall to the bottom of the beaker. These types of reactions are known as **precipitation reactions**. For example, the scale that builds up in kettles, taps and pipes is solid calcium carbonate ($CaCO_3$) that has precipitated out of the tap water.

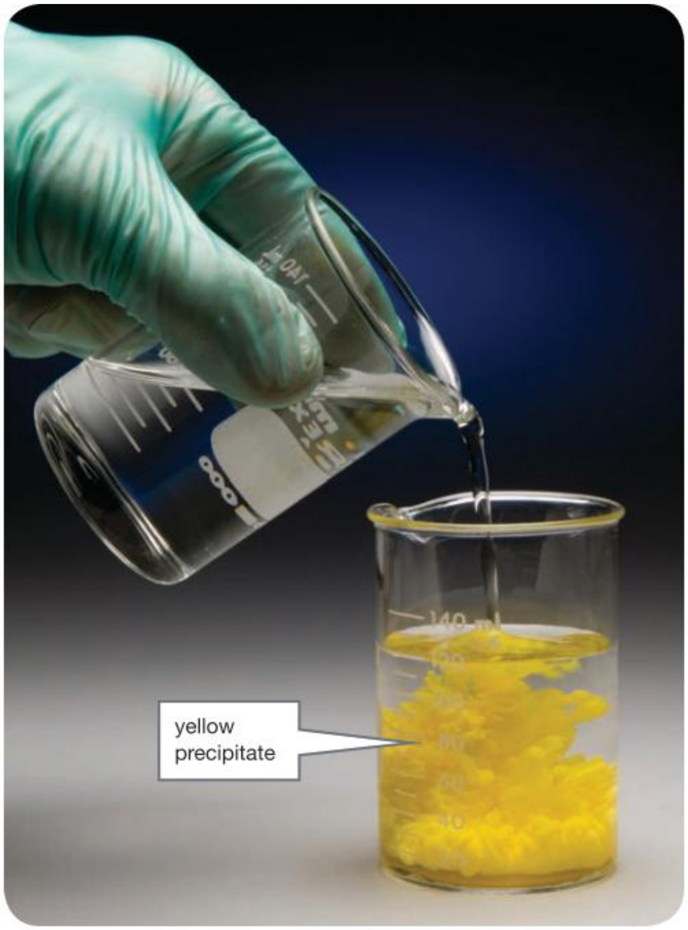


Figure 5.2.4 Precipitation reactions occur when two aqueous solutions react to produce a solid.

SciFile

Painful precipitates

Your body is full of dissolved compounds. However, sometimes these compounds precipitate out as hard deposits in the kidneys. These deposits, called kidney stones, are extremely painful. Usually kidney stones will pass out of the body with urine. However, in severe cases, the stones may have to be removed surgically or shattered by intense soundwaves.

Precipitation reactions and solubility

A precipitation reaction occurs when two **soluble** reactants combine to form an **insoluble** product known as the **precipitate**. A substance is said to be soluble if it dissolves. For example, sugar is soluble in water. A substance is insoluble if it does not dissolve. For example, chalk is insoluble in water.

When a soluble substance is dissolved in water, the particles that make up the substance are spread thinly throughout the solution. The particles are so small and so thinly distributed that they cannot be seen with the naked eye. As a result, the solution appears transparent (clear, not cloudy or murky). It may be coloured like food colouring in water, but you can see through it clearly.

For example, when table salt or sodium chloride (NaCl) dissolves, it breaks apart into positive sodium **ions** (Na^+) and negative chloride ions (Cl^-) as shown in Figure 5.2.5. This is because table salt is an **ionic compound**.

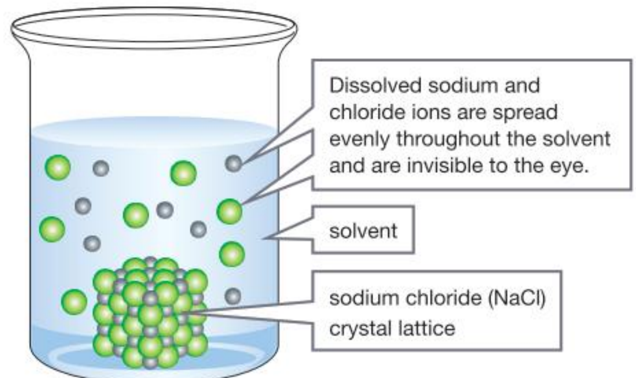


Figure 5.2.5 When sodium chloride dissolves, the lattice breaks apart and the ions distribute through the solution.

Ionic compounds

Ionic compounds are crystalline substances that are made up of a crystal lattice of positive ions (**cations**) and negative ions (**anions**). Ionic compounds are usually hard, brittle and can be brightly coloured like the ones shown in Figure 5.2.6.

Figure 5.2.6 There are many different types of ionic compounds such as salts that come in a wide variety of colours.

The cations that make up the crystal lattice are atoms (or groups of atoms) that have lost electrons and therefore have a positive charge. Anions are atoms (or groups of atoms) that have gained electrons and therefore have a negative charge. Table 5.2.1 lists common cations and anions.

Table 5.2.1 Common cations and anions

		Chemical name	Symbol
Cations	Lost 1 electron	Hydrogen ion	H^+
		Lithium ion	Li^+
		Sodium ion	Na^+
		Potassium ion	K^+
		Ammonium ion	NH_4^+
		Copper(I) ion	Cu^+
	Lost 2 electrons	Calcium ion	Ca^{2+}
		Magnesium ion	Mg^{2+}
		Barium ion	Ba^{2+}
		Copper(II) ion	Cu^{2+}
		Iron(II) ion	Fe^{2+}
	Lost 3 electrons	Iron(III) ion	Fe^{3+}
		Aluminium ion	Al^{3+}
Anions	Gained 1 electron	Fluoride	F^-
		Chloride	Cl^-
		Bromide	Br^-
		Iodide	I^-
		Hydroxide	OH^-
		Nitrate	NO_3^-
		Hydrogen carbonate	HCO_3^-
	Gained 2 electrons	Oxide	O^{2-}
		Sulfide	S^{2-}
		Sulfate	SO_4^{2-}
		Carbonate	CO_3^{2-}
	Gained 3 electrons	Nitride	N^{3-}
		Phosphate	PO_4^{3-}

Naming ionic compounds

The name of an ionic compound is simply the name of the cation together with the name of the anion. For example, barium sulfate ($BaSO_4$) is made up of the barium cation (Ba^{2+}) and the sulfate anion (SO_4^{2-}). In the cases where an atom can have more than one type of ion (such as copper(I), Cu^+, and copper(II), Cu^{2+}), a roman numeral is included in the name of the compound. For example, copper(I) hydroxide ($CuOH$) or copper(II) sulfate ($CuSO_4$).

Ionic compounds are always charge neutral. This is represented in the chemical formula by ensuring that the total charge on the cations balances the total charge on the anions. For example, sodium oxide is made up of sodium ions (Na^+) with a charge of +1 and oxide ions (O^{2-}) with a charge of –2. Therefore, the symbol for sodium oxide is Na_2O. This formula indicates that there needs to be two sodium ions for every oxide ion in the crystal lattice to balance the charge.

Polyatomic ions are ions with more than one atom. Examples are NH_4^+ and SO_4^{2-}. The chemical symbol of these ions is put inside brackets when more than one is needed for a balanced formula. For example, the chemical formula for calcium hydroxide is $Ca(OH)_2$. This indicates that there are two hydroxide ions (OH^-) to balance the charge of each calcium ion (Ca^{2+}).

Predicting precipitation reactions

Scientists use the solubility rules in Table 5.2.2 to predict if a precipitation reaction will occur when two ionic solutions are mixed.

Table 5.2.2 Solubility rules

Negative ions (anions)	Positive ions (cations)	Solubility of compounds
Acetate, CH_3COO^-	All	Soluble
All	Li^+, Na^+, K^+, Rb^+, NH_4^+	Soluble
Chloride, Cl^- Bromide, Br^- Iodide, I^-	Ag^+, Pb^{2+}, Hg^{2+}, Cu^+	Low solubility
	All others	Soluble
Hydroxide, OH^-	Li^+, Na^+, K^+, Rb^+, NH_4^+, Sr^{2+}, Ba^{2+}	Soluble
	All others	Low solubility
Nitrate, NO_3^-	All	Soluble
Phosphate, PO_4^{3-} Carbonate, CO_3^{2-}	Li^+, Na^+, K^+, Rb^+, NH_4^+	Soluble
	All others	Low solubility
Sulfate, SO_4^{2-}	Ca^{2+}, Sr^{2+}, Ba^{2+}, Pb^{2+}	Low solubility
	All others	Soluble
Sulfide, S^{2-}	Li^+, Na^+, K^+, Rb^+, NH_4^+, Be^{2+}, Mg^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+}	Soluble
	All others	Low solubility

Using the solubility rules, it is possible to predict that a potassium chloride solution and a silver nitrate solution will react to form a silver chloride precipitate and leave behind a potassium nitrate solution (Figure 5.2.7). The balanced equation for this reaction is given by:

$$\text{potassium chloride} + \text{silver nitrate} \rightarrow \text{potassium nitrate} + \text{silver chloride}$$

$$KCl(aq) + AgNO_3(aq) \rightarrow KNO_3(aq) + AgCl(s)$$

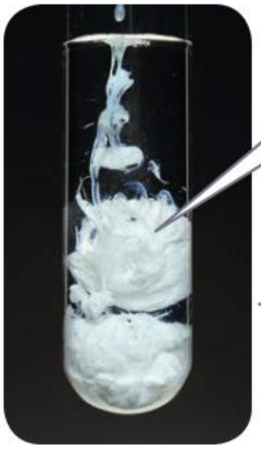


Figure 5.2.7 Silver chloride precipitates out as a white solid when potassium chloride is mixed with silver nitrate.

The solubility rules state that all potassium ionic compounds are soluble and therefore potassium chloride (KCl) is soluble. The rules also state that all nitrates are soluble. Therefore, silver nitrate ($AgNO_3$) must be soluble. Together, these solutions can combine to create potassium nitrate (KNO_3) and silver chloride (AgCl). Potassium nitrate (KNO_3) must be soluble because all potassium ionic compounds and all nitrates are soluble. However, the solubility rules show that silver chloride is only slightly soluble in water and therefore it must precipitate out of the solution as a solid. Using these rules, scientists can predict the outcome of any precipitation reaction.

p160

SKILL BUILDER

Predicting precipitation reactions

It is possible to predict the outcome of mixing two solutions by considering the solubility of all the possible combinations of cations and anions. Consider a mixture of solutions of magnesium sulfate ($MgSO_4$) and barium nitrate ($Ba(NO_3)_2$).

Step 1: Swap the cations and anions of the reactants to get the possible products.

Product 1 = Magnesium nitrate ($Mg(NO_3)_2$)

Product 2 = Barium sulfate ($BaSO_4$)

Step 2: Check the solubility of the possible products in Table 5.2.2.

Product 1 = Magnesium nitrate is soluble because all nitrates are soluble.

Product 2 = Barium sulfate is insoluble because all sulfates are soluble except Ba^{2+}, Ca^{2+}, Sr^{2+}, Pb^{2+}.

Step 3: Write the chemical equation for the reaction showing that barium sulfate is a solid precipitate.

barium nitrate solution + magnesium sulfate solution → barium sulfate solid + magnesium nitrate solution

$$Ba(NO_3)_2(aq) + MgSO_4(aq) \rightarrow BaSO_4(s) + Mg(NO_3)_2(aq)$$

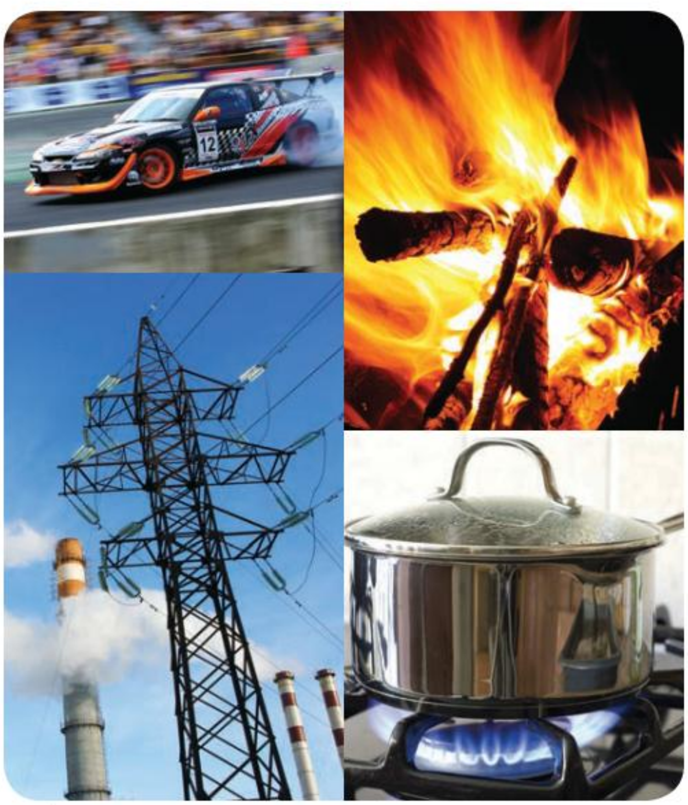


Figure 5.2.8 Combustion is a chemical reaction used every day to cook, provide warmth, run cars and produce electricity.

Oxidation and reduction reactions

Oxidation and reduction reactions include a wide variety of reactions. However, it is not always obvious when an oxidation and reduction reaction has taken place.

Oxidation reactions

If a substance combines with oxygen during a chemical reaction, then you can be sure that an **oxidation** reaction has occurred. Two familiar examples of oxidation reactions are combustion and corrosion.

During **combustion** reactions, substances burn rapidly in oxygen and produce large amounts of heat and light. Lighting a match, burning gas on a stove top, igniting fuel in car engines and burning coal in an electrical power station are all examples of combustion (Figure 5.2.8).

When methane gas is burnt in oxygen on a gas stove or Bunsen burner, the chemical combustion reaction is:

methane + oxygen → carbon dioxide + water

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$$

In this reaction, the methane is oxidised because it combines with oxygen in the air to form carbon dioxide and water. The oxygen is referred to as the oxidising agent because it has caused the methane to oxidise.

5.3

INQUIRY science 4 fun

Acrobatic flame

Can a flame travel along candle fumes?

Yes

Collect this ...

- candle
- box of matches

Do this ...

1. Light the candle and let it burn for a couple of minutes.
2. Strike another match and then blow out the candle.
3. Put the flame of the lit match in the fumes coming from the unlit candle.
4. The candle should reignite as if by magic. See how far you can get the flame to jump.

SAFETY

Be very careful when using matches and candles. Be careful to blow matches out and rinse with water to make sure they are out before disposing of them.

Record this ...

Describe what you saw.
Explain why you think this happened.

Corrosion occurs when metals react with oxygen to form metal oxides. For example, when iron is exposed to oxygen in the presence of water, it forms rust or iron(III) oxide (Fe_2O_3). You can see it in Figure 5.2.9. The equation for this reaction is:

iron + oxygen gas → iron(III) oxide

$$2Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$$

In this case, the iron metal is being oxidised and the oxygen gas is the oxidising agent.

Figure 5.2.9 Rust is the product of an oxidation reaction, more specifically called corrosion.

Reduction reactions

Reduction reactions are the opposite of oxidation reactions. If a compound loses oxygen atoms, you can be sure a reduction reaction has taken place. For example, when copper oxide is heated to very high temperatures in the presence of carbon, the copper(II) oxide loses its oxygen and forms copper metal. The chemical equation for this reaction is:

copper(II) oxide + carbon → copper + carbon dioxide

$$2CuO(s) + C(s) \rightarrow 2Cu(s) + CO_2(g)$$

Here, the copper oxide is reduced and carbon is the reducing agent. However, you could also say that the carbon is oxidised and that the copper(II) oxide is the oxidising agent. Oxidation and reduction reactions always occur in pairs. Therefore, they are commonly referred to as **redox** reactions.

3 p161

Redox reactions and electrons

Redox reactions do not always involve oxygen. Redox reactions also include any chemical reaction where electrons are transferred from one substance to another substance. The substance that loses its electrons is said to be oxidised. The substance that gains the electrons is said to be reduced. An easy way to remember this is by the mnemonic OILRIG:

Oxidation **I**s **L**oss **R**eduction **I**s **G**ain

In short:

Oxidation is the gain of oxygen or the loss of electrons.

Reduction is the loss of oxygen or the gain of electrons.

Identifying redox reactions is not always easy. For example, precipitation reactions are not redox reactions. There is no exchange of electrons even though the charged ions in solution come together to form a crystal lattice. Similarly, neutralisation reactions between acids and bases also are not redox reactions because there is no exchange of electrons between atoms.

Metal displacement reactions

Metal displacement reactions are simple redox reactions that involve only the transfer of electrons from one metal atom to another. For example, when zinc metal is placed in a solution of copper sulfate, the zinc atoms form zinc ions (Zn^{2+}) that dissolve into solution. At the same time, the copper(II) ions (Cu^{2+}) form solid copper crystals on the zinc as shown in Figure 5.2.10. Here, the zinc is said to displace the copper from solution.

The chemical equations for this reaction are:

copper(II) ions + zinc → copper + zinc ions

$$Cu^{2+}(aq) + Zn(s) \rightarrow Cu(s) + Zn^{2+}(aq)$$

Figure 5.2.10 When zinc metal is placed in a copper sulfate solution, crystals of pure copper begin to form on the zinc metal strip.

Remembering the mnemonic OILRIG, you can see that the zinc atoms are being oxidised in this reaction because the zinc atoms lose their electrons to the copper(II) ions. Similarly, you can see that the copper(II) ions are reduced in this reaction because they gain electrons from the zinc atoms.

In this redox reaction, electrons have been transferred from the zinc atom to the copper(II) ion. Therefore, the zinc has been oxidised and the copper(II) ion is the oxidising agent. In contrast, the copper(II) ions are reduced by the zinc atoms. So the zinc is the reducing agent.

5.4

Activity series

Displacement reactions do not work for every combination of metal and ionic solution. For example, if you put copper metal in a solution of zinc sulfate ($ZnSO_4$), then nothing happens. Whether or not a displacement reaction occurs depends on which atom is better at holding onto its own electrons.

The tendency for metals to react is summarised by the activity series shown in Table 5.2.4.

Table 5.2.4 Activity series for common metals

		Metal	Method of extraction
Lose electrons easily ↑	More reactive ↑	Potassium K	Electrolysis
		Sodium Na	
		Calcium Ca	
		Magnesium Mg	
		Aluminium Al	
		Zinc Zn	Carbon reduction
		Iron Fe	
		Nickel Ni	
		Tin Sn	
		Lead Pb	
		Copper Cu	
Hold on to electrons more tightly	Less reactive	Silver Ag	Native metals
		Gold Au	

Metals closer to the top of the activity series lose their electrons easily. Metals at the bottom of the activity series hold on to their electrons more tightly and can remove electrons from atoms above them. Therefore, a metal displacement reaction will only occur if the solid metal is higher on the activity series table than the metal ions in solution.

According to the activity series, zinc is more likely to lose electrons than copper. Therefore, a copper(II) ion can remove electrons from a zinc atom. But a zinc ion cannot remove electrons from a copper atom.

Extraction of metals

The activity series plays an important role in determining how metals are extracted. Metals that are low on the activity series rarely form compounds. Therefore, metals like gold and silver may exist in their elemental form naturally. Metals in the middle of the activity series tend to form compounds. These compounds can be reduced via a redox reaction to produce the pure metal. Metals at the top end of the activity series have a very high tendency to form compounds or ions. Therefore, the ions of these metals can only be reduced by electrolysis. Electrolysis uses an electrical current to push electrons onto the ions and force them to reduce to the pure element.

Native metals

Pure metals that can be found in nature are known as native metals. Gold is a native metal, as is silver. Therefore, chemical extraction is not required. This is why it is possible to pan for gold or find gold nuggets, as shown in Figure 5.2.11.

Figure 5.2.11 Gold is a native metal, which means it can be found in nature in its elemental form.

However, the fact that gold is not chemically reactive poses a challenge for gold mining companies. These companies must find physical processes for separating the gold from the sand and other minerals. One method is to crush the rocks and sand into a very fine powder. The powder is then put into a tank of water with a chemical similar to washing detergent. When air it bubbled through the liquid, the gold particles stick to the bubbles and float to the surface. The sand and rocks settle to the bottom to be removed as waste. This process of separation is known a **froth flotation**.

Gold and mercury

SciFile

Liquid mercury is one of the few chemicals that can dissolve gold and remove it from crushed ore. The mercury is then heated to evaporate it, leaving the gold behind. Mercury is toxic to humans, so its use in gold mining is banned in many countries, including Australia. However, many poorer countries still use this method, putting workers and people living nearby at risk.

Carbon reduction

Unlike native metals, most other metals exist in nature as compounds. Naturally occurring compounds that are used in the production of pure metals are known as ores. Some common ores are listed in Table 5.2.5.

Table 5.2.5 Common ores and the metals extracted from them

Ore name	Chemical formula	Metal extracted
Zinc blende	ZnS	Zinc Zn
Calamite	$ZnCO_3$	
Haematite	Fe_2O_3	Iron Fe
Magnetite	Fe_3O_4	
Iron pyrites	FeS_2	
Galena	PbS	Lead Pb
Copper pyrites	$CuFeS_2$	Copper Cu
Malachite	$CuCO_3.Cu(OH)_2$	
Cinnabar	HgS	Mercury Hg

The pure metals can usually be extracted from their ores through chemical processes such as carbon reduction.

In **carbon reduction**, the ore is heated to very high temperatures with a source of pure carbon, usually coke. In the blast furnaces used for extracting iron from iron ore (Fe_2O_3), the carbon reduction occurs as a two-step process as shown in Figure 5.2.12.

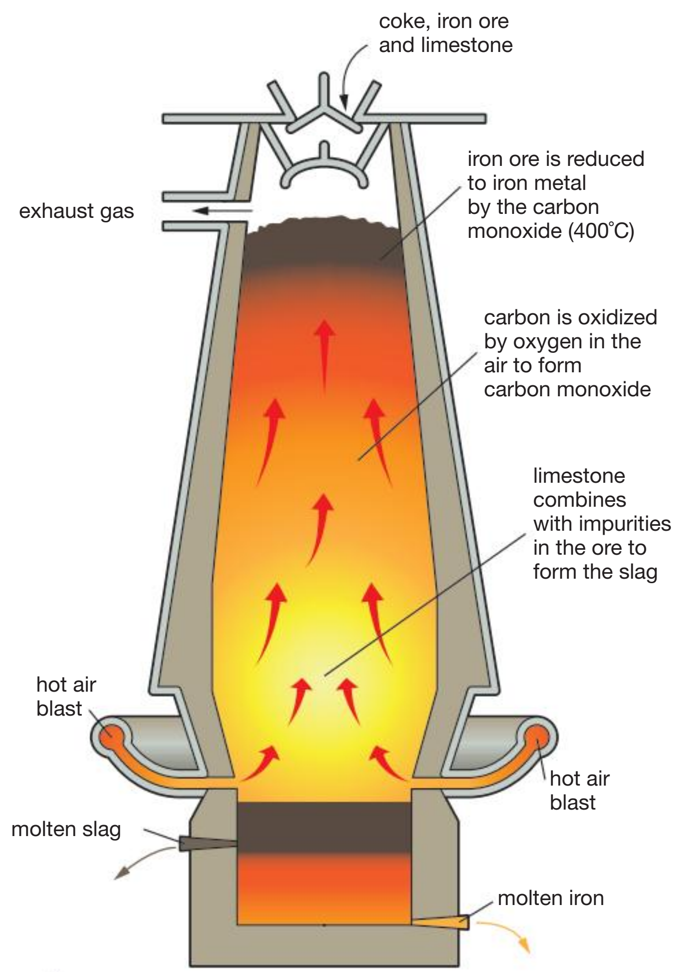


Figure 5.2.12 A blast furnace produces liquid iron by heating iron ore, carbon and limestone to a high temperature.

The iron ore is fed into the top of the blast furnace with coke (pure carbon) and limestone. The carbon is initially oxidised by oxygen in the air to produce carbon monoxide, according to the reaction:

carbon + oxygen gas → carbon monoxide gas

$$2C(s) + O_2(g) \rightarrow 2CO(g)$$

The carbon monoxide then reduces iron ore to produce the iron metal and carbon dioxide.

iron(III) oxide + carbon monoxide gas → iron + carbon dioxide gas

$$Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(s) + 3CO_2(g)$$

The limestone reacts with the sand and dirt in the ore to form waste known as slag. The slag floats to the top of the molten iron metal and can be drained off separately.

This process of using heat and carbon to extract a metal from its ore is known as **smelting**. Smelting can be used to extract the metals from a wide variety of ores such as zinc blende (ZnS), malachite ($CuCO_3$.$Cu(OH)_2$), galena (PbS) and tin oxide (SnO).

Figure 5.2.13 Molten iron being poured from a blast furnace

Electrolysis

Carbon reduction is not suitable for the more reactive metals such as sodium, calcium, potassium and magnesium. The most economically viable way of extracting these highly reactive metals is by electrolysis.

Electrolysis is the process in which an electric current is passed through the molten ore (in the liquid phase) in which metal ions are free to move. The electric current pushes electrons onto the metal ions, reducing the ions to atoms of the pure metal. In the mining industry, electrolysis is also called **electrowinning**.

Electrolysis could be used to extract any metal from its ore. However, the process uses huge amounts of electricity and therefore is very expensive. For this reason, electrolysis is used only when cheaper methods (such as carbon reduction) won't work. Common metals extracted by electrolysis are aluminium, sodium, magnesium, calcium and potassium.

Sodium metal is extracted by placing positive and negative electrodes into molten sodium chloride (NaCl) as shown in Figure 5.2.14. Melting the sodium chloride crystal breaks apart the sodium ions and chloride ions, which are then free to move towards the electrodes.

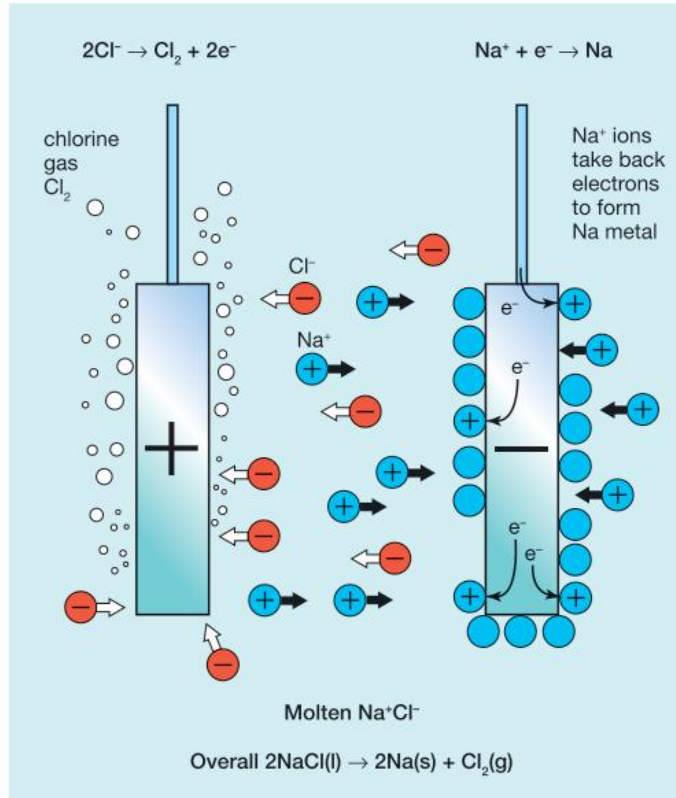


Figure 5.2.14 Pure sodium metal can be extracted from molten sodium chloride through the process of electrolysis.

The positive sodium ions (Na^+) are attracted to the negative electrode, which is charged because of an excess of electrons. When the sodium ions come into contact with the negative electrodes, the excess electrons are pushed onto the sodium ions and the ions are reduced to sodium metal atoms. This can be expressed by the equation:

sodium ion + an electron → sodium

$$Na^+(aq) + e^- \rightarrow Na(s)$$

This is a reduction reaction because the sodium ions have gained electrons. An oxidation reaction occurs at the other electrode. The negative chloride ions are attracted to the positive electrodes, where each chloride ion loses one electron. This causes the chlorine atoms to combine into pairs and form chlorine gas (Cl_2). The gas is chemically stable and bubbles off. This reaction can be expressed by the equation:

chloride ion → chlorine gas + electrons

$$2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$$

This is an oxidation reaction because the chloride ions have lost electrons. Together, the two equations complete the full redox reaction for the electrolysis of sodium chloride:

sodium chloride → sodium + chlorine gas

$$2NaCl(l) \rightarrow 2Na(s) + Cl_2(g)$$

5.2 Unit review

Remembering

1 **List** two examples each of combination, decomposition, precipitation and redox reactions.

2 **Name** two metals that are:
- a native
- b extracted by carbon reduction
- c extracted by electrolysis.

3 **Name** a positive ion that is non-metallic.

4 **List** names and symbols of three polyatomic ions.

5 **State** whether nitrates are normally soluble or insoluble.

6 **Name** the following ionic compounds.
- a RbBr
- b K_2S
- c BeO
- d Na_3N
- e NH_4Cl
- f LiOH
- g Ag_2CO_3
- h $ZnSO_4$

Understanding

7 **Explain** why oxygen is written as O_2 in chemical reactions rather than just O.

8 **Explain** why combination and decomposition reactions could be considered the reverse or opposite of each other.

9 **Describe** what happens when sodium ions come in contact with the negative electrode in a cell used for electrolysis.

10 **Describe** what observations may be made when a precipitation reaction occurs.

Applying

11 **Identify** a combination reaction that occurs in a blast furnace.

12 **Apply** rules for formula writing to write the formula for calcium chloride.

13 **Identify** if the following reactions are combination, combustion or decomposition reactions.
- a $2KClO_3 \rightarrow 2KCl + 3O_2$
- b $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
- c $O_2 + 2H_2O \rightarrow 2H_2O_2$

14 **Use** formula equations to rewrite the following word equations.
- a carbon + oxygen → carbon dioxide
- b copper(II) carbonate → copper(II) oxide + carbon dioxide
- c propane (C_3H_8) + oxygen → carbon dioxide + water

15 **Use** word equations to rewrite the following formula equations.
- a $2Mg + O_2 \rightarrow 2MgO$
- b $2H_2O \rightarrow 2H_2 + O_2$
- c $CaO + H_2O \rightarrow Ca(OH)_2$

16 **Use** Table 5.2.2 on page 152 to **predict** the precipitate formed when these solutions are mixed.
- a silver nitrate and sodium chloride
- b mercury(II) nitrate and potassium iodide
- c calcium nitrate and lithium carbonate
- d barium nitrate and sodium sulfate

17 **Use** word and formula equations to **describe** the following redox reactions.
- a aluminium corroding
- b magnesium combusting in oxygen to form magnesium oxide
- c magnesium metal displacing nickel ions from solution

Analysing

18 **Discuss** ways in which combustion is important in our everyday lives.

19 **Calculate** the number of each type of atom in the following chemical formulas.
- a $(NH_4)_2SO_4$
- b $K_2Cr_2O_7$
- c $Ca(OH)_2$

Evaluating

20 **Evaluate** how learning to classify reactions into types has helped you to better understand reactions.

Creating

21 **Construct** a table to **summarise** the different reaction types in this unit. Use your own headings to help you clarify the typical reaction and examples.

Inquiring

1 Explain why the decomposition of mercury oxide (HgO) was a very important reaction for 18th-century chemists Carl Wilhelm Scheele, Joseph Priestley and Antoine-Laurent Lavoisier.

2 Research the ingredients used in gun powder and how the chemical reaction works. Identify which reactants might be oxidizing agents and which might be reducing agents.

3 Research car airbags and find out what heats the sodium azide in a collision.

4
- a Design an experiment to determine the contents of three unlabelled beakers, containing a solution of either sodium chloride, barium nitrate or potassium nitrate.
- b Describe what you expect to observe.
- c Write balanced formula equations for each.

5.2 Practical activities

1 Heating metal carbonates

Purpose

To investigate the effect of heat on metal carbonates.

SAFETY

Wear safety glasses. Do not stop heating the copper carbonate for more than about 10 seconds (while the delivery tube is in the limewater) or the limewater will be pushed into the hot test-tube with copper carbonate and it will shatter. One team member must watch this during the heating.

Materials

- 2 large test-tubes
- stopper for test-tube with a delivery tube
- 2 retort stands
- 2 bossheads and clamps
- Bunsen burner and mat
- spatula
- limewater (calcium hydroxide solution $Ca(OH)_2$)
- 5 g copper(II) carbonate

Procedure

1 Use the spatula to put about 5 g (or about 2 cm depth) of copper(II) carbonate ($CuCO_3$) in one of the test-tubes.

2 Fit the test-tube with the stopper and delivery tube.

3 Use the bosshead and clamp to secure the test-tube on an upward angle with the delivery tube pointing down as shown in Figure 5.2.15.

4 Half-fill the second test-tube with limewater and clamp it to the retort stand so that the delivery tube dips into the limewater.

5 Use the Bunsen burner to heat the copper carbonate gently at first and then more strongly.

6 Record your observations but remove the delivery tube from the limewater as soon as the heat is stopped to prevent limewater rising up the delivery tube.

Discussion

1 **Assess** if a chemical reaction has taken place.

2 **Propose** whether the mass of the substance left in the test-tube after heating would be greater or less than the mass of copper carbonate put into the test-tube originally.

3 **Research** how limewater acts as an indicator for carbon dioxide. **Construct** a word equation for the reaction that takes place in the limewater when carbon dioxide is bubbled through it.

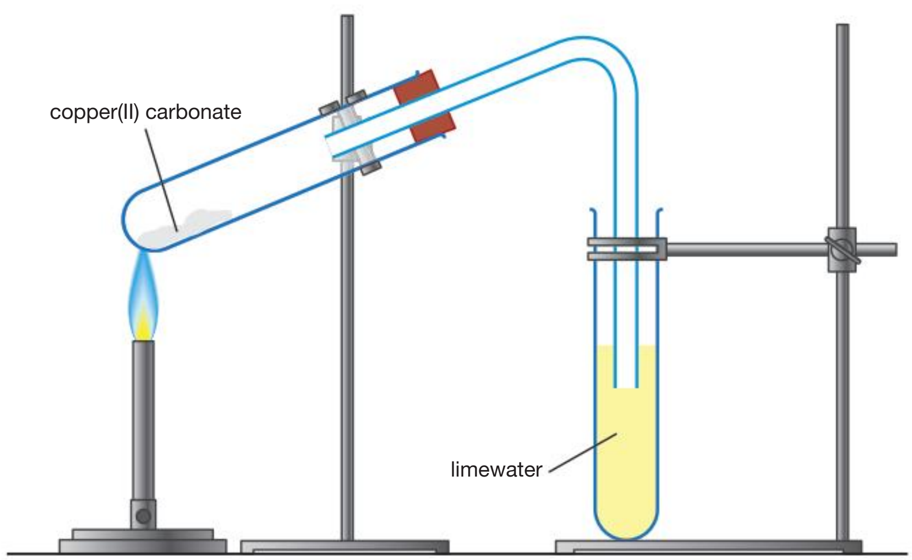


Figure 5.2.15

2 Precipitation reactions

Purpose

To predict and then test particular precipitation reactions.

Material

- Table 5.2.2 (page 152)
- 0.1 M solutions of silver nitrate, sodium carbonate, sodium hydroxide, barium nitrate and copper sulfate (all in 'dropper' bottles)
- 10 small test-tubes and test-tube rack
- gloves

SAFETY

Solutions from this experiment must not be washed down the sink. They should be placed in a clearly marked waste bottle.

Wear gloves and safety glasses at all times.

Procedure

1 Construct a table like the one in the results section. You need 11 rows to record 10 tests.

2 In your table, enter all possible combinations of two of the test solutions.

3 Using Table 5.2.2, predict what should happen in each tube and write your prediction in the table.

4 For your first pair of solutions, place 10 drops of solution A in a test-tube, and then add 10 drops of solution B to the same test-tube. Place the tube in a test-tube rack and record your observations.

5 Repeat step 4 for each pair of solutions.

Results

Copy and complete the table below—you will need 11 rows.

Discussion

1 **Analyse** the solubility rules in Table 5.2.2 on page 152 to work out what has precipitated from each solution.

2 **Construct** word equations and formula equations to describe what is happening in each case where a reaction occurred.

Solution A	Solution B	Prediction of precipitation (yes/no)	Observations before mixing	Observations after mixing	Name of precipitate (if any)
Silver nitrate	Sodium carbonate				

3 Carbon reduction

Purpose
To use carbon reduction to extract a metal.

Material
- crucible and lid
- Bunsen burner, tripod and bench mat
- pipe clay triangle
- copper oxide
- powdered carbon
- tin can with top and bottom removed
- 2 teaspoons
- icy-pole stick
- tongs
- stereomicroscope

SAFETY

Be very careful with the hot crucible and pipe clay triangle.

Wear safety glasses at all times.

Procedure
1. Place about one teaspoon of the copper oxide into your crucible.
2. Use a different spoon to add about half a teaspoon of carbon powder. Do not mix up the two spoons.
3. Use the icy-pole stick to thoroughly mix the two together.
4. Use the first spoon (for carbon) to add another teaspoon of carbon to the crucible, but do not mix it. Use the icy-pole stick to spread the carbon into a layer over the top of the mixture in the crucible. Do not mix it with the lower layer.
5. Put a lid on the crucible and stand it in a pipe clay triangle on a tripod stand. Place the tin on the tripod so that it surrounds the crucible. The setup is shown in Figure 5.2.16.
6. Light your Bunsen burner and heat the crucible with a hot flame for about 10 minutes.
7. Let the crucible cool for several minutes. Using the tongs, tip the contents of the crucible onto a tin lid or other container that will not melt. Allow it to cool.

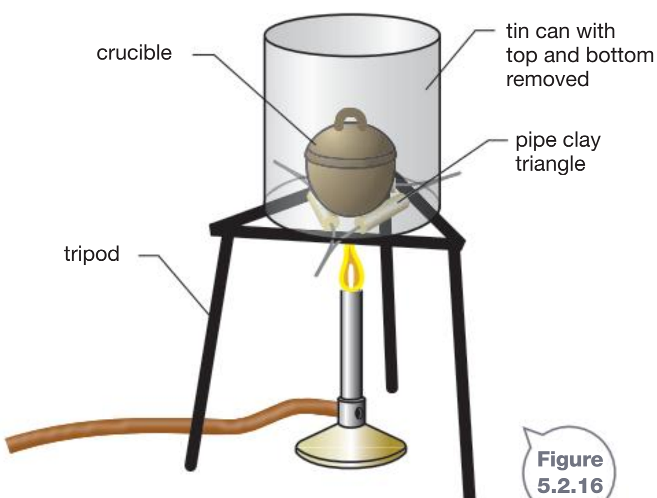


Figure 5.2.16

Results
Observe the contents of the crucible under a stereomicroscope or hand lens, and record your observations.

Discussion
1. **Describe** the contents of your crucible before and after heating.
2. **Construct** a word equation and a formula equation to **describe** what happened in the crucible.
3. Carbon reduction using this method works with copper in a laboratory, but not very well with iron. **Propose** a reason for this difference.
4. Another way of using carbon reduction to extract copper from copper oxide is using equipment like that shown in Figure 5.2.17. **Predict** what would happen to the carbon block and the copper oxide powder.

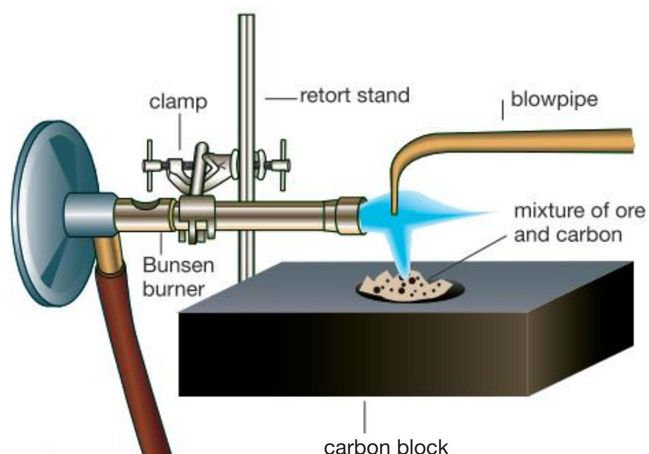


Figure 5.2.17 Alternate way of extracting copper

5.3 Rates of chemical reactions

Explosions are combustion reactions that occur in a fraction of a second. In contrast, the corrosion reaction that rusts a shipwreck may take years. Being able to control how fast chemical reactions occur is of great use in industry, medicine, at home and in science laboratories. Scientists can slow down unwanted reactions and speed up useful reactions for our benefit.

Fast and slow chemical reactions

The speed at which a chemical reaction proceeds is known as the **rate of reaction**. Some chemical reactions that proceed quickly are explosions and combustion reactions (Figure 5.3.1), when vinegar is mixed with bicarbonate of soda and the burning of gas in a Bunsen burner. These reactions are said to have a fast rate of reaction. Chemical reactions that proceed slowly are said to have a slow rate of reaction. Rusting, ripening and the fermentation of wine (Figure 5.3.2) are examples.

Figure 5.3.1 Welders use the rapid combustion of acetylene to produce the extremely hot flame required to weld and cut metals.

Figure 5.3.2 The slow chemical reactions that ferment wine and give it its flavour mean that it can take years before the wine is ready to drink.

Controlling the rate of chemical reactions

The rate of almost every reaction can be increased or decreased. For example, when you run a race and then breathe deeply, your heart pumps faster to speed up the rate of respiration. In contrast, the rate of respiration slows down when you're calm and relaxed. Scientists examine how each chemical reaction works to determine the best method for controlling its rate of reaction.

Factors that affect the rate of reaction are:

- temperature
- concentration of the reactants
- surface area (if the reactants are in lumps or fine powder)
- agitation (mixing and stirring)
- catalysts (chemical helpers).

By changing these variables, scientists can control how fast or slow a chemical reaction proceeds.

Temperature

Increasing the temperature will normally increase the rate of a chemical reaction. This occurs for two reasons.

First, increasing the temperature increases the speed of the particles in liquids and gases. As a result, particles collide more frequently, so more chemical reactions occur in a shorter amount of time.

Second, increasing the temperature gives the particles more energy. So, when the molecules collide, chemical bonds are more likely to break and the atoms in the reactants can rearrange more easily to form products.

1 p169

There are many reasons for using heat to increase the rate of a reaction. When you bake a batch of biscuits, you place it in the oven to increase the rate of chemical reactions that convert your dough into biscuits. However, you can't increase the temperature too much or the rate of reaction will be so fast that the biscuits will burn before they are cooked all the way through. This is what has happened in Figure 5.3.3.

Figure 5.3.3 Biscuits must be baked at the right temperature. If the temperature is too high, the reaction is so fast that they burn before they are cooked inside.

Sometimes you may want to decrease the rate of reaction by lowering the temperature. When you place a carton of milk in the fridge, it slows the rate of the chemical reaction that turns milk sour. Similarly, fruit farmers will transport their produce in refrigerated trucks to stop the fruit ripening before it gets to market.

SciFile

Putting life on hold

Through the process of in-vitro fertilisation (IVF), human egg cells can be fertilised and frozen for later use. Freezing the eggs stops the chemical reactions that cause the embryo to develop. Today, one in 33 births in Australia is the result of IVF. That's almost one in every classroom.

Figure 5.3.4 Frozen human eggs

Concentration

The term **concentration** refers to the amount of reactants present in a particular volume of liquid or gas during the reaction. For example, if you put 20 teaspoons of sugar in a litre of water, then the concentration of sugar is high. The solution is concentrated. However, if you put 1 teaspoon of sugar in a litre of water, then the concentration of sugar is low. The solution is dilute. Concentrated and dilute solutions are shown in Figure 5.3.5.

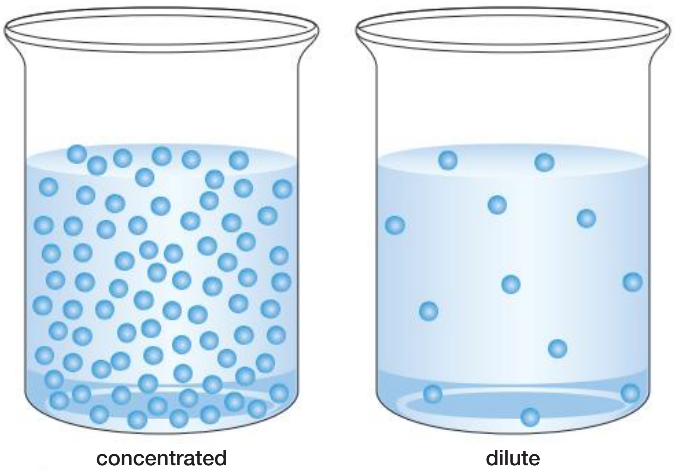


Figure 5.3.5 A concentrated solution has a large number of sugar molecules in the beaker of water. A dilute solution has very few sugar molecules in the same volume.

Increasing the concentration of the reactants will increase the rate of reaction. This is because the particles are more likely to collide and react when they are highly concentrated. Collisions between particles are necessary to allow the bonds to break and new bonds to form.

Increasing the concentration of reactants is a very common way of increasing the rate of reaction. You concentrate the reactants whenever you turn up the gas knob on a heater or stove like in Figure 5.3.6, add more wood to a fire, add more sugar to a breadmaker or drink 20 mL instead of 10 mL of antacid to relieve heartburn.

2 p170

Figure 5.3.6 When you increase the flow of gas on a gas stove, you increase the concentration of reactants to produce a bigger flame and more heat.

It is also common to reduce the concentration of reactants in order to slow the rate of some reactions. When you place food in a zip-lock bag or air-tight container, you are limiting the concentration of oxygen and therefore limiting how quickly the food can go stale. A similar principle is used to protect some iron structures from rusting. Iron is often coated with paint to limit the amount of oxygen that can react with the surface to form iron(II) oxide (rust).

Agitation

Stirring reactants can also increase the rate of reaction. Stirring is known scientifically as **agitation**. Agitation ensures that the reactants are kept in contact, by removing build-up of products around the reactants. For example, if a solid piece of calcium carbonate is dropped into the bottom of a beaker of sulfuric acid, it will react with the acid to produce calcium sulfate, water and carbon dioxide gas. The word equation for this reaction is:

$$\text{calcium carbonate} + \text{sulfuric acid} \rightarrow \text{calcium sulfate} + \text{water} + \text{carbon dioxide}$$

and the formula equation is:

$$CaCO_3(s) + H_2SO_4(aq) \rightarrow CaSO_4(aq) + H_2O(l) + CO_2(g)$$

Although the carbon dioxide bubbles off as a gas, the other products—calcium sulfate and water—build up around the calcium carbonate as shown in Figure 5.3.7. The products surround the calcium carbonate, which means less sulfuric acid contacts the calcium carbonate to react. Agitating the reaction flushes the products away from the calcium carbonate, and allows the sulfuric acid to attack the surface of the calcium carbonate. Magnetic stirrers (Figure 5.3.8) are used in the laboratory to constantly agitate reactions and ensure the maximum rate of reaction.

3 p171

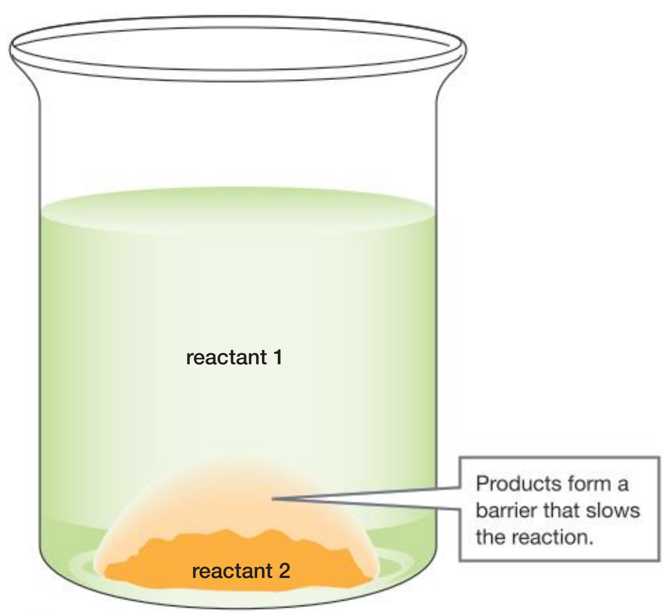


Figure 5.3.7 When a solid reacts with a liquid, the products build up around the solid, slowing down the rate of reaction. Agitation removes the build-up of products to maximise the rate of reaction.

Figure 5.3.8 In the laboratory, scientists use magnetic stirrers to constantly agitate and ensure maximum rate of reaction.

Surface area of reactants

The rate of reaction between calcium carbonate and sulfuric acid can be increased further if the calcium carbonate is crushed into a powder rather than used as one solid piece. If the calcium carbonate is placed in the acid as a single, solid lump, the sulfuric acid can only react with the outside of the lump, as shown in Figure 5.3.9. However, if the lump is broken down into smaller pieces, then particles originally on the inside of the lump are now exposed and can react with the acid. This means more particles are reacting at the same time, so the reaction is faster. Dividing up solid reactants into smaller pieces creates a much larger surface in contact between the reactants.

Having a large surface area is important in the delivery of medicines in the form of capsules. The capsules contain powdered medicines so that when the capsule breaks apart in your stomach, the powdered medicines can be absorbed into your bloodstream more quickly.

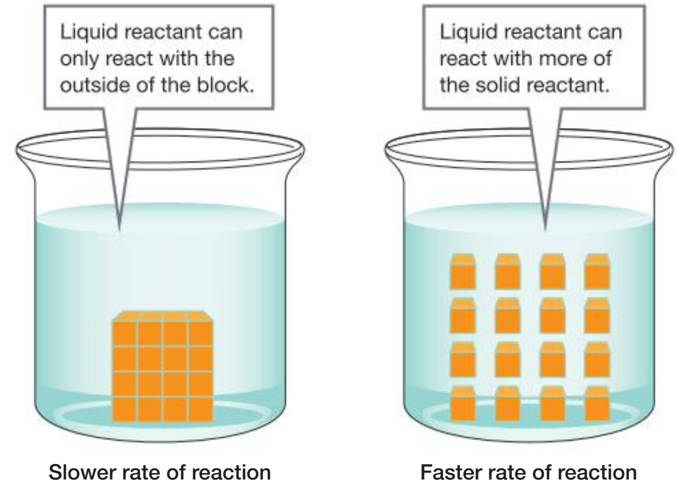


Figure 5.3.9 If the solid reactant is divided into smaller pieces, more of the solid is exposed to the liquid reactant and the rate of reaction is increased.

4 p171 5.6

Catalysts

Catalysts are chemicals that speed up reactions but are not consumed (used up) during the reaction. They can be considered 'chemical helpers' that help the reactants to form the products. Catalysts can do this in two ways:

- They reduce the amount of energy that is required to convert the reactants into products
- They make it easier for reactant molecules to collide and form products.

For example, a catalytic converter in a car exhaust system uses platinum metal as a catalyst to help convert the poisonous gas carbon monoxide (CO) into the less toxic carbon dioxide (CO_2). Normally, carbon monoxide and oxygen would not react fast enough to form carbon dioxide (Figure 5.3.10).

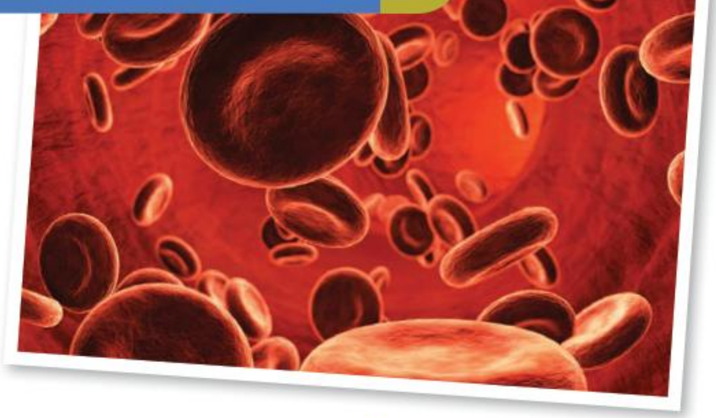
Figure 5.3.10 Catalytic converters in car exhaust systems prevent toxic chemicals from being released into the environment.

However, in a catalytic converter the carbon monoxide and oxygen molecules both stick to the platinum catalyst and move around on its surface. When they finally collide, the platinum helps the reactant molecules to rearrange and form carbon dioxide, which then leaves the surface of the platinum and is flushed out via the exhaust. Catalytic converters also remove some dangerous nitrogen oxides.

SciFile

Carbon monoxide poisoning

Carbon monoxide is a colourless, odourless gas that is produced when petrol is burnt in a limited supply of oxygen. Haemoglobin is the molecule in red blood cells that transports oxygen around your body. However, carbon monoxide binds to haemoglobin more strongly than oxygen does. This leaves no space for the oxygen, so your cells quickly become starved of oxygen and die.



Enzymes

Enzymes are biological catalysts. Enzymes are natural molecules that hold reactant molecules together until they rearrange to form products. Many enzymes are at work in your body right now. One of the first processes of digestion uses an enzyme called amylase, which is found in your saliva (Figure 5.3.11). Similar enzymes are secreted by your pancreas and small intestine. Amylase is responsible for breaking down the starches in complex carbohydrates, such as in breads and potatoes, into simple sugars for easy absorption into the body.

5.7

Figure 5.3.11 Saliva uses the enzyme amylase to break down starches into simple sugars.

INQUIRY science 4 fun

Jellied enzymes

How do the enzymes in pineapple affect jelly?

Yes

Collect this …

- jelly powder
- water
- fresh pineapple
- apple
- banana
- 4 small containers to set the jelly
- kettle
- refrigerator

Do this …

1. Cut up the fruit into small pieces, about 1–2 cm cubes.
2. Dissolve the jelly in hot water according to the instructions on the packet.
3. Divide the jelly mix evenly between the four small containers.
4. Allow the jelly to cool in the fridge for a few hours, but not set. Place the pineapple in one container of jelly, the apple in the second and the banana in the third. Don't put any fruit in the fourth.
5. Place the containers in the refrigerator and wait for them to set.

Record this …

Describe what you observed.
Explain why you think this happened.

SCIENCE AS A HUMAN ENDEAVOUR

Nature and development of science

Enzymes for fuels and pharmaceuticals

Figure 5.3.12 The enzymes in yeast cells like this one may hold the key to producing renewable biofuels.

Enzymes are natural catalysts that control biological processes such as digestion, respiration and photosynthesis. Scientists are constantly finding new ways to apply enzymes in industrial processes, such as the production of renewable, environmentally friendly fuels and the development of new pharmaceutical drugs.

Biofuels

As the world's fossil fuel resources start to run out, scientists around the world are looking for alternative fuels and resources. Biofuels are a new type of fuel that promises to be a renewable resource. The biofuel can be manufactured by fermenting the sugars in crops such as sugar cane, potato and corn. The fermentation process uses enzymes in microorganisms such as yeast to convert the sugars into ethanol according to the reaction:

glucose + enzyme → ethanol + carbon dioxide

$C_6H_{12}O_6$ + zymase → $2C_2H_6O$ + $2CO_2$

Figure 5.3.13 This is one of a new generation of vehicles that use biofuels.

Ethanol is found in alcoholic drinks, but also makes up to 25% of the petrol used in cars around the world.

Pharmaceuticals

The field of medicine has also benefited greatly from scientists' deeper understanding of enzymes. One of the most revolutionary discoveries has been the synthesis of penicillin, which is the world's most widely used antibiotic and has saved countless lives.

The process for producing penicillin involves the use of two different enzymes to combine three different biochemicals into the wonder drug. These enzymes occur naturally in the *Penicillium* fungi, in which the drug was first discovered by Scottish scientist Alexander Fleming in 1928. However, it was Australian scientist Howard Florey (Figure 5.3.14) and his colleagues Ernest Chain and Norman Heatley who discovered how to produce large quantities of the drug in the laboratory. Their discoveries earned Florey, Fleming and Chain a Nobel Prize in 1945.

Figure 5.3.14 In 1945, Howard Florey won Australia's second ever Nobel Prize for his work on the mass production of penicillin.

5.3 Unit review

Remembering

1 **List** three examples each of fast and slow reactions.

2 **State** the five ways that the rate of reaction can be controlled.

3 **State** the name given to chemicals that speed up a chemical reaction but are not used up during the chemical reaction.

Understanding

4 **Define** the term *rate of reaction*.

5 **Explain** why you need to choose the right temperature when baking a cake.

6 Scientists use magnetic stirrers to maximise the rate of reaction. **Explain** how continually stirring the reaction helps to make it go faster.

7 **Explain** how a catalyst increases the rate of reaction.

8 **Explain** why particles must collide before they can react.

Applying

9 a **Identify** two examples of reactions at home that you speed up.

b **Identify** two examples of reactions at home that you slow down.

c For each case, **describe** what you do to change the rate.

10 To remove a stain faster, Jenny applies more stain remover. **Identify** which of the methods of increasing the rate of reaction Jenny is using.

11 The advice on headache tablet boxes is that adults can take two, but a child should only take one. **Identify** a factor affecting reaction rate that is relevant to this advice.

Analysing

12 **Distinguish** between the terms *chemical change* and *chemical reaction*.

13 **Discuss** two other examples where the word *rate* is used in everyday life. Assess what this word means in each context.

14 **Compare** the similarities in how increasing agitation and increasing the surface area of reactants increase the rate of a reaction.

Evaluating

15 **Propose** the effect of the following changes on a wood fire heater. **Justify** your predictions.

a The wood is chopped into smaller pieces.

b The vent is closed so that less air can get in.

16 Athletes use altitude training to increase their numbers of red blood cells and hence the concentration of oxygen in their bloodstream. **Propose** how this might help them during a race.

Creating

17 **Construct** a labelled diagram showing how the concentration of hydrochloric acid increases the rate that it reacts with a block of calcium carbonate.

Inquiring

1 Research metabolism to answer the following questions.

a What is metabolism and what is meant by your *metabolic rate*?

b How can you change your metabolic rate?

c How does metabolic rate change as you get older?

2 Investigate metabolism in ectothermic (cold-blooded) and endothermic (warm-blooded) animals and how the rate of metabolism is controlled in each case.

3 Research the role of enzymes in digestion. Write a paragraph about their role in digestion and the types of enzymes that exist.

4 Design an experiment to investigate the effect of temperature on the rate of reaction between calcium carbonate and hydrochloric acid.

5.3 Practical activities

1 Rate of reaction: The effect of temperature

Purpose

To determine how temperature affects the light intensity of light sticks.

Materials

- 2 light sticks
- 2 beakers
- iced water
- hot water

Procedure

1. Start the light sticks glowing and darken the room as much as possible.
2. Place one light stick in a beaker of iced water and one in a beaker of hot tap water as shown in Figure 5.3.15.

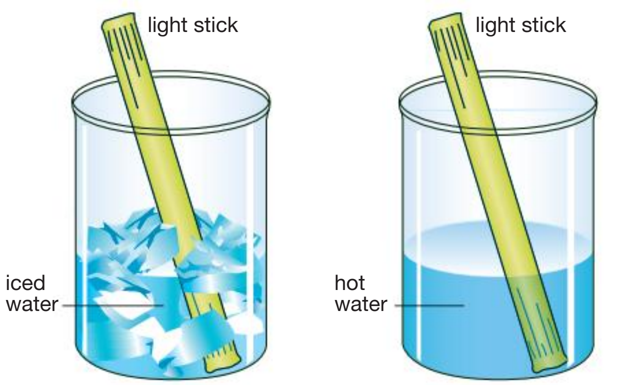


Figure 5.3.15

Results

Record your observations

Discussion

1. **State** what evidence there is that a chemical reaction is taking place inside the light sticks.
2. **State** what changing the temperature has done to the rate of reaction. **Justify** your answer based on your observations.
3. Light sticks work by a chemical reaction between hydrogen peroxide and a chemical called an ester. A product of this reaction then causes a dye to emit light. **Explain** how temperature may be affecting the reaction.

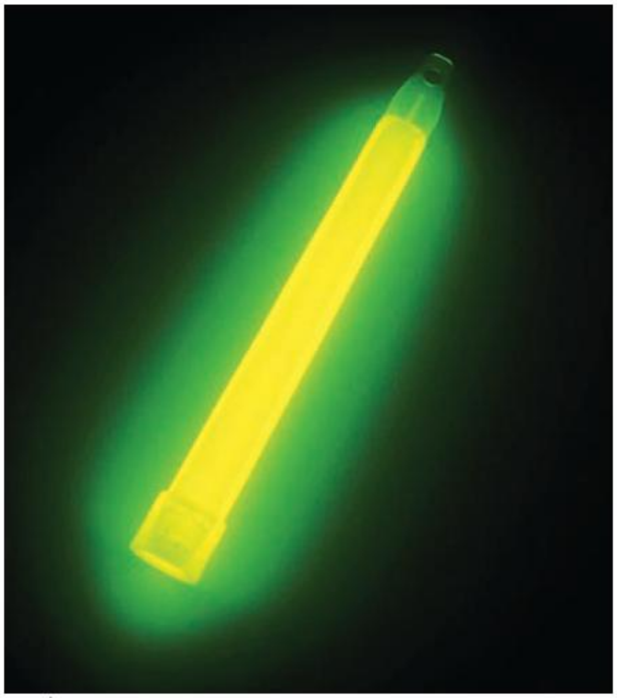


Figure 5.3.16 A light stick glowing

2 Rate of reaction: The effect of concentration

Purpose

To examine how the concentration of hydrochloric acid affects the rate at which it reacts with marble chips.

Materials

- marble chips
- 20 mL of 0.5 M hydrochloric acid in a small beaker
- 20 mL of 2 M hydrochloric acid in a small beaker
- 3 large test-tubes
- rubber stopper with flexible delivery tube
- large deep tray
- retort stand with test-tube clamp
- timer
- ruler
- water

SAFETY

Wear safety glasses at all times.

Procedure

1. Place a few marble chips in two of the large test-tubes. Make sure the amount of marble chips is the same in each test-tube.

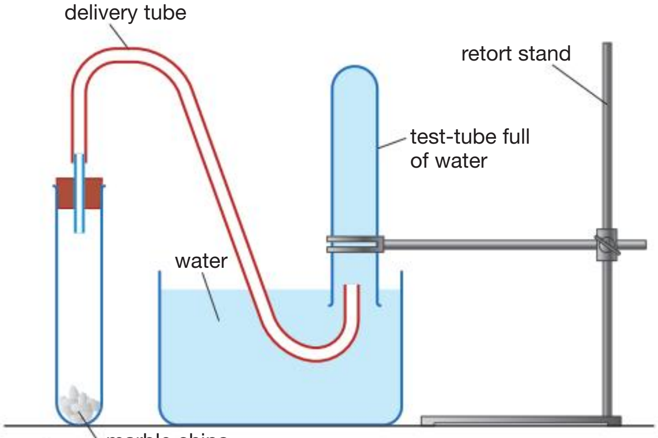


Figure 5.3.17

2. Set up the rest of the apparatus as shown in Figure 5.3.17. Fill the tray with water, fill the large test-tube with water and place it horizontally in the tray then invert the test-tube. Make sure the mouth of the test-tube remains submerged and then clamp the test-tube as shown.
3. Carefully pour 20 mL of 0.5 M hydrochloric acid into one of the test-tubes containing marble chips then immediately connect it to the rubber stopper and hose.
4. Start the timer and let the reaction run for 5 minutes.
5. Record how much water was displaced in the inverted test-tube in the table in the results section.
6. Set up the apparatus again so that the inverted test-tube is filled with water.
7. Repeat steps 3–5 using 2 M hydrochloric acid.

Results

Copy and complete the following table.

Acid	Displaced water (cm)
0.5 M hydrochloric acid	
2 M hydrochloric acid	

Discussion

1. Marble chips are a form of calcium carbonate. When they react with hydrochloric acid, they produce calcium chloride, carbon dioxide and water. **Construct** word and formula equations for this reaction.
2. **Compare** the rate of reactions for the 0.5 M and 2 M hydrochloric acid.
3. **Explain** your observations.
4. **Discuss** other factors that should be kept constant during this experiment to ensure that only the concentration of the acid affects the rate of reaction.
5. **Evaluate** your experiment.

3 Rate of reaction: The effect of agitation

Purpose

To see the effect of stirring on the rate at which chalk dissolves in hydrochloric acid.

Materials

- 2 × 5 mm pieces of chalk
- 2 × 250 mL beakers
- stirring rod
- 1 M hydrochloric acid
- stopwatch

Procedure

1. Fill both beakers with 50 mL of hydrochloric acid.
2. Place one piece of chalk into each beaker of acid at the same time.
3. Start the stopwatch.
4. Stir one beaker with the stirring rod continuously while leaving the other standing still.
5. Record the time that both pieces of chalk finish reacting in the table in the results section.

Results

Copy and complete the following table.

Reaction	Time for reaction to complete
Still reaction	
Agitated reaction	

Discussion

1. **State** what indicates that a chemical reaction is taking place.
2. **Discuss** anything you observed that suggested one chemical reaction was going faster than the other.
3. **Identify** which reaction was faster. **Justify** your choice.

4 Rate of reaction: The effect of surface area

Purpose

To design and conduct an experiment to determine how changing the surface area of a reactant changes the rate of reaction.

Materials

- chalk
- 1 M hydrochloric acid
- beakers
- timers
- rulers
- marking pens

Procedure

1. To design your experiment you should consider the following.
   - How will you measure the rate of reaction?
   - What one factor will you change in each of your samples?
   - What factors will you try and keep the same for each sample?
2. Assess how you will carry out your experiment, how you will collect your data and a list of equipment you will need.
3. Construct a diagram of your experimental apparatus. Show this to your teacher before you start experimenting.
4. Carry out your experiment and collect your data.
5. Assess the safety aspects of this activity

Results

Present your data in a suitable way and answer the discussion questions.

Discussion

1. **Describe** any pattern or patterns you found in the data.
2. **Summarise** the relationship between surface area and rate of reaction.
3. **Explain** the relationship between surface area and rate of reaction.

5 Chapter review

Remembering

1 **State** the law of conservation of mass.

2 **List** five different types of chemical reaction.

3 **State** the meaning of the symbols (s), (l), (g) and (aq) in a chemical equation.

4 **Name** the gas given off when calcium carbonate undergoes thermal decomposition.

5 **Recall** the two-step process for the reduction of iron ore in a blast furnace by writing the chemical equations.

6 **List** ways in which the speed of a chemical reaction can be controlled.

Understanding

7 **Define** the term *rate of reaction*.

8 **Describe** what distinguishes redox reactions from other chemical reactions.

Applying

9 **Identify** types of ionic compounds that are almost always soluble and list any exceptions.

10 **Identify** two reactions that should be slowed down and how they are slowed down.

11 **Demonstrate** the action of heat on a metal carbonate using word and formula equations.

12 **Calculate** the correct number of reactants and products to balance the following equations. Include any missing states.

- a $H_2(g) + O_2(g) \rightarrow H_2O$
- b $Na + Cl_2 \rightarrow NaCl(s)$
- c $CaCO_3(s) \rightarrow CaO(s) + CO_2$
- d $CH_4(g) + O_2 \rightarrow CO_2 + H_2O(l)$
- e $HNO_3(aq) + Ca \rightarrow Ca(NO_3)_2(aq) + H_2$

Analysing

13 **Classify** each of the following reactions as decomposition, combination, combustion or precipitation.

- a $Ba(NO_3)_2(aq) + Na_2SO_4(aq) \rightarrow BaSO_4(s) + 2NaNO_3(aq)$
- b Magnesium carbonate is heated to produce magnesium oxide and carbon dioxide.
- c methane + oxygen → carbon dioxide + water
- d Hydrogen gas (H_2) and chlorine gas (Cl_2) are reacted together to produce hydrogen chloride (HCl).

Evaluating

14 For each of the following reactions, **deduce** the:

- a word equation
- b balanced formula equation, including states.
  - i Dilute sodium hydroxide solution is added to dilute sulfuric acid. Sodium sulfate and water are produced.
  - ii Clear silver nitrate solution is mixed with a clear sodium chloride solution. White silver chloride precipitates out, leaving behind a clear solution of sodium nitrate.
  - iii Hydrochloric acid reacts with calcium metal. A solution of calcium chloride is produced, through which rise bubbles of hydrogen.

15 Refer to Table 5.2.2 on page 152. **Assess** which of the following substances would be soluble in water.

- a $BaSO_4$
- b $LiNO_3$
- c $CaCO_3$
- d $MgCl_2$

16 Hydrogen peroxide breaks up slowly by itself to form oxygen and water. When some manganese(IV) oxide (MnO_2) is added to it, there is a sudden increase in the production of oxygen gas. However, none of the manganese(IV) oxide seems to be used up in the reaction. **Propose** why the manganese(IV) oxide has this effect.

Creating

17 **Use** the following ten key terms to **construct** a mind map.

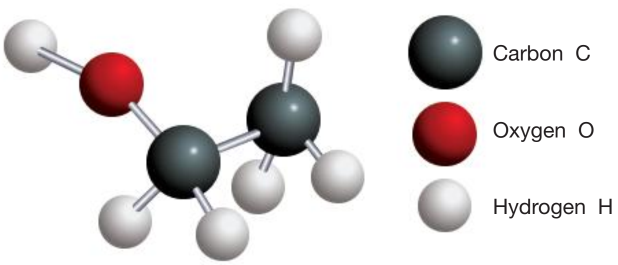
balanced equation
chemical reaction
chemical equation
combination
combustion
corrosion
decomposition
metal displacement
precipitation
redox

5.8

Thinking scientifically

Q1 Scientists use molecular formulas as short-hand notation for describing the structure of molecules. The formulas can be used to communicate which types of atom are in the molecule and how many of each type there are. For example, the chemical formula for water, H_2O, says that in every water molecule, there are two hydrogen atoms and one oxygen atom.

Shown here is a molecule of the compound ethanol. Which of the following molecular formulas best describe this molecule?



A C_2H_4O
B C_2H_5O
C C_2H_6O
D $C_2H_4O_2$

Q2 The law of conservation of mass states that during a chemical reaction, atoms cannot be created or destroyed. From this law, it follows that during a chemical reaction, the total mass of the reactants and products:

A always increases
B always decreases
C may increase or decrease
D always stays the same.

Q3 The term *solubility* is used to describe how well a compound dissolves. A compound that dissolves well is referred to as soluble, while a compound that does not dissolve is referred to as insoluble. Scientists use solubility tables like the one below to predict whether a compound will be soluble or insoluble in water.

Type of compound	Solubility	Exceptions
Nitrates NO_3^-	Soluble	None
Chlorides Cl^- Bromides Br^- Iodide I^-	Soluble	Ag^+, Hg^+, Pb^{2+}
Sulfates SO_4^{2-}	Soluble	Ca^{2+}, Ba^{2+}, Pb^{2+}, Ag^+
Carbonates CO_3^{2-}	Insoluble	Li^+, Na^+, K^+, NH_3^+
Phosphates PO_4^{3-}	Insoluble	Li^+, Na^+, K^+, NH_3^+

Use this solubility table to determine which of the following compounds is insoluble.

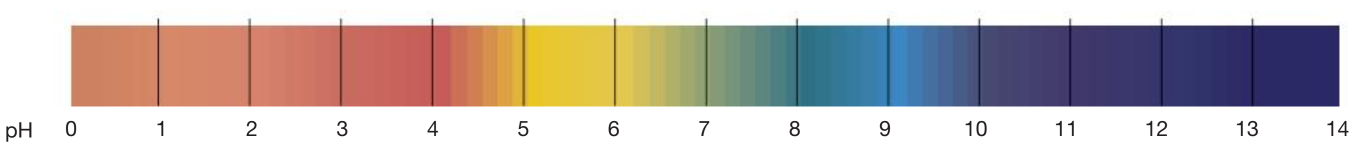
A $NaNO_3$
B $MgCl_2$
C K_2CO_3
D $PbSO_4$

Q4 Scientists use the pH scale (shown below) to measure the concentration of acids and bases. The pH scale ranges from 0 to 14. Substances with a pH less than 7 are acidic, while substances with a pH greater than 7 are basic.

The pH of a substance can be measured by an indicator. An indicator is a chemical that changes colour depending on the pH. Indicators change colour because they react with the acid or base. Universal indicator is made up of a combination of several of these chemicals so that it changes colour many times as the pH changes from 0 to 14. Below is a chart that shows the colour of universal indicator over the full pH range.

Lemon juice has pH 2.3. It is most likely to turn universal indicator:

A red-orange
B yellow
C yellow-green
D green.



Thinking scientifically

Q5 Michelle performed five experiments to see how different factors influence how quickly hydrochloric acid reacts with blackboard chalk.

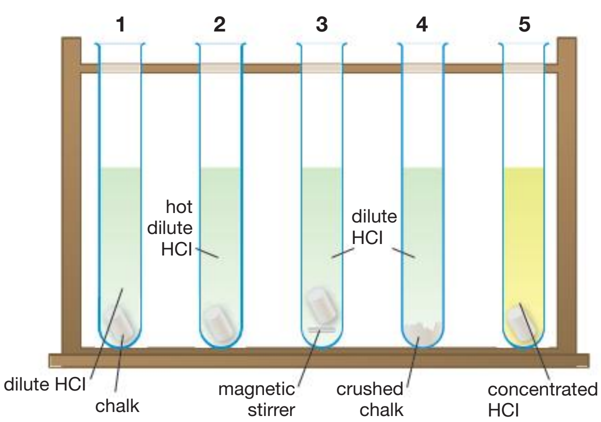
Experiment 1: 1 cm of chalk in dilute hydrochloric acid at room temperature

Experiment 2: 1 cm of chalk in dilute hydrochloric acid heated to 80°C

Experiment 3: 1 cm of chalk in dilute hydrochloric acid with a magnetic stirrer

Experiment 4: 1 cm of chalk crushed and put in dilute hydrochloric acid

Experiment 5: 1 cm of chalk in concentrated hydrochloric acid



In each case, Michelle collected and measured the volume of carbon dioxide gas (CO_2) produced in 5 minutes. Her results are tabulated below.

Experiment	Volume of CO_2 produced (mL)
1	5
2	10
3	30
4	50
5	10

From her data, Michelle can conclude that:

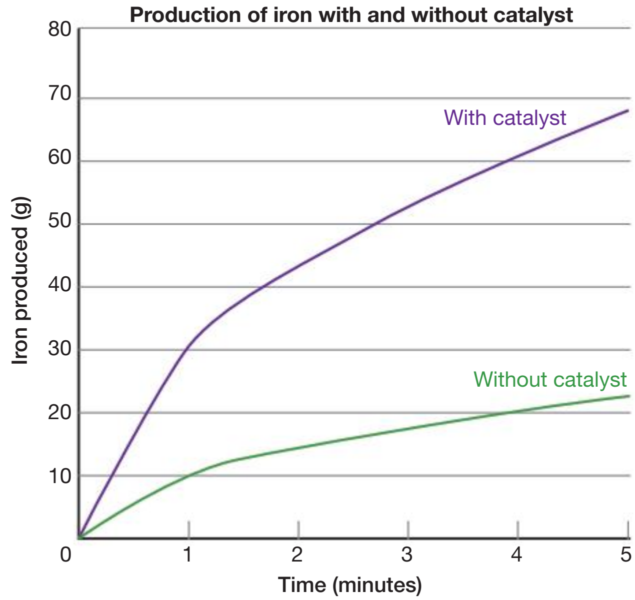
A increasing the temperature had no affect on the rate of reaction

B increasing the concentration of the acid increased the rate of reaction more than stirring the reaction

C stirring increased the rate of reaction the most

D crushing the chalk increased the rate of reaction the most.

Q6 Wasim is developing a new chemical reaction for converting iron ore into iron metal. He wants to determine how adding a catalyst changes the rate of reaction. To do this, Wasim measures the amount of iron metal produced by the chemical reaction every minute for the first 5 minutes. He has plotted the results in the graph below.



From his graph, Wasim can conclude that the catalyst:

A has no effect on the rate of reaction

B halves the rate of reaction

C doubles the rate of reaction

D triples the rate of reaction.

Glossary

Unit 5.1

Aqueous solution: a solution of a substance dissolved in water

Aqueous solution

Balanced equation: a chemical equation in which the number of each type of atom is the same on both sides of the equation

Chemical equation: a short-hand notation that scientists use to communicate what happens during a chemical reaction

Formula equation: a chemical equation where the reactants and products are identified by their chemical formulas

Law of conservation of mass: the law that states that atoms cannot be created or destroyed during a chemical reaction

Product: a substance produced by a chemical reaction

Reactant: the initial substance of a chemical reaction

Word equation: a chemical equation where the reactants and products are identified by their chemical names

Unit 5.2

Anion: a negatively charged ion

Carbon reduction: a chemical process of separation of metals from their ores using carbon

Cation: a positively charged ion

Combination reaction: a chemical reaction where two reactants combine to form one product

Combustion reaction

Combustion reaction: any chemical reaction where a substance burns in oxygen to produce heat and light

Decomposition reaction: a chemical reaction where one reactant breaks apart into two or more products

Electrolysis: a technique for reducing the ions of highly reactive metals by using an electrical current to force electrons onto the ions

Electrowinning: A process of extracting metals from solutions using electrolysis

Froth flotation: a physical process of separation of metals from their ores

Insoluble: does not dissolve

Ion: an atom that has gained or lost electrons to become electrically charged

Ionic compound: a substance made up of positive and negative ions

Oxidation: when a substance gains oxygen atoms or loses electrons

Precipitation reaction

Polyatomic: having many atoms

Precipitate: the insoluble product of a precipitation reaction

Precipitation reaction: when two clear solutions react to produce an insoluble solid

Redox: an abbreviation for oxidation and reduction pairs of reactions

Reduction: when a substance loses oxygen atoms or gains electrons

Soluble: able to dissolve

Smelting: a chemical method of extracting a metal from its ore in which the ore is heated with a reducing agent such as carbon

Unit 5.3

Agitation: stirring

Agitation

Catalyst: a chemical that helps to speed up a chemical reaction but is not used up during the reaction

Concentration: the amount of a chemical in a certain volume of water

Enzyme: a natural occurring catalyst

Rate of reaction: how fast a chemical reaction proceeds

6 Global systems

HAVE YOU EVER WONDERED…

- what happens to dead plants and animals in nature?
- why the weather is not the same every year?
- how climate and weather are different?
- why Australia gets droughts and floods
- why there is so much concern about burning fossil fuels?
- why some people are worried about climate change?

After completing this chapter students should be able to:

- use models to explain the natural cycling of matter in the biosphere, including carbon, nitrogen and water
- use models to explain factors influencing the Earth's climate including ocean currents
- explain how sea ice, glaciers, fossils and sea levels are used as evidence of climate change
- discuss potential impacts of climate change on ecosystems and biodiversity
- compare the cause and effects of the 'greenhouse effect' and the 'enhanced greenhouse effect'
- discuss the evidence that world climates have changed in the past and will continue to change in the future
- discuss the evidence that measurable changes in the Earth's atmosphere in the 20th century are related to human activity.

6.1 Recycling in nature

In Australia, household rubbish is usually sorted into separate bins. Regional and city councils have collections for green waste and other recyclable waste too. The idea of recycling comes from nature. Oxygen, nitrogen, carbon and other elements in the environment cannot be manufactured from nothing. In natural ecosystems, these elements are recycled, forming part of different compounds at different times. Fungi are one example of natural recyclers.

The biosphere

The **biosphere** includes all parts of the Earth's surface and atmosphere where living things exist. It is the sum of all ecosystems. The biosphere is where other spheres of the planet interact. The land (**lithosphere**) interacts with the water (**hydrosphere**). The land and air (**atmosphere**) interact. Living things interact with the land, water and air. Part of the interaction is the natural recycling of water and elements such as carbon and nitrogen. Natural recycling has enabled natural ecosystems to be sustainable (self-renewing). An example is the wetland shown in Figure 6.1.1. **Sustainable ecosystems** are ecosystems that are diverse and provide for the needs of the organisms that live there.

Figure 6.1.1 Wetlands ecosystems are important parts of the biosphere. A large variety of organisms live in wetlands or use them as a resource during migration. Many wetlands hold flood waters, removing silt from them before the water flows out to the oceans.

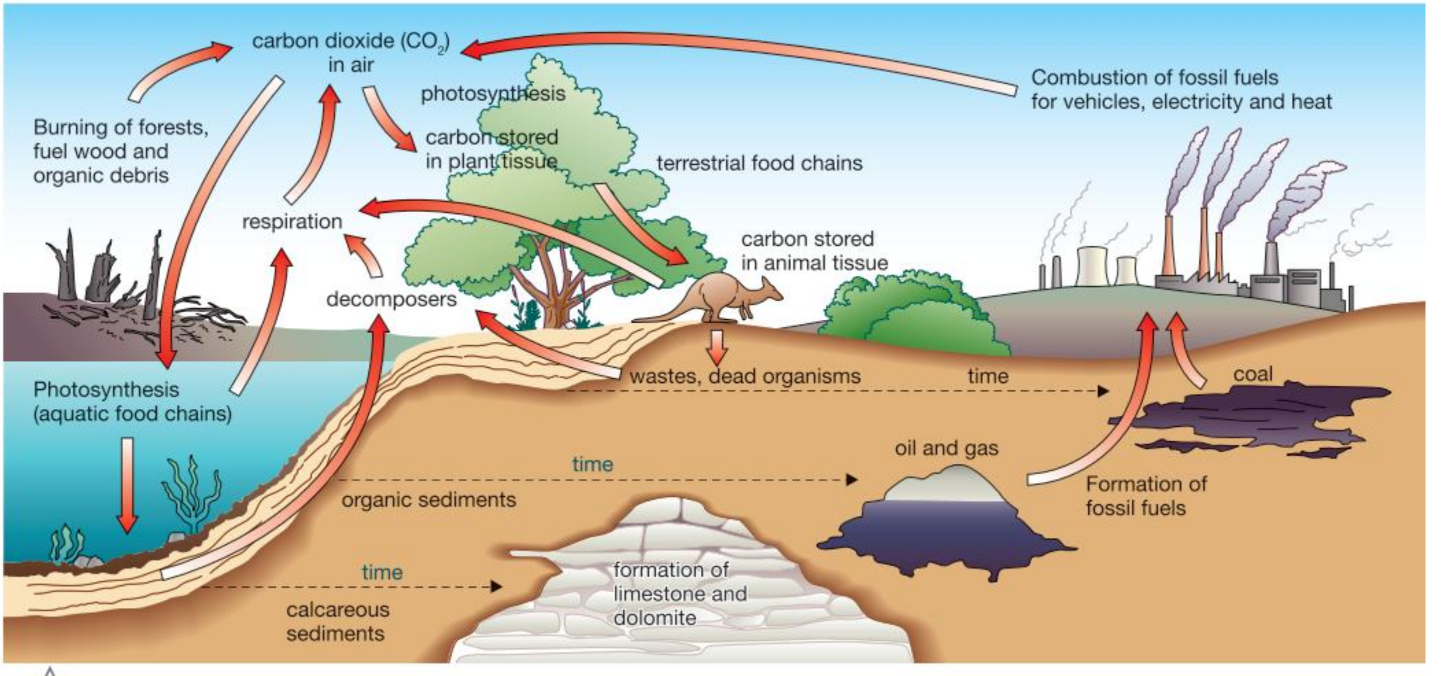


Figure 6.1.2 The carbon cycle moves carbon between the living and non-living parts of ecosystems.

Carbon cycle

The carbon cycle is essential for life on Earth. Carbon is found in all living things, and in their dead bodies and wastes. It is part of the carbohydrates, fats, proteins, vitamins and DNA found in cells, tissues and organs. Carbon is also found in the atmosphere as carbon dioxide (CO_2).

Carbon dioxide is used in photosynthesis when plants combine it with the hydrogen from water to form glucose. Animals and other consumer organisms obtain the carbon they need from the food they eat. However, there is not an endless supply of carbon. Carbon is recycled through the soil, through living things and the atmosphere in the **carbon cycle**, shown in Figure 6.1.2.

As part of this cycle, the process of photosynthesis in green plants incorporates carbon into living things. Respiration releases carbon back into the atmosphere and hydrosphere as carbon dioxide, where it again becomes available for photosynthesis. Organisms release carbon into the soil in wastes such as faeces, urine and fallen leaves. These wastes are used as food by decomposer organisms. As the decomposer organisms respire, carbon is released into the atmosphere, water and soil.

Fossils are the preserved remains of once-living organisms. **Fossil fuels** such as coal and oil contain the carbon of plants and animals that died and were preserved millions of years ago. Burning coal and oil releases carbon that has been unavailable to the carbon cycle for millions of years. Burning wood releases carbon stored for hundreds or maybe even a thousand years.

Earth's largest and oldest long-term store of carbon is calcium carbonate ($CaCO_3$). This chemical is found in limestone, a sedimentary rock usually made from the shells of molluscs and other marine organisms.

SciFile

Recycled carbon

All the carbon on Earth and in the atmosphere is cycled and recycled. The carbon in your body may once have been part of a dinosaur, or even part of a famous person such as Leonardo da Vinci.

Nitrogen cycle

The **nitrogen cycle** is an important natural cycle for living things, because nitrogen is an important element in proteins. Air is 78% nitrogen, but most living things cannot use nitrogen when it is in the form of a gas. Plants use nitrogen compounds from the soil. Animals are consumers that obtain their nitrogen by eating plants or other animals.

Figure 6.1.3 shows that when an organism dies, bacteria in the soil cause nitrogen to be released into the soil as ammonia (NH_3). A second, different group of bacteria get their energy from ammonia. In the process they release water-soluble nitrates back into the soil. Plants take up both the ammonia and the nitrates through their roots.

A third group of bacteria known as **nitrogen-fixing bacteria** absorb nitrogen from the air trapped in soil. Nitrogen-fixing bacteria convert nitrogen into ammonia and then into nitrates.

The actions of a fourth group of bacteria, called **denitrifying bacteria**, are opposite to those of nitrogen-fixing bacteria. Denitrifying bacteria obtain their energy from the nitrates and convert them back into gaseous nitrogen (N_2). This is then released back into the atmosphere.

6.1

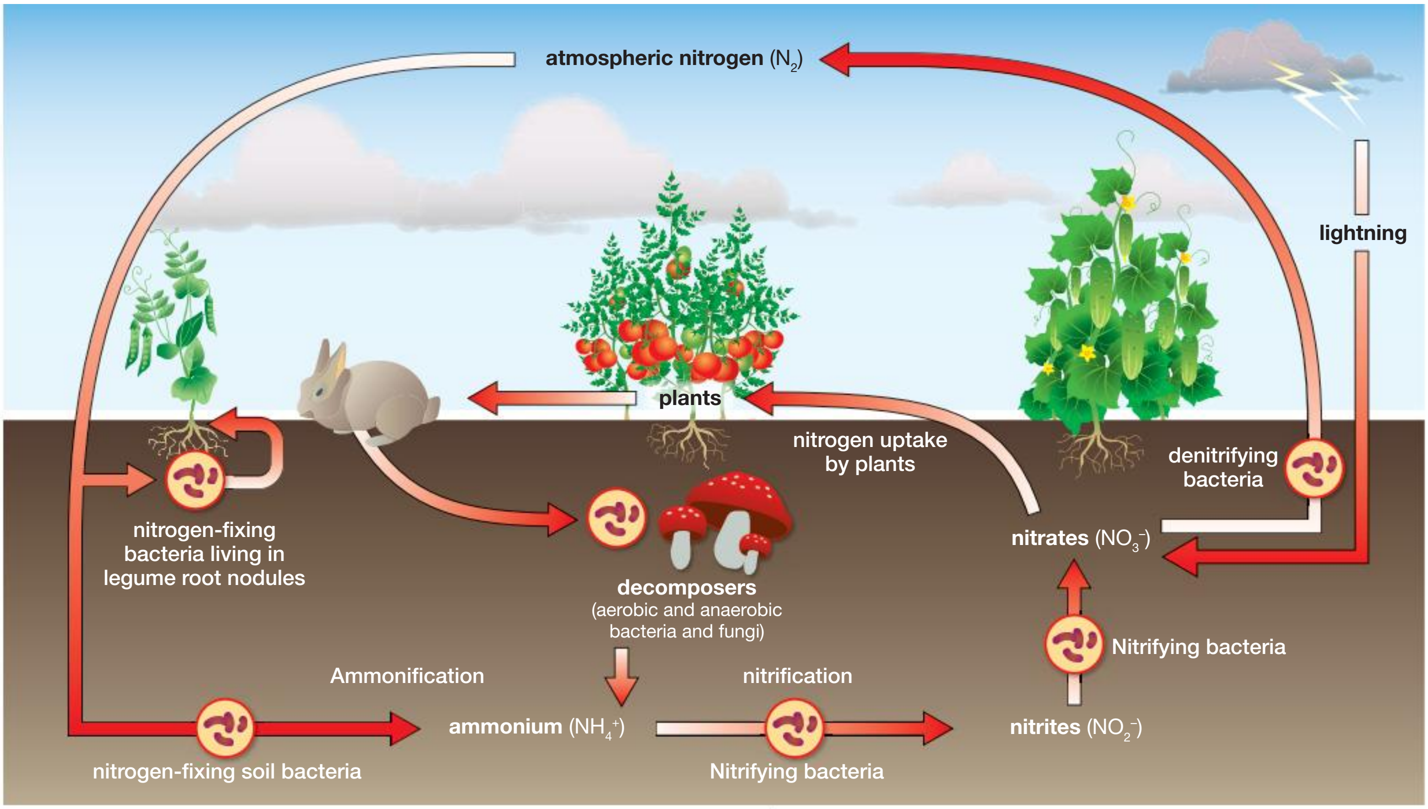


Figure 6.1.3 The nitrogen cycle shows how important different groups of bacteria are in the recycling process. Sometimes the work done by one group of bacteria is undone by another group.

INQUIRY **science 4 fun**

Natural recycling

What happens to the leaves and fruit that fall off trees in the natural environment?

Yes

Collect this …

- natural materials such as leaves and fruit
- 4 flower pots (an area of the garden could be used instead of pots)
- garden soil
- icy-pole sticks as labels

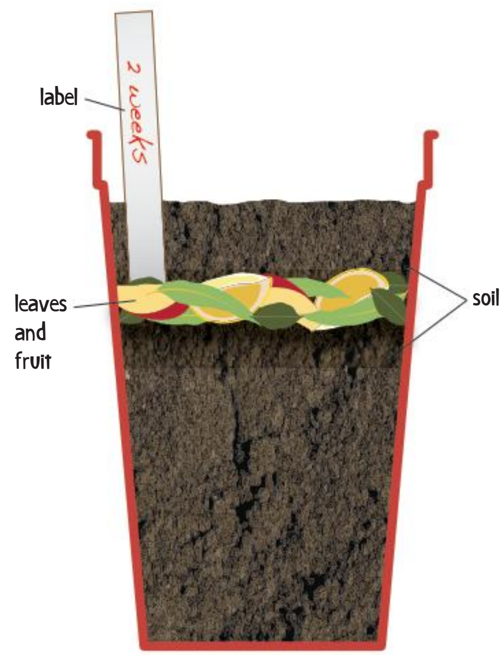
SAFETY

Wash your hands thoroughly after working with soil.

Do not inhale dust.

Do this …

1. Divide the materials collected into four identical groups.
2. Fill the four flower pots three-quarters full with garden soil. Alternatively, mark out four small plots in the garden and scrape away about 4 cm of soil.
3. Photograph the fruit and leaves.
4. Place one set of materials in each of the pots and cover them with 4 cm of soil.
5. Label the pots (or plots) '1 week', '2 weeks', '3 weeks', '4 weeks'.
6. Ensure that the soil remains moist but not waterlogged.
7. At the end of the relevant time period, clear off the top 4 cm of soil.
8. Photograph the materials to record any changes.



Record this …

Describe what happened.

Explain why you think this happened.

Rain and storms

During electrical storms like the one in Figure 6.1.4, the energy of lightning breaks nitrogen molecules (N_2) in the atmosphere into nitrogen atoms. The nitrogen atoms combine with oxygen in the air, forming nitrogen oxides. These dissolve in rain to form nitrates that enter the soil with the rain. The nitrates are then available for plants to use.

Figure 6.1.4 During lightning storms, nitrates are produced in the atmosphere and dissolve. The falling rain adds these nutrients to the soil.

Leguminous plants

Plants that produce seeds in pods such as peas, beans, clover and wattles (Figure 6.1.5) are known as legumes or **leguminous plants**. They live in a symbiotic relationship with *Rhizobium* bacteria. Both the plant and the bacteria depend on each other for survival. *Rhizobium* bacteria are a type of nitrogen-fixing bacteria. The bacteria live in nodules in the roots of the leguminous plant (Figure 6.1.6). *Rhizobium* bacteria take nitrogen gas from air in the soil and manufactures nitrates. The nitrates pass into the cells of the plant and the plant uses them to build proteins.

Figure 6.1.5 Australian wattles are leguminous plants. They perform the vital role of making nitrogen available to native food webs.

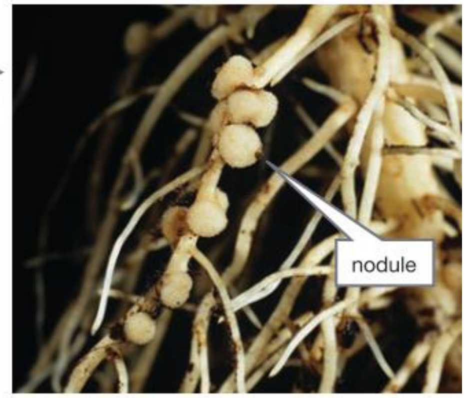


Figure 6.1.6 *Rhizobium* bacteria in root nodules gain protection and glucose from the plant. Leguminous plants gain nitrates and contain more protein than other plants.

1 p182

The water cycle

Water is one of the most precious resources on Earth and is an essential part of all living things.

The water on Earth is recycled continuously in the water cycle. Energy from the Sun causes water to evaporate from moist surfaces such as oceans, soil, plants and animals. The largest amount of water vapour comes from the oceans because they are the largest bodies of water on Earth. The water cycle is summarised in Figure 6.1.7.

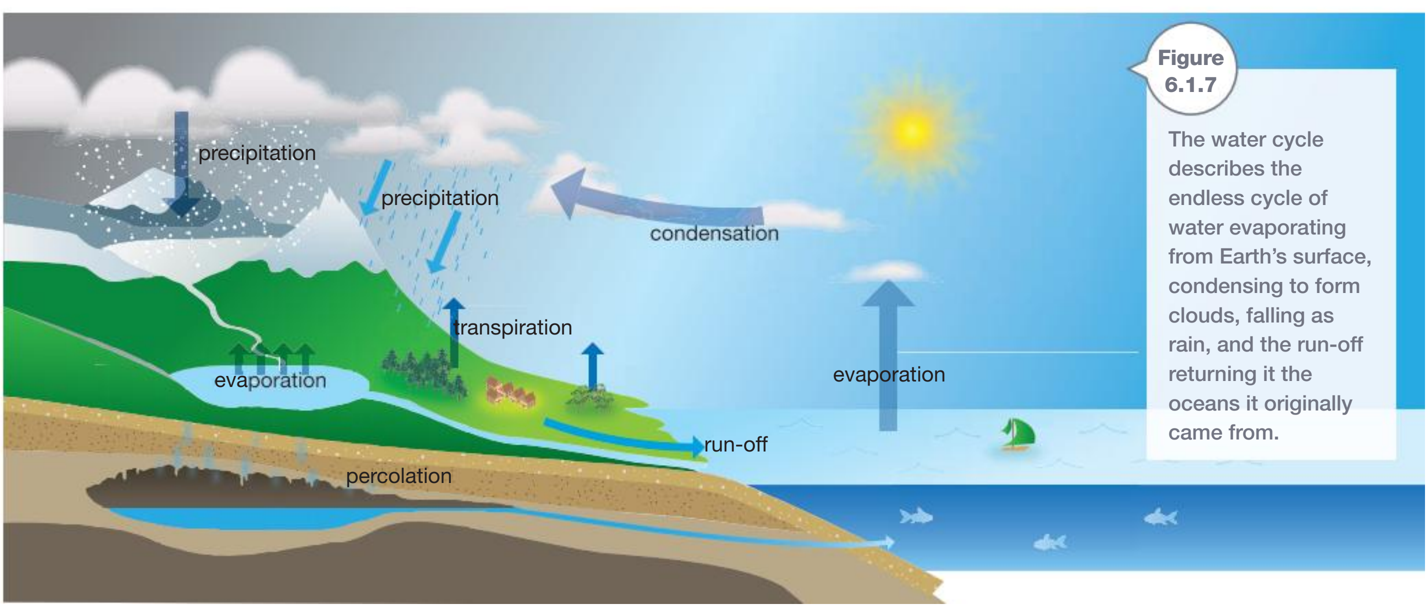


Figure 6.1.7 The water cycle describes the endless cycle of water evaporating from Earth's surface, condensing to form clouds, falling as rain, and the run-off returning it the oceans it originally came from.

6.1 Unit review

Remembering

1 **Name** the process that takes carbon into food chains.

2 **Name** the biological process that removes oxygen from the atmosphere.

3 **State** the form in which nitrogen can be used by plants.

Understanding

4 **Define** the terms:
- a biosphere
- b sustainable ecosystem.

5 a Carbon is a major part of all living things. **Explain** how the carbon gets into living things.
- b **Explain** what the carbon is used for in the bodies of living things.

6 **Explain** how decomposers return carbon to the atmosphere.

7 **Explain** how nitrogen from the air is made available to plants.

8 **Explain** where the carbon in coal and oil came from.

9 a **Explain** what is meant by *long-term stores*.
- b **Name** two stores of carbon.
- c **Explain** why these stores of carbon are considered to be long-term stores.

10 **Explain** why plants can suffer from a lack of nitrogen despite being surrounded by air that is 78% nitrogen.

11 **Explain** what is meant by the cartoon in Figure 6.1.8.

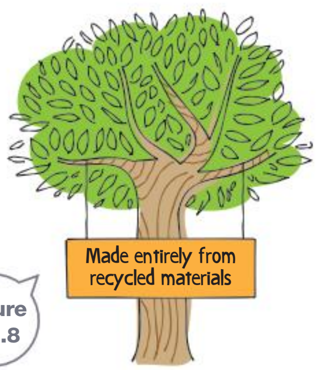


Figure 6.1.8

Applying

12 **Use** a diagram to **demonstrate** how the carbon cycle would change in an area if a forest was replaced by an urban area.

Analysing

13 Nitrogen-fixing bacteria and denitrifying bacteria are both part of the nitrogen cycle. **Contrast** the part they play.

Evaluating

14 a **Classify** the type of biological relationship between *Rhizobium* and leguminous plants.
- b **Justify** your answer.

15 Grass grows well when it is provided with nitrogen-rich fertiliser. **Deduce** the reason why grass that has been provided with plenty of water appears to grow better after a thunderstorm.

16 Nitrifying bacteria in the soil and *Rhizobium* in root nodules both convert nitrogen in the air to nitrates. **Propose** reasons why plants are able to use a greater proportion of the nitrates produced by *Rhizobium* than nitrates produced by nitrifying bacteria in the soil.

17 During extended periods of dry weather many gullies are dry. When significant rain falls, water flows through these gullies. However, after the rain has stopped, water often remains in these gullies and continues to flow for some time.
- a **Deduce** where this water comes from.
- b **Use** a diagram to help you **justify** your answer to part **a**.

18 In the cooler climates of southern Australia some farmers plant lupins (a leguminous plant) in their fields. The lupins are ploughed into the ground before the next crop is panted. **Propose** a reason for the farmer doing this.

Creating

19 **Use** information about the processes involved in the carbon cycle diagrams to **construct** a diagram to show how oxygen cycles in the environment.

20 **Design** an investigation into the benefits for future crops of growing leguminous plants.

Inquiring

1 Research how teams of scientists are involved in analysing environmental contamination in soil and/or water. Explain how the contamination could affect the cycling of matter.

2 Research the cycling of phosphorus in natural ecosystems.

3 Investigate the effect of mining coal and its impact on the biosphere.

6.1 Practical activities

1 Nitrogen cycle game

Purpose

To simulate the nitrogen cycle.

Materials

- 5 containers labelled 'Plant', 'Animal', 'Decomposer', 'Soil', 'Air'
- 4 or 5 cards for each container, as described in step 1 of the procedure

Procedure

1 As a class, construct the following 22 cards for the game.

Plant

Eaten by animal → animal

Plant waste → decomposer

Plant death → decomposer

STAY in plant (2 cards)

Animal

Animal waste → decomposer

Animal death → decomposer

STAY in animal (2 cards)

Decomposer

Nitrates in the soil → plant

Nitrates in the soil → soil

STAY in decomposer (2 cards)

Soil

Nitrogen-fixing bacteria → plants

Denitrifying bacteria → air

STAY as nitrates in the soil (2 cards)

Air

Nitrogen-fixing bacteria → plants

Lightning storm → soil

STAY in air (3 cards)

Place the cards in the relevant containers.

2 Copy Figure 6.1.9 into your workbook. This diagram of the nitrogen cycle should take up half a page.

3 To play the game, set up five stations around the room. Label them 'Plant', 'Animal', 'Decomposer', 'Soil', and 'Air'. Place the relevant cards at each station.

4 Start at any one of the stations and record the name of the station.

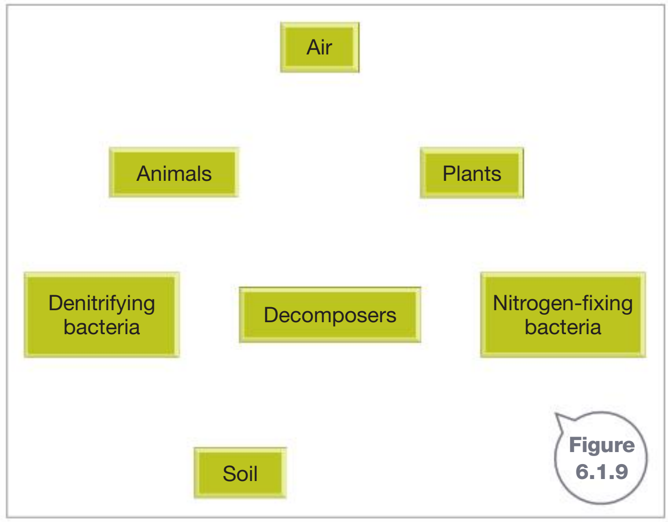


Figure 6.1.9

5 Take a card from the container, read the card and return it to the container. Mix the cards around before the next student takes a card. For all cards except those that say 'STAY', record what it said and move to the next station. If you pick a 'STAY' card, record 'stay', put the card back in the pack, then go to the back of the queue at the station before you pick your second card.

6 You should have a record of the card you picked each time at each stop.

7 The game is complete when you have made 15 visits to stations.

Results

1 On your diagram of the nitrogen cycle, record the pathway that you took through the cycle. Use arrows to show the direction you moved.

2 Draw a square around any part of the cycle where you had to 'stay'. There should be a separate square for each 'stay' card.

Discussion

1 **Compare** the nitrogen cycle you have constructed with Figure 6.1.3 on page 179 and give reasons for any differences.

2 **Identify** the areas where nitrogen did not move quickly on to another part of the cycle.

3 **Identify** the parts of the cycle where nitrogen moved rapidly on to the next stage.

4 **Discuss** the aspects of the nitrogen cycle that you understand better as a result of taking part in the simulation.

6.2 Natural influences on climate

Weather is a common topic of conversation, with people making comments about the lack of rain or the hotter than average temperatures experienced. Weather forecasts can be accessed on television or the internet to find out if sun or rain can be expected for sporting events. More recently, climate and climate change have been topics that are regularly in the news. These topics have led to heated debate.

Weather and climate

Weather describes the state of the atmosphere in terms of temperature, wind, cloud cover and precipitation (Figure 6.2.1). Weather is created by interactions between the hydrosphere (all the water on Earth), the lithosphere (Earth's land masses) and the atmosphere (the layers of gases surrounding the planet). Weather changes from day to day and sometimes there are extreme events.

Climate is the long-term averages of weather conditions. Average statistics using 30 years of weather records and including extreme events are used to describe the climate of an area. To understand **climate change**, you first have to understand what influences climate and the particular factors that affect Australia's climate.

Figure 6.2.1 Rain is a form of precipitation and is one aspect of weather.

Influences on climate

The Sun is the ultimate source of energy for most living things, and it keeps the planet warm enough to support life. Energy from the Sun is a major influence on climate. However, other factors also influence the world's climate.

Surface of the Earth

Characteristics of the Earth's surface determine how much of the energy from the Sun is reflected back into space. This is shown in Figure 6.2.2. Clouds and the ice of the Arctic and Antarctic reflect most of the energy coming in from the Sun. Ice reflects about 84% compared with the dark green forests, which reflect 14%. If all the Earth was covered in forests, a lot more of the Sun's energy would be absorbed and the Earth would be warmer than it is today.

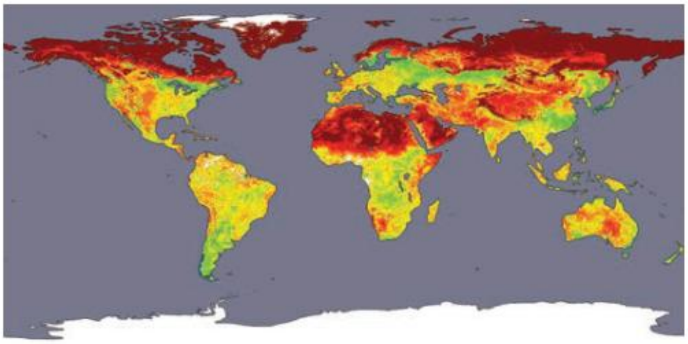


Figure 6.2.2 The white and red areas indicate more reflection of the Sun's rays. In the green and yellow areas, more of the energy from the Sun is absorbed.

Gases in the atmosphere

The energy that comes from the Sun is short-wave radiation. It is absorbed by clouds and the Earth's surface and radiated back out into space as long-wave radiation (heat). Nitrogen and oxygen are the gases that make up most of Earth's atmosphere, and they have no effect on the radiation coming in from the Sun or on the radiation going back out into space. However, the same is not true for a number of other gases in the atmosphere.

Water vapour, carbon dioxide, methane, nitrous oxide and ozone all allow the incoming short-wave solar radiation to pass through. However, they absorb the out-going long-wave radiation (heat). They re-emit the heat in all directions. Some is radiated back to the Earth's surface. These gases have the effect of trapping heat close to the Earth's surface, keeping it warmer than it would be if these gases were not present. These gases are known as **greenhouse gases** and the effect they have on warming the Earth is known as the **greenhouse effect**. Figure 6.2.3 shows what happens in a greenhouse. Greenhouses (or glasshouses) heat up because the short-wave solar radiation can pass through glass into the greenhouse, where it is absorbed by the air, soil and objects in the greenhouse.

The heat that is re-radiated is long-wave radiation and cannot pass through glass. It causes the temperature inside to increase. Figure 6.2.4 illustrates the effect of greenhouse gases on the Earth's atmosphere. Without the protection of the atmosphere, the days would be hotter and the nights colder. Without the greenhouse effect, the Earth's average temperature would be around –18°C rather than 15°C. This would affect weather conditions, plant growth and animal survival.

1 p192

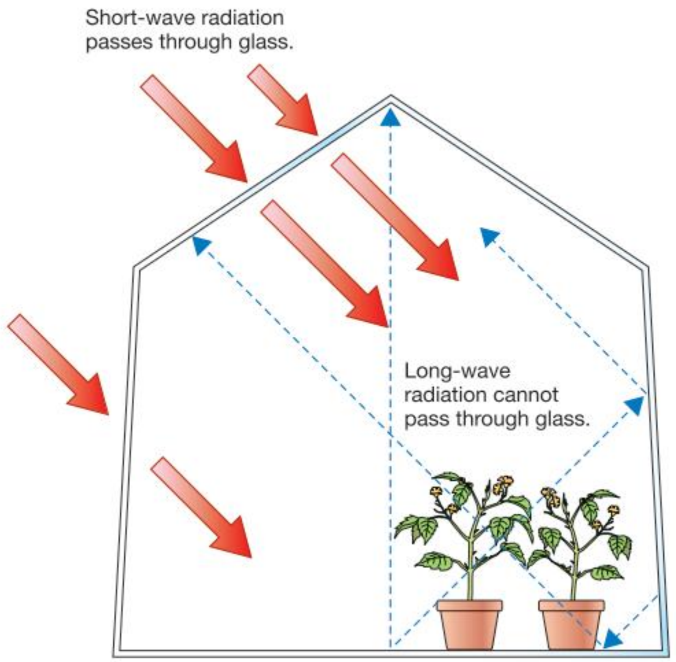


Figure 6.2.3 How a greenhouse heats up

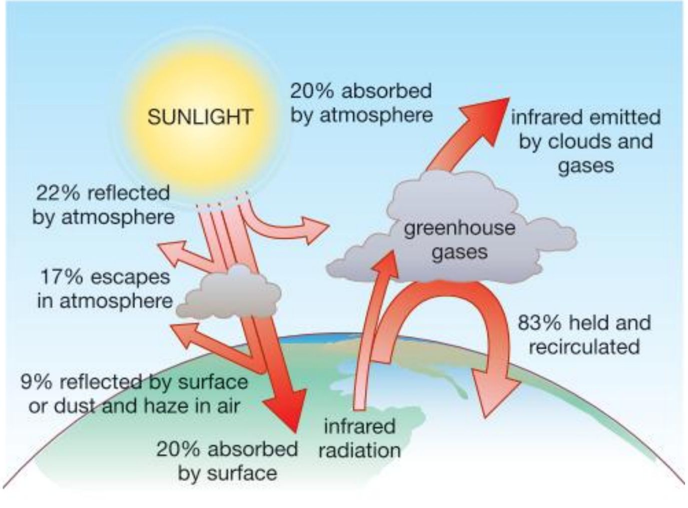


Figure 6.2.4 The effect of greenhouse gases on the Earth's atmosphere

Orientation of the Earth

The Earth is roughly spherical. It orbits the Sun and rotates on its own tilted axis. Figure 6.2.5 demonstrates how the tilt of the axis and the Earth's movement around the Sun cause the seasons. If the tilt of the Earth was different, the characteristics of the seasons would also be different.

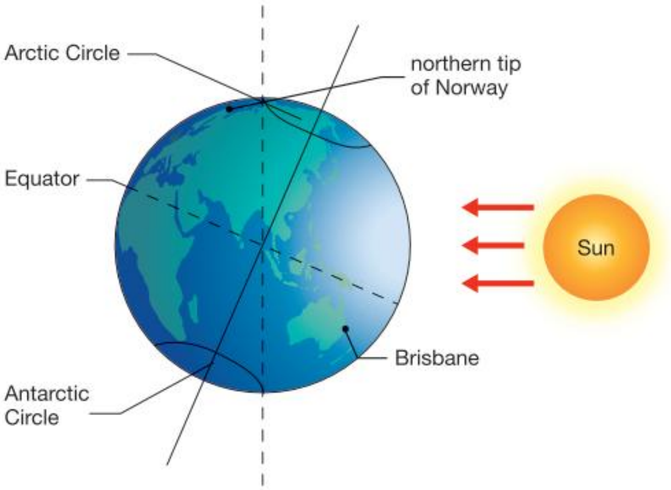


Figure 6.2.5 The diagram shows the northern summer. Radiation from the Sun is reaching a larger proportion of the northern hemisphere than the southern hemisphere.

As the Earth rotates, the atmosphere and the waters of the oceans are dragged around with it. This movement influences the circulation of the air and water on a global scale. However, the major factor influencing circulation of water in the oceans is temperature.

Differences in the temperature of the oceans in different parts of the world have a major impact on Australia's climate.

Ocean currents

Ocean currents are continuous movements of ocean water. They can flow for great distances and cause water to circulate continuously around the whole of the Earth. This circulation plays an important part in determining the climate of many of the Earth's regions.

Currents can be at the surface or deep in the ocean. The main causes of currents are:

- wind
- temperature
- variations in salinity (salt levels)
- the rotation of the Earth on its own axis
- the gravitational pull of the Sun and Moon.

INQUIRY science 4 fun

Spinning oceans

Does the spinning of the Earth really drag the water with it?

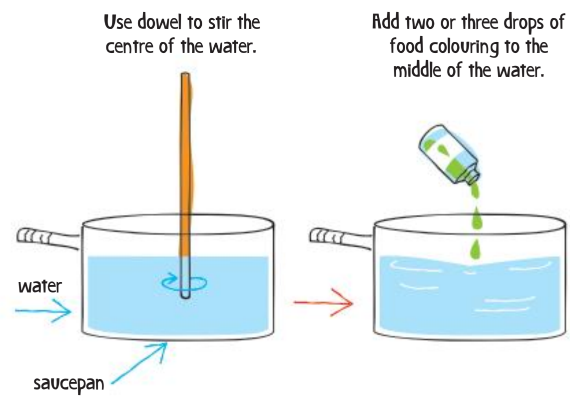
Yes

Collect this …

- large circular container such as a saucepan or baking bowl
- water
- wooden dowel for stirring
- food colouring

Do this …

1 Fill the container with water.
2 Stir the water in the centre only until a good current is achieved (see diagram). Stop stirring.



3 Add two or three drops of food colouring into the centre of the container.
4 Observe the way the food colouring spreads through the water.

Record this …

Describe what happened.
Explain why this happened.

Major surface currents

The major surface currents of Earth are caused by wind. Wind pushes the surface water along until it reaches land. Then the water has to flow left or right or sometimes downwards. In the major ocean basins, the currents form the circular patterns shown in Figure 6.2.6 on page 186. These circular patterns, called **gyres**, flow in a clockwise direction in the northern hemisphere and anticlockwise in the southern hemisphere. The circular pattern of gyres is caused by the rotation of the Earth.

Deep currents

Deep currents begin at the poles, where extremely cold water is found. They flow through the ocean, carrying very cold water along the bottom.

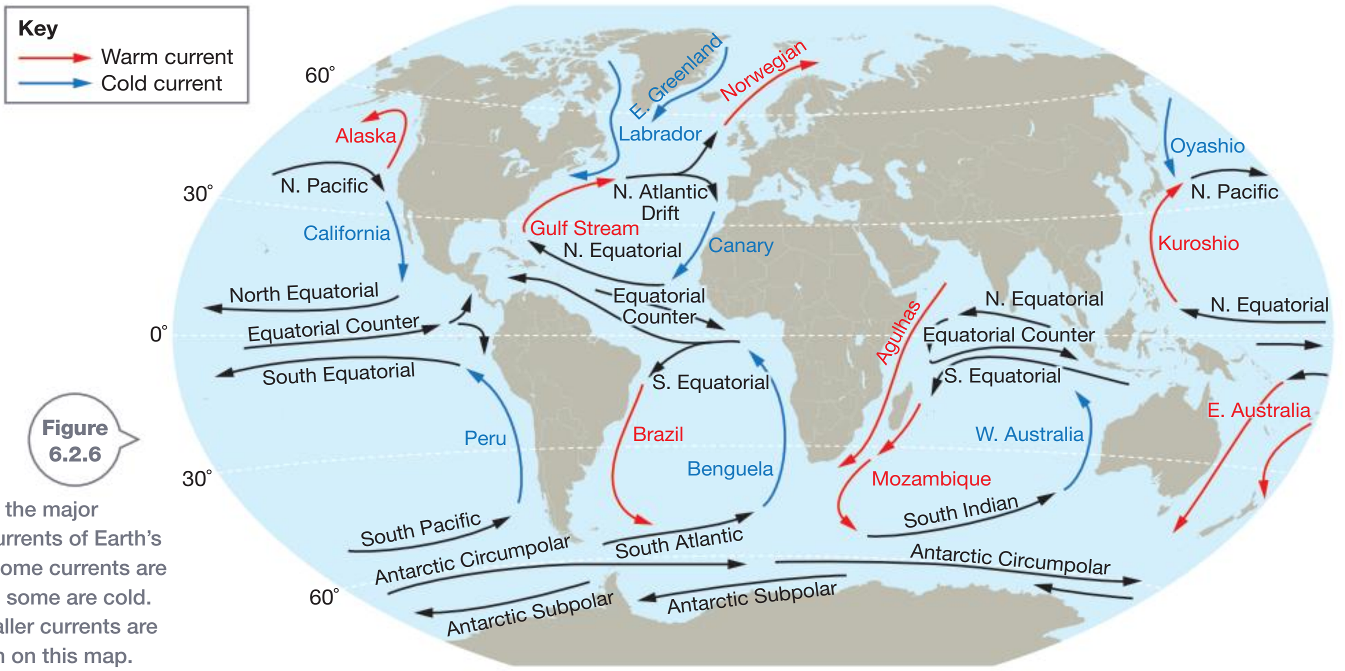


Figure 6.2.6

These are the major surface currents of Earth's oceans. Some currents are warm and some are cold. Many smaller currents are not shown on this map.

Currents and climate

Surface currents and deeper currents interact. Water cycles from deep currents to surface currents, and then back to the deep again, forming the **thermohaline circulation** (*thermo* means temperature, *haline* means salt). The thermohaline circulation is very slow, taking around 1600 years to complete just one circuit! Scientists commonly call the thermohaline circulation the **global conveyor belt**. It is shown in Figure 6.2.7.

The global conveyor belt is important because it distributes heat around the globe. By distributing heat, the global conveyor belt affects the climates of the Earth.

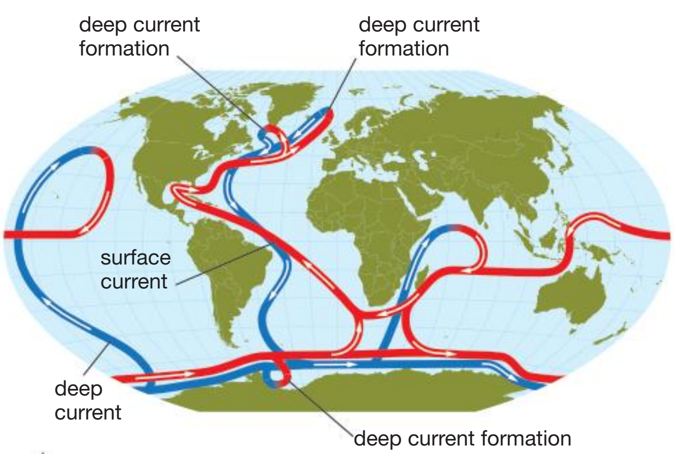


Figure 6.2.7 The global conveyor belt of interconnected ocean currents distributes heat around the Earth and affects its climates.

The Gulf Stream

The Gulf Stream is part of the global conveyor belt. It is a current that makes western Europe much warmer in winter than any other region at the same latitude. For example, northern United Kingdom and Norway are much warmer than Greenland and Canada. A computer-enhanced image of the Gulf Stream is shown in Figure 6.2.8. The Gulf Stream flows from the warm Caribbean Sea carrying heat across the North Atlantic Ocean towards Europe. The Gulf Stream feeds into the North Atlantic Drift and the Norwegian currents and into the Labrador and Greenland seas. Very cold Arctic winds then cool the water of the Gulf Stream, increasing its density. The denser water sinks, pushing away water below it and creating a deep current. This cold deep current flows all the way south to Antarctica.

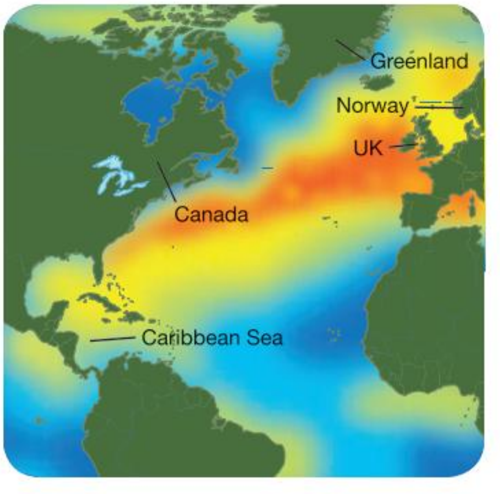


Figure 6.2.8

The Gulf Stream is a warm ocean current. In this image orange indicates the warmest water. Blue is coldest.

Australia's climate

Australia is a land of contrasts—Queensland can be in drought while Victoria is experiencing floods. The causes of these extremes of weather are two climate phenomena:

- the Southern Oscillation, which gives rise to the El Niño and La Niña effects
- the Indian Ocean Dipole.

As climatologists and meteorologist gain greater understanding of these patterns, they can use them to make more accurate predictions of what to expect in particular seasons.

Southern Oscillation

The **Southern Oscillation** is a sequence of changes to the way the atmosphere and water circulate across the Pacific Ocean and Indonesian islands. In most years, a cold current flows northwards along the coast of South America, then westwards along the equator, where it is warmed by the Sun. This 'normal' situation is shown in Figure 6.2.9. The result is a temperature difference of 3°C to 8°C between the cooler eastern Pacific and the warmer western Pacific.

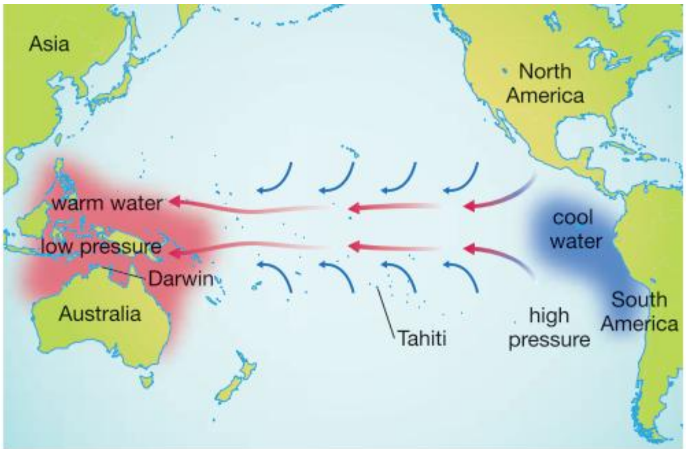


Figure 6.2.9 In normal conditions where there is no El Niño or La Niña, the trade winds blow strongly from the western Pacific Ocean to the east. This brings average rainfall to northern Australia.

The **Southern Oscillation Index (SOI)** is a measure of the atmospheric and ocean conditions across the Pacific Ocean. It is calculated using the difference in air pressure between Tahiti and Darwin. Under 'normal' conditions, the SOI is close to zero (Figure 6.2.10). During El Niño events, the SOI is strongly negative. During La Niña, the SOI is strongly positive.

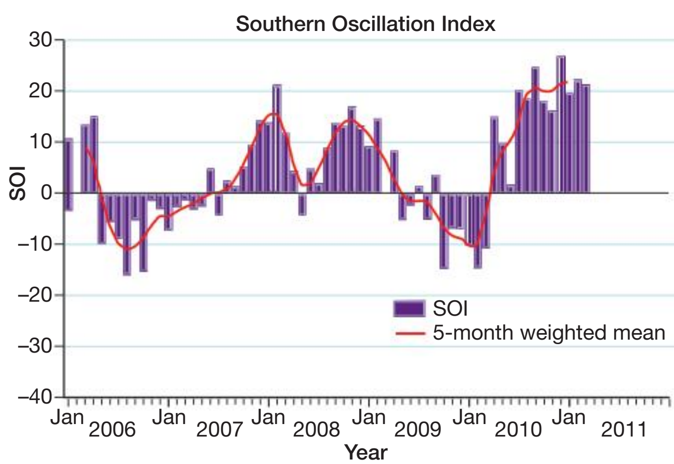


Figure 6.2.10 Changes in the SOI can be used to predict good rains and droughts for Queensland and New South Wales. Negative SOI values indicate periods of drought.

El Niño is the best known extreme of the Southern Oscillation and is probably one of the most important influences on the climate in Australia, particularly in Queensland and much of New South Wales. Figure 6.2.11 shows that in El Niño years there may be little or no difference in temperature between the western and eastern Pacific. With little temperature difference, there is also little air pressure difference. The trade winds that normally blow strongly from South America weaken and the winds carrying a lot of moisture do not reach Australia. Cool air descends over Australia bringing little rainfall.

The opposite of El Niño is **La Niña**. As Figure 6.2.12 shows, during a La Niña, the central and eastern Pacific Ocean becomes much cooler than normal. The trade winds blow more strongly than usual and Australia experiences more cloud and wetter-than-normal conditions, especially in the north. La Niña events usually last for more than one year.

2 p193
6.2

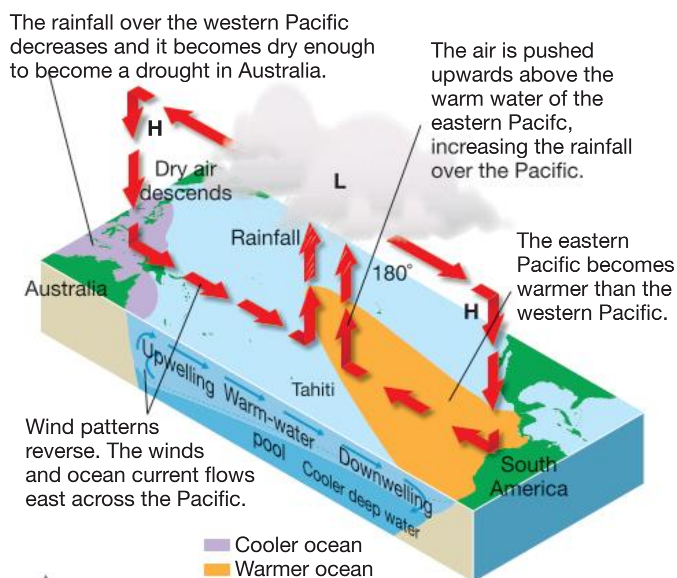


Figure 6.2.11 During an El Niño event, large areas of Australia may experience drought.

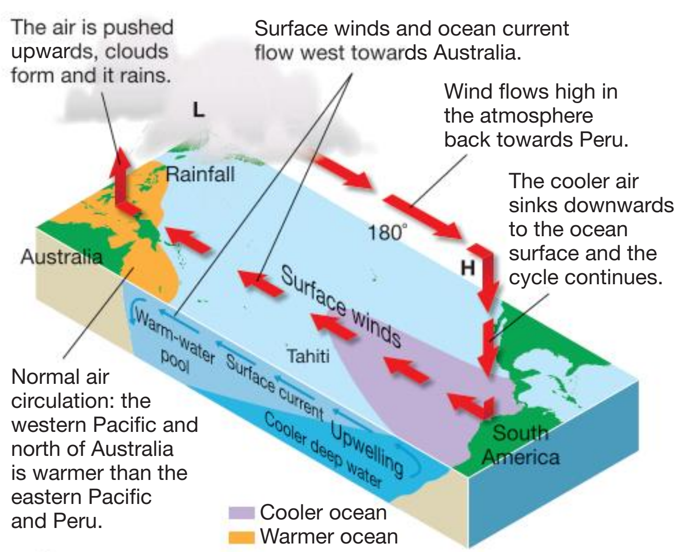


Figure 6.2.12 When La Niña takes over, there are often floods.

Indian Ocean Dipole

Weather in the southern parts of Australia is influenced by the **Indian Ocean Dipole (IOD)**. The IOD is a cycle of change in the water temperature between the eastern and western areas of the Indian Ocean, near the equator. The change is not a regular one. It does not happen every year or at the same time of year.

Figure 6.2.13 shows the cool sea temperatures in the Indian Ocean near Australia that leads to poor rainfall in central and southern Australia. In this case, the IOD is positive, meaning temperatures are higher in the western Indian Ocean and lower in the east near Australia.

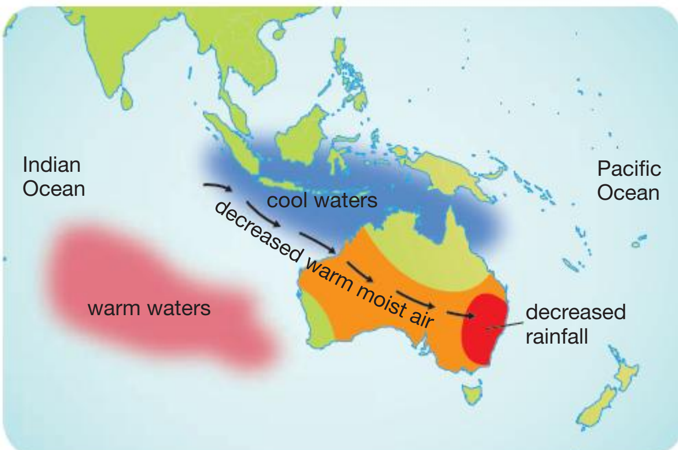


Figure 6.2.13 A positive IOD causes drought in central and southern Australia.

Figure 6.2.14 illustrates the opposite situation. Warm waters near Australia cause a negative IOD, causing increased rainfall in central and southern Australia.

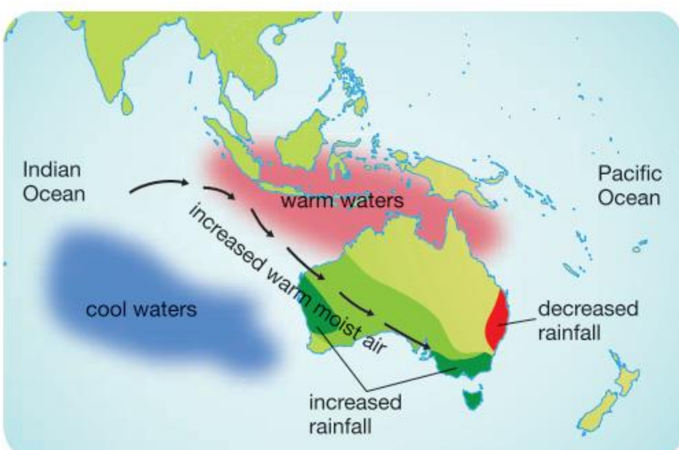


Figure 6.2.14 There is a good chance of rain in the southern states of Australia when the IOD is negative.

An IOD event usually starts in May or June and peaks between August and October. The amount of difference between the sea temperatures and how long this difference exists determines the length of droughts in southern Australia. Figure 6.2.15 illustrates the changes in the IOD from 2005 to 2009.

Figure 6.2.15 A positive IOD indicates less than usual rainfall for the southern states. This graph shows that in the early years of the 21st century, southern Australia was affected by several positive IOD events.

Changing climate

There is evidence that Australia's climate has been very different in the past from the climate experienced today. More than 62 million years ago, the land mass that became Australia was still joined to Gondwana. Then Australia experienced a warmer and wetter climate. As you can see in Figure 6.2.16, there have been many cycles of cooling and warming in the Earth's history. About 2.5 million years ago, an ice sheet covered Tasmania (Figure 6.2.17) and southern Australia. Cycles of warming and cooling followed. Then about 20 000 years ago, the current period of warming began.

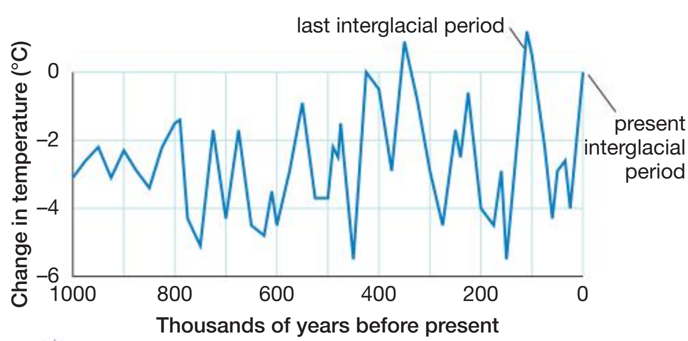


Figure 6.2.16 In the history of the Earth, there have been many periods of cooler conditions when ice covered large areas (glaciation). These periods of glaciation varied in length and intensity. There have also been periods when the world's climate was warmer.

Figure 6.2.17 The rocks on the top of Mt Wellington in Hobart, Tasmania, were shattered during the last ice age.

As an ice age approaches, the ice caps at the north and south poles expand and the amount of liquid water on the Earth decreases. Sea levels fall, exposing additional land on the coasts. Figure 6.2.18 shows where there were land bridges during the last ice age. At that time it would have been possible to walk from mainland Australia to Tasmania and the island of New Guinea.

Figure 6.2.18 During cooler periods, the amount of ice on the Earth's surface increases. Water is held in the ice caps and ocean levels fall, exposing more land.

Global warming

Interglacials are periods between glaciations—they are periods of **global warming.** Warming means an increase in average world temperature. During interglacials, ice caps melt and this causes the sea level to rise and coastal lands to flood. Evidence for the rise and fall of sea level can be seen in the patterns of sediments and fossils in coastal rocks.

Reasons for the past warming and cooling of Earth are not understood completely. Therefore, it is challenging to fully assess the contribution that human actions are making to the present period of global warming. The data in Figure 6.2.19 show that the current period of global warming started 20 000 years ago when humans were just about to emerge from the Stone Age.

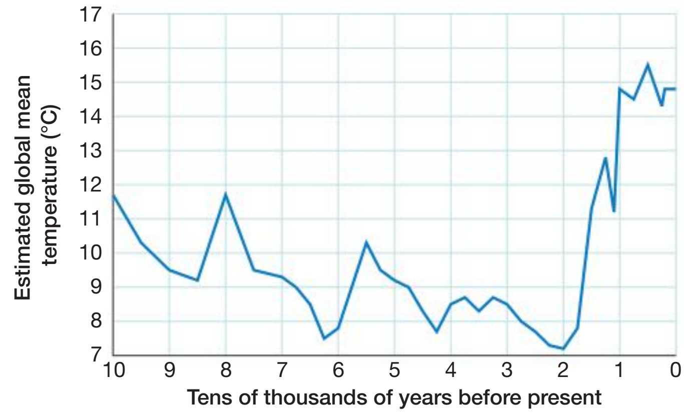


Figure 6.2.19 The current period of global warming started long before the Industrial Revolution (1750–1850). Therefore, it cannot be blamed entirely on human actions and increased production of greenhouse gases.

Evidence for climate change

Evidence for past changes in climate has come from a variety of sources, which are described below.

Glaciers

Glaciers are indicators of climate change, advancing when the climate cools and retreating when the climate warms.

As glaciers move, they grind against the rocks on the sides and floor of the valley through which they flow. The rocks on the side of the valley are deeply scored by broken rocks being dragged along the sides and base of the glacier. When the glacier retreats, the scoring of the rocks becomes visible. The pile of grey rock at the front of the glacier in Figure 6.2.20 is a moraine. This is the debris the glacier was carrying and has left behind as the glacier retreated.

Figure 6.2.20 The black material in the front of the glacier is the debris that has been dropped as the glacier retreated. On the older part of the moraine, grass and trees are growing.

SciFile

Return of the ice

Approximately every 100 000 years, Earth's climate warms up. These interglacial periods are temporary. They last approximately 15 000–20 000 years, and then an ice age returns. It has been over 18 000 years since the last ice age, so our current interglacial vacation from freezing conditions is nearer its end than its beginning.

Ice cores

On some glaciers and ice sheets, sufficient snow falls each year to form recognisable annual layers. Scientists take cores, such as the one in Figure 6.2.21, from ice sheets in places such as Antarctica. By analysing the physical and chemical properties of ice cores, they gain information about temperatures and the composition of the air from hundreds of thousands of years in the past. These data show links between temperature and variations in the global sea level. They also reveal that the amount of carbon dioxide in the atmosphere has varied in the past.

Figure 6.2.21 The bands seen in a core represent ice of different ages and composition.

In early 2010, scientists studying Antarctic ice cores discovered a strong link between the amount of snow that falls in eastern Antarctica and drought in south-western Western Australia. Ice cores reveal that in the last 30–40 years, eastern Antarctica has experienced higher than average snowfalls. During this time, winter rainfall in south-west Western Australia has decreased by 15%. These data are shown in Figure 6.2.22.

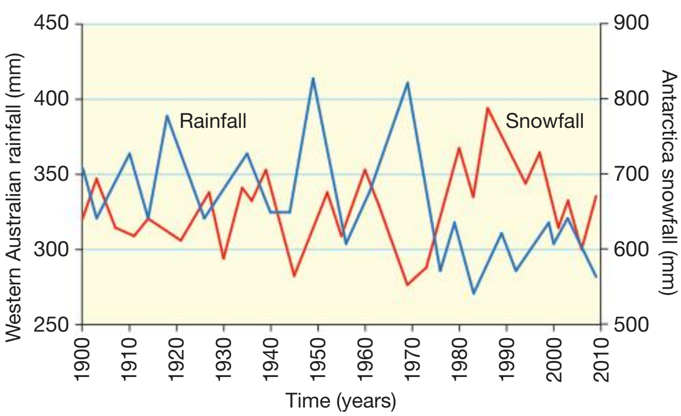


Figure 6.2.22 The graph shows the relationship between snowfall in eastern Antarctic and rainfall in south-west Western Australia.

The reduced rainfall is thought to be caused by climate change modifying the path followed by the Antarctic Circumpolar Current seen in Figure 6.2.23. This current circulates round Antarctica and usually sends moist warm air up to Western Australia. A change in the pattern is causing the warm moist air to be directed to Antarctica where snowfall is the result. Cold, dry air directed towards Australia results in reduced rainfall.

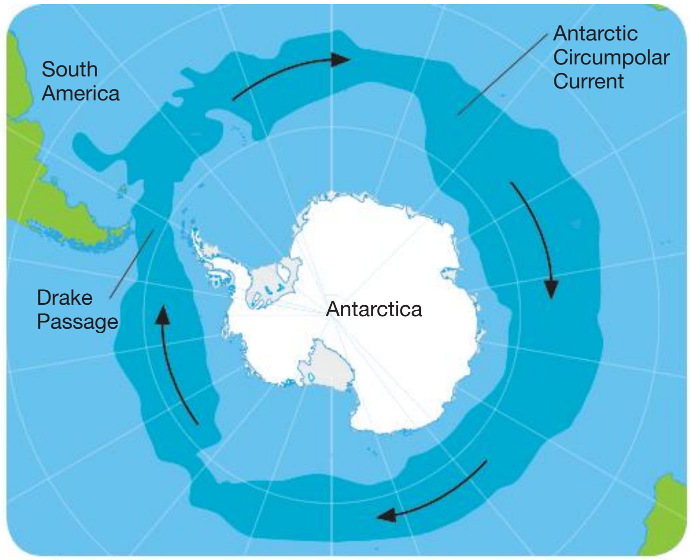


Figure 6.2.23 The path of the Antarctic Circumpolar Current

SciFile

Strong current

As the Antarctic Circumpolar Current passes through the Drake Passage (between Antarctica and South America) it carries about 134 × 10^6 cubic metres of water per second. This is like all the water in Sydney Harbour passing you in 3 seconds.

Pollen analysis

Pollen decays very slowly and often becomes fossilised. Fossil pollen indicates the species growing in the area when the sediments that created the fossils were laid down. Changes in the types of pollen found indicate changes in vegetation and climate.

Sea level change

The worldwide distribution of sedimentary rocks and the types of fossils found in them are indicators of changes in sea level in the past (Figure 6.2.24). For example, sedimentary rocks in central Australia contain fossils of sea creatures.

Figure 6.2.24 Fossils in rocks provide evidence of past climate and changes in sea level.

6.2 Unit review

Remembering

1 **State** the increase in average temperature in Australia in the past 50 years.

2 **List** three factors that affect the world's climate.

3 **Name** three main greenhouse gases.

4 **List** main factors that cause ocean currents**.**

5 **State** the main cause of:
   a surface currents
   b deep currents.

6 **State** whether the following are true or false.
   a The climate of Australia varies from day to day.
   b The forests of the Amazon jungle reflect more of the Sun's energy than the polar ice caps.
   c The Southern Oscillation has more influence on rainfall in southern Australia than the Indian Ocean Dipole.

Understanding

7 a **Define** the term *interglacial*.
   b **Outline** the relationship between interglacials and global warming.

8 **Explain** the relationship between El Niño, La Niña and the Southern Oscillation Index.

9 **Describe** the global conveyor belt idea of ocean currents.

10 **Explain** how ocean currents can distribute heat around the Earth.

11 **Explain** how it was possible to walk to Tasmania from Victoria during the last ice age.

12 **Explain** the link between air pressure differences in Tahiti and Darwin and the weather in Australia.

Applying

13 **Use** diagrams to **demonstrate** how the greenhouse effect influences conditions on Earth.

Analysing

14 Figure 6.2.10 on page 187 is a graph of the Southern Oscillation Index for the years 2004 to 2009.
   a **Interpret** the information presented in the graph to decide the number of La Niña events during that time.
   b **Explain** how you made your decision in part **a**.
   c **Discuss** how likely it was that northern Queensland had a good wet season in early 2009.

15 **Use** Figure 6.2.11 on page 187 to **contrast** the features of the atmosphere and ocean during normal climatic conditions in Australia with their features during an El Niño event.

Evaluating

16 Figure 6.2.15 on page 188 is a graph of the Indian Ocean Dipole for the years 2005–09.
   a **Interpret** the information presented in the graph to decide at which time southern and central Australia would have experienced drier than normal conditions.
   b **Justify** your answer to part **a**.
   c **Propose** what conditions in southern Australia would have been like in late 2007 and early 2008.
   d **Justify** your response to part c.

17 **Propose** the changes that would occur on Earth if carbon dioxide, methane and other greenhouse gases were removed from the atmosphere.

18 The occurrence of sedimentary rock with marine fossils at a height of 500 metres above sea level is used as evidence of a different sea level in the past.
   a **Justify** the use of this as evidence of higher sea levels in the past.
   b **Propose** whether the climate at that time was warmer or cooler than at present, and justify your answer.

Creating

19 **Construct** a concept map of the different types of evidence used to indicate climate change.

Inquiring

1 Find out what the climate of Australia was like 300 million years ago when materials were laid down that became the coal deposits Australia has today.

2 Research the work of F.S. Rowland and M.J. Molina, who were awarded the 1995 Nobel Prize in Chemistry for their work on ozone depletion in the atmosphere.

3 Research the importance of the greenhouse effect in making life on Earth possible.

6.2 Practical activities

1 Greenhouse effect

Purpose

To investigate the greenhouse effect.

Materials

- 2 thermometers (or temperature probes and datalogging equipment)
- 3 microscope slides
- sticky tape
- 2 triangular pieces of cardboard to fit the ends of the 'greenhouse'
- block of wood
- modelling clay

SAFETY

Take care when handling glass microscope slides.

Procedure

1 Copy the results table into your workbook.

2 Create a hole in one of the pieces of cardboard, just large enough for the thermometer to pass through. Use the modelling clay to hold the thermometer in place. It needs to be a good seal, to stop air escaping.

3 Construct the model greenhouse as shown in Figure 6.2.25.

4 Place the 'greenhouse' outside in a sunny position.

5 Place the second thermometer on the block of wood next to the greenhouse. Ensure that the bulb of the thermometer is suspended in the air.

6 Record the temperature on the two thermometers at the beginning of the experiment.

7 Record the temperatures every 2 minutes for 14 minutes.

Results

1 Copy and complete the following table.

Time (minutes)	Temperature (°C)	
	Greenhouse	Air
0		
2		
4		
6		
8		
10		
12		
14		

2 Construct two line graphs on the same set of axes to display the temperatures.

Discussion

1 **Explain** why the second thermometer recording air temperature was used.

2 **Compare** the temperature patterns inside and outside the greenhouse.

3 **Deduce** the effect of your model greenhouse on the air inside it.

4 **Discuss** any other factors that could have affected the temperature.

5 **Explain** what has happened in this model of the greenhouse effect.

6 **Compare** the model in this prac to the global greenhouse effect.

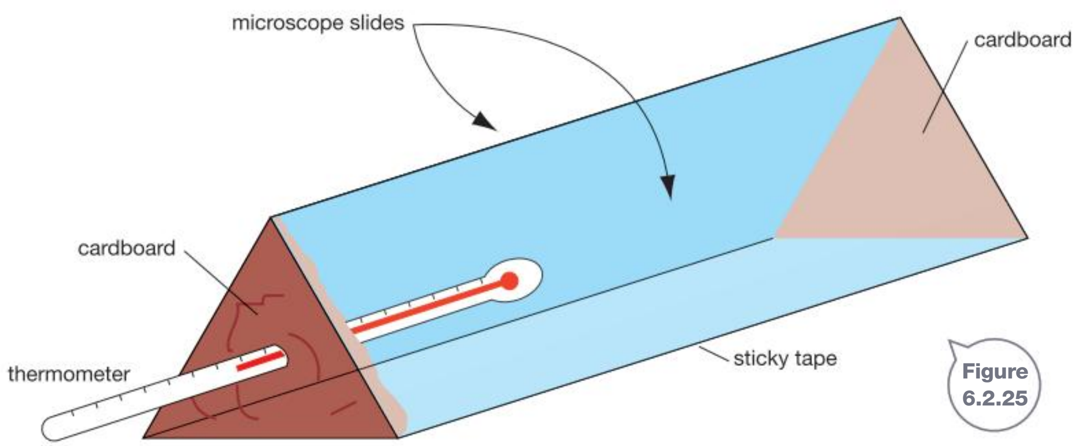


Figure 6.2.25

2 El Niño

Purpose

To demonstrate ocean currents.

Materials

- medium-sized, flat rectangular plastic container
- 400 mL ice-cold water (no ice)
- 250 mL beaker
- 50 mL hot water from a hot water tap
- food colouring
- teaspoon

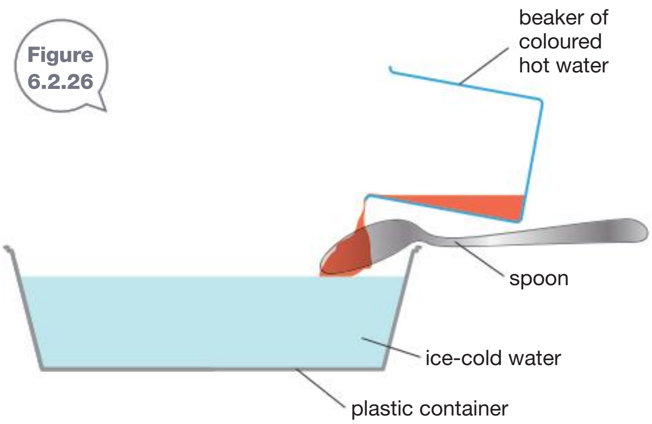
Procedure

1. Place the plastic container flat on the bench.
2. Three-quarters fill the container with ice-cold water.
3. Allow the water to become completely still.
4. Add a few drops of food colouring to the hot water in the beaker.
5. Add the hot water to one end of the container by carefully pouring it over the back of the teaspoon, as shown in Figure 6.2.26. This will minimise the disturbance to the cold water in the container.
6. Without touching the container, observe the container from the side.

Extension

7. If datalogging equipment is available, try recording the differences in temperature between the water at the surface and bottom of the container.
8. Design an investigation to demonstrate what would happen if cold water (such as a cold current) met a body of warm water.

Figure 6.2.26



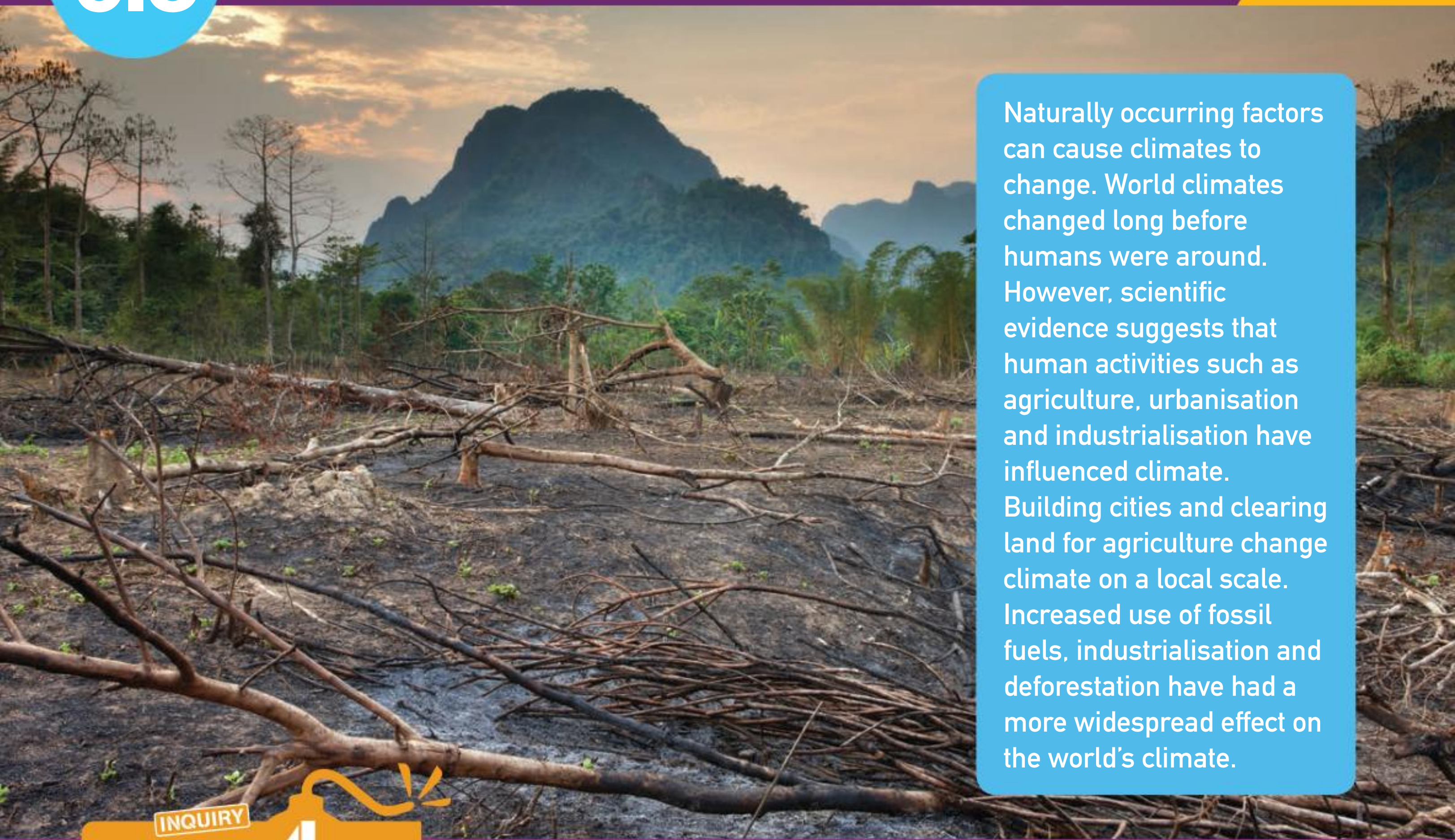
Results

Record in words and pictures the movement of the coloured water over the next 5 minutes.

Discussion

1. **Describe** the movement of the coloured water.
2. **Explain** why the coloured water moved in this way.
3. **Explain** how this situation could arise in an ocean.
4. **Discuss** the relationship between this demonstration and the development of:
   a. El Niño
   b. La Niña
   c. the Indian Ocean Dipole.

6.3 Human influence on climate



Naturally occurring factors can cause climates to change. World climates changed long before humans were around. However, scientific evidence suggests that human activities such as agriculture, urbanisation and industrialisation have influenced climate. Building cities and clearing land for agriculture change climate on a local scale. Increased use of fossil fuels, industrialisation and deforestation have had a more widespread effect on the world's climate.

INQUIRY science 4 fun

Melting icebergs

What effect do melting icebergs and glaciers have on sea levels?

Yes

Collect this ...

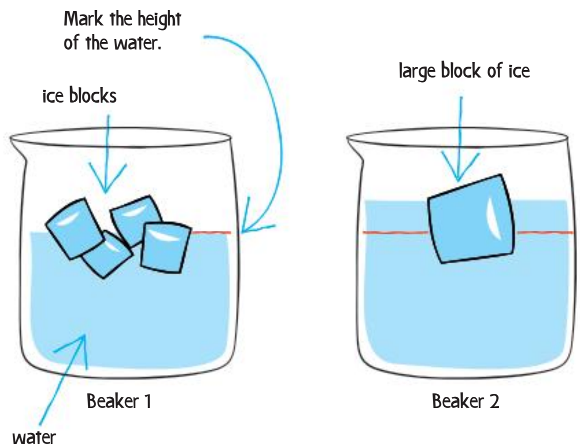
- 2 glasses or beakers of equal size and large enough to contain 300 mL of water each
- 4–6 small ice blocks that have been made using 100 mL of water
- large block of ice made from 100 mL of water
- yoghurt container or similar in which to create the block of ice
- measuring jug
- 400 mL water

Do this ...

1 Place the small ice blocks in one of the empty beakers and half fill it with water. Mark the water level on the side, as shown in the diagram. This beaker represents the ocean in which icebergs are floating.

2 Pour water into the second beaker until it is at the same level as in beaker 1. Mark the water level on the side. This beaker represents the ocean into which a glacier is flowing.

3 Place the large block of ice into beaker 2. The ice block represents a large chunk of ice that has broken off a glacier in Antarctica.



4 When all the ice has melted, mark the new water levels on both beakers.

Record this ...

Describe what happened.

Explain whether icebergs or the melting glaciers will contribute most to sea level rises.

Is the Earth warming?

All indications are that Earth is in a period of warming. According to the World Meteorological Organization (WMO), the decade of the 2000s (2000–09) is the warmest on record. This is shown in Figure 6.3.1.

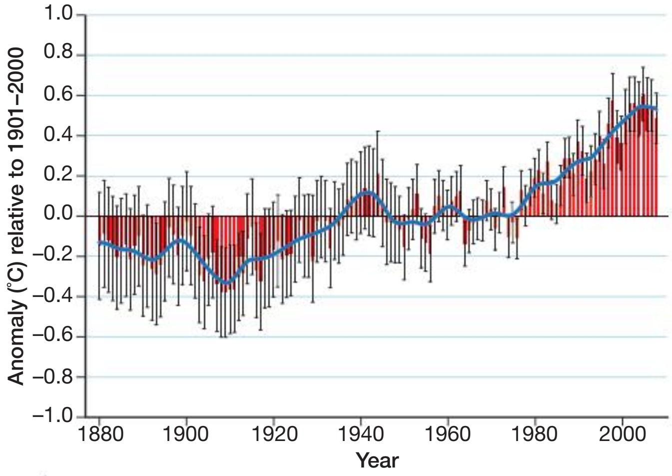


Figure 6.3.1 The zero line on this graph is the average global surface temperature for the years 1901–2000 which is 14°. The blue line indicates the number of degrees Celsius above or below that average, for the mean temperature in any year. For example, in 2000 the temperature was 0.4°C above the long-term average. In 2009, it was 0.44°C above the long-term average of 14°C.

The Intergovernmental Panel on Climate Change (IPCC) conducted a comprehensive review of the scientific evidence for climate change. In 2007, the IPCC reported:

- increases in global average air and ocean temperatures
- widespread melting of snow and ice (Figure 6.3.2)
- rising global average sea level (Figure 6.3.3).

Figure 6.3.2 A scientific study of more than 100 000 glaciers worldwide has found that most glaciers are shrinking. A significant retreat in the 1940s was followed by stability or growth in the 1970s. From 1980 onwards most glaciers have been in retreat.

Figure 6.3.3 At their highest point, the islands of Tuvalu (in the Pacific Ocean between Hawaii and Australia) are only 4.5 metres above sea level. Most of the land is less than 1 metre high. If there is a significant rise in sea level, then Tuvalu will experience severe flooding.

The enhanced greenhouse effect

Many scientists believe that human activities are having a significant effect on the rate and intensity of global warming, and that this is influencing climate change. However, measurement of climate variables on a worldwide scale has been occurring for little more than a century. Many of the trends that drive climate change occur over periods much longer than this—hundreds of thousands of years. Therefore it is difficult to identify the exact effect of changes caused by humans.

The IPCC report suggested that global warming is partly due to natural processes but is also caused by the **enhanced greenhouse effect**. The enhanced greenhouse effect is an increase in the natural greenhouse effect caused by human activity.

The major cause of the enhanced greenhouse effect is an increase in carbon dioxide, methane and nitrous oxide concentrations in the atmosphere.

Scientists have created computer models to try to forecast the effects of global warming on Earth's climate. Not all the computer models agree in specific details. However, there is agreement that if greenhouse gases continue to be produced at the same rate as in the year 2000, then there will be a 0.1°C increase in temperature per decade. What actually happens will depend on the actual carbon dioxide emissions that occur. As can be seen from Figure 6.3.4, Australia's emissions already exceed the 2000 levels.

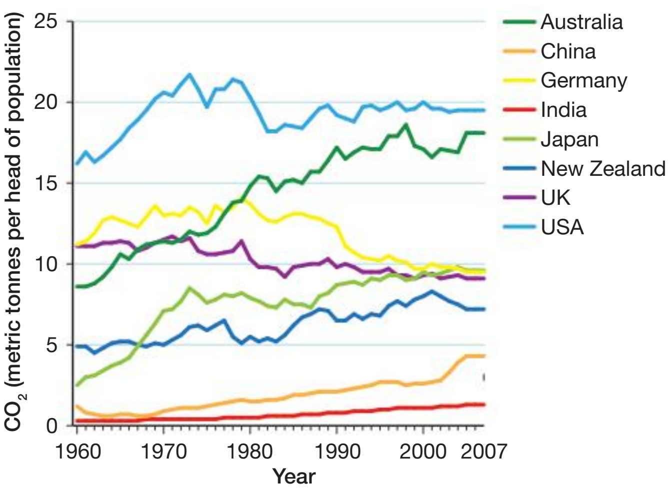


Figure 6.3.4 Australia's carbon dioxide emissions have risen since 2000. Other developed nations have reduced or stabilised their emissions per head of population.

Carbon dioxide in the atmosphere

Of all the carbon dioxide produced on Earth, 95% would be emitted whether humans were present or not. The largest source is natural decay of organic material in forests and grasslands. However, the carbon dioxide produced by natural means is balanced by natural carbon sinks—these are places and events that remove carbon dioxide from the atmosphere.

In 1957, measurements of carbon dioxide began at the Mauna Loa Observatory on Mauna Loa, Hawaii (USA), and in Antarctica. Figure 6.3.5 demonstrates the increase in atmospheric carbon dioxide over Mauna Loa in the past 50 years.

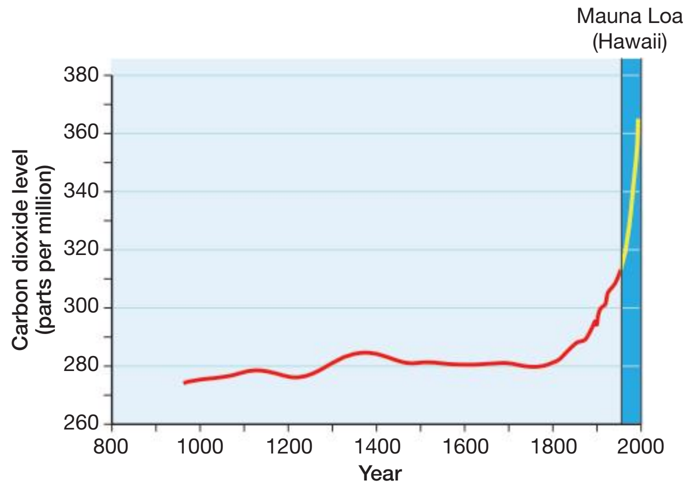


Figure 6.3.5 Ice core analysis provides information about carbon dioxide levels in the atmosphere before measurements were taken over Mauna Loa. The rapid increase in concentration coincides with the Industrial Revolution, which began around 1750.

The concentration of carbon dioxide in the atmosphere has increased from 280 parts per million (ppm) before the Industrial Revolution to 391 ppm in 2010. Compare this with an increase of only 20 ppm in the 8000 years before industrialisation.

Coal and gas are both major carbon sinks. Since the Industrial Revolution, humans have been extracting and burning coal and gas as a primary energy source, releasing carbon dioxide into the atmosphere.

In Australia most of the energy used in homes and by industry is produced by coal-fired power stations. Figure 6.3.6 shows the output of carbon dioxide in Australia per head of population compared with other nations.

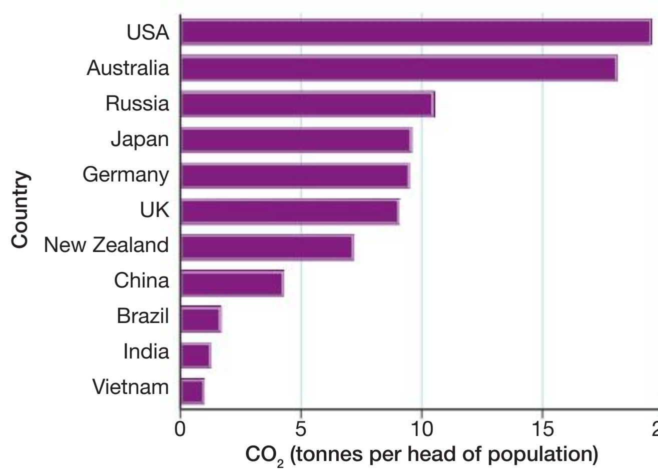


Figure 6.3.6 In 2007, Americans produced more carbon dioxide per head of population than any other nation, but Australians are not far behind.

India and China produce only a small amount of carbon dioxide per person when compared with Australia. However, when the population of these countries is taken into account, the picture is different. Table 6.3.1 compares the populations of these four countries.

Table 6.3.1 Comparing the populations of four countries

Country	Population (millions)	Total CO_2 output (millions of tonnes)
Australia	22.3	400
United States	307.0	5990
India	1140.0	1140
China	1325.0	5300

6.3 1 p201

Methane

Methane (CH_4) is able to trap more than 20 times the heat of carbon dioxide. It is formed from the breakdown of organic matter. Methane is produced in the stomachs of cows and sheep as bacteria digest the cellulose in the grass the animals eat (Figure 6.3.7). Rice paddies, garbage tips, coal mines and natural gas fields also release methane. The concentration of methane in the atmosphere in 2010 was 18.5 ppm, which is more than double the level before the Industrial Revolution.

Figure 6.3.7 Digestion of plant material releases methane. Livestock produce 11% of Australia's methane emissions.

SciFile

Gas emissions!

About 90% of New Zealand's methane emissions are produced as animals such as cows and sheep burp and break wind. The 45 million sheep and 10 million cattle in New Zealand make for a lot of methane!

On Earth, there are areas near the poles where the temperature in layers of soil or rock beneath the surface never rises above freezing point. These layers are known as **permafrost**. Vast areas of the Arctic are boggy wetlands of permafrost where the remains of plants and animals decompose, producing methane. Permafrost traps the methane (Figure 6.3.8). However, rising temperatures in the Arctic causes the boggy soils to melt and release the trapped methane. Estimates suggest that Arctic soils store billions of tonnes of methane.

Increased methane emissions may cause the temperature to rise further, melting more ice and releasing more methane in a process known as positive feedback.

Figure 6.3.8 Bubbles of methane are trapped in the ice of the permafrost. Between 2003 and 2007, methane emissions from the Arctic increased by 31%.

Nitrous oxide

Nitrous oxide (N_2O) is capable of trapping 300 times more heat than carbon dioxide. Its concentration in the atmosphere in 2010 was 3.19 ppm—this is about 18% higher than before the Industrial Revolution. Nitrous oxide is produced in car exhausts and through many industrial processes, as well as the burning of forests and the use of nitrogenous fertilisers.

Loss of ice

During winter, the amount of ice in the Antarctic doubles to cover an area of about 19 million square kilometres. That is an area about three times the size of Australia. Scientists are currently gathering information that seems to suggest that the extent and thickness of the ice has an effect on climate.

Figure 6.2.2 on page 184 shows that areas of the globe covered in ice reflect more of the Sun's rays and have a cooling effect on Earth. Any reduction in the area of Antarctic ice would reduce this cooling effect.

When it covers the ocean water, ice acts as a blanket. The amount of heat that moves from the ocean to the atmosphere is reduced. Less ice means that more heat will be added to the atmosphere.

Ice is fresh water. As salt water freezes, the salt remains in the ocean. The salinity increases and therefore the density of the water also increases. The dense water sinks, moving into the deep currents that circle the Earth as seen in Figure 6.2.7 on page 186.

The Antarctic Ocean is Earth's major source of the cold dense water that is the driving force for the global conveyor belt. Changes to the amount of Antarctic ice will cause changes in the amount of cold dense water entering the global conveyor belt. This in turn could cause changes in the currents and the global climate.

Carbon dioxide absorption

Water at the surface of the oceans absorbs carbon dioxide from the atmosphere. As the cold dense water of the Antarctic Ocean sinks, the carbon dioxide is carried with it. This has the effect of pumping carbon dioxide out of the atmosphere. Without this process, any build-up of carbon dioxide in the atmosphere would be faster.

Shrinking Antarctica

Scientists are carrying out research to answer the question of whether or not the Antarctic ice is melting. Satellites are used to measure the total mass of ice on Antarctica. Figure 6.3.9 represents the results collected so far. The results indicate that Antarctica is losing ice and that the rate of loss is increasing.

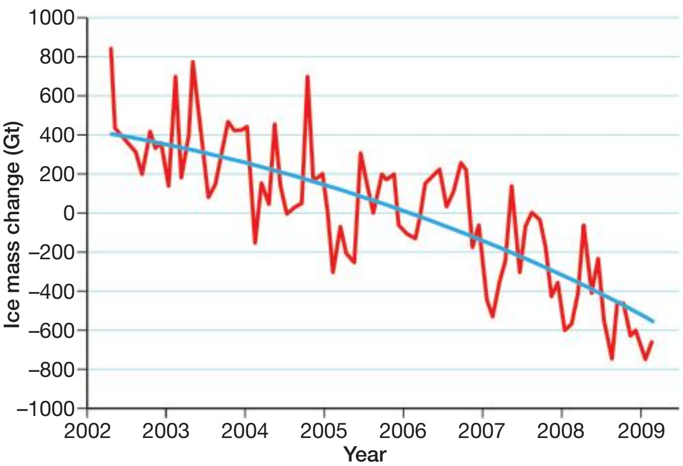


Figure 6.3.9 This graph shows that the amount of Antarctic ice increases in the middle of year (winter) and decreases in the summer. The actual amount of change varies from year to year. However, the general trend, shown by the blue line, is a decrease in the mass of ice for the years 2002–09.

Different things are happening in different parts of the continent of Antarctica. Under the ice of east Antarctica is a land mass about the size of Australia. In this part of the continent, there is a little loss of ice at the edges and an accumulation of snow in the interior. Therefore, there is not much change.

West Antarctica is more like a series of islands so a lot of the ice is sitting in water. Here the sea ice surrounding the islands is retreating. Loss of sea ice allows the glaciers to flow more rapidly, sending large amounts of ice into the ocean.

In February 2010, an iceberg 78 km long and 39 km wide broke off the tongue of the Mertz Glacier in East Antarctica. The tongue of the glacier was hit by an iceberg known as 'B9B' which is 97 kilometres long. Some scientists are concerned that this event may affect wildlife in the area. You can see this collision in Figure 6.3.10.

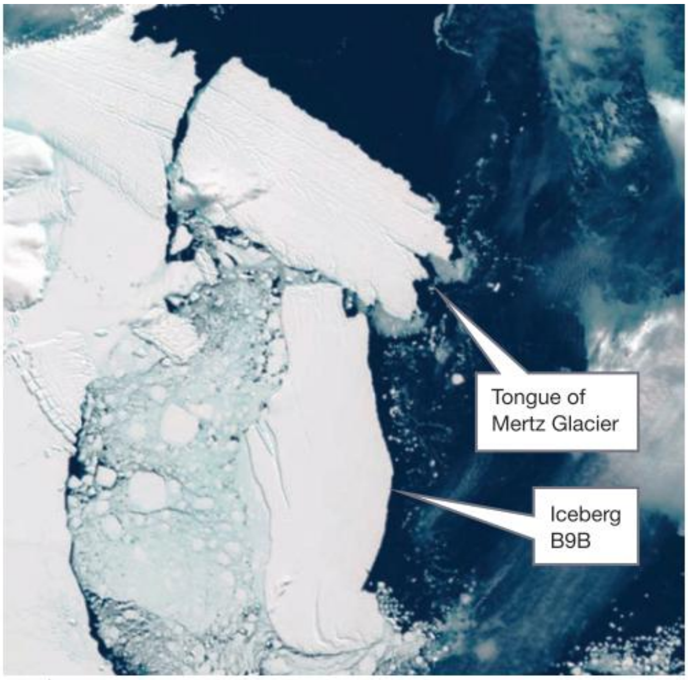


Figure 6.3.10 The tongue of the Mertz Glacier broke off when it was hit by Iceberg B9B.

SciFile

Ozone

Ozone reacts easily with organic molecules. These reactions can break down the walls surrounding the spores of fungi and bacteria, leaving behind only harmless wastes. Ozone can be used as an environmentally friendly alternative to chlorine in the purification of water.

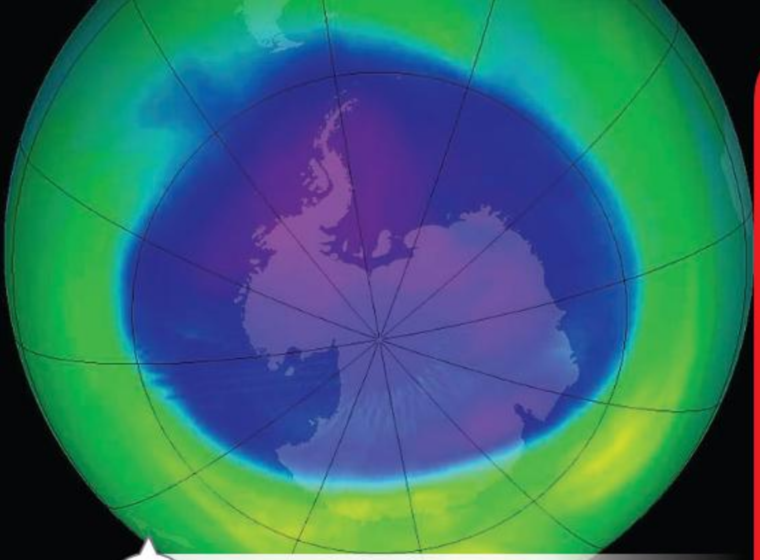


Figure 6.3.11 The hole in the ozone layer over Antarctica (shown in purple)

SCIENCE AS A HUMAN ENDEAVOUR

Use and influence of science

Ozone

Ozone (O_3) occurs naturally in the atmosphere, mostly in the stratosphere. It is vitally important to life on Earth because it absorbs ultraviolet (UV) radiation emitted by the Sun (Figure 6.3.12). Too much exposure to UV radiation can cause skin cancers and eye disease.

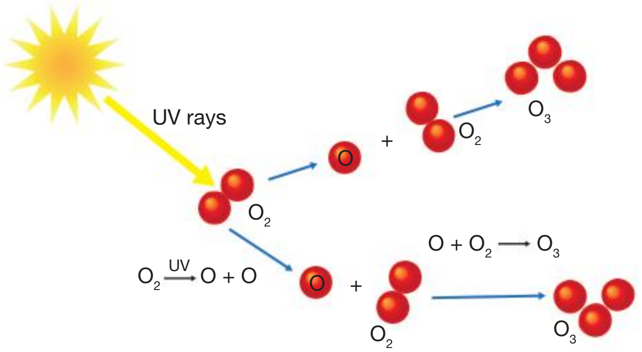


Figure 6.3.12 Ozone is formed when UV light strikes an oxygen molecule (O_2) and splits it into individual atoms, which then combine with O_2 molecules to form O_3 molecules.

The 'thickness' of the ozone layer is measured in Dobson units (DU). Ozone is spread throughout the stratosphere, so the term *thickness* is misleading. If all the ozone in the world could be concentrated into a pure layer at ground level, it would be 5 mm thick or 500 DU.

A value of less than 220 DU is considered a 'hole'.

The concentration of ozone in the atmosphere varies throughout the year and around the world. Measurements over Antarctica show that the values are lowest during September to October, when daylight returns after the long dark winter. At this time chlorine is most effective at breaking down ozone molecules. In November, prevailing winds carry ozone-rich air from other regions and repair the hole. But lower ozone levels still remain over Australia and New Zealand.

An increase in the rate of ozone destruction was linked to the release into the atmosphere of manufactured compounds such as chlorofluorocarbons (CFCs) (Figure 6.3.13) and halons. CFCs are very stable compounds that scientists now know react with UV radiation to release chlorine, which destroys ozone. Halons were developed to fight fire.

Figure 6.3.13 CFCs were developed in the 1920s as propellants in spray cans and coolants in refrigerators and air conditioners. They were used to make the bubbles in foam packaging and were included in industrial cleaners.

When the destructive powers of CFCs and halons were recognised in the 1970s, the use of CFCs was banned in the United States, Canada and Norway. However, it took until 1985 and the identification of a hole in the ozone layer over Antarctica, to convince the rest of the world that there was a serious problem. In 1987, 196 countries agreed to stop producing CFCs. This treaty (known as The Montreal Protocol) demonstrates the contribution that science can make to environmental protection agreements. Scientists predict that the ozone layer will recover to its pre-1980 concentrations by the middle of the 21st century.

6.4

6.3 Unit review

Remembering

1 **Name** two factors that influence world climate.

2 **Name** two aspects of climate that have been measured and have increased since the Industrial Revolution.

3 **State** the term used by scientists for the interconnected currents that influence world climate.

Understanding

4 **Explain** why melting icebergs will not affect sea levels but melting glaciers will.

5 **Explain** the term *carbon sink*.

6 **Explain** why nitrous oxide became more important as a greenhouse gas in the second half of the 1900s.

7 a **List** the sources of methane in the atmosphere.

b **Describe** the human actions that are increasing methane levels in the atmosphere, and explain how the increase is brought about.

8 **Explain** why there is so much concern about the increase in carbon dioxide in the atmosphere.

9 **Explain** how the amount of ice in polar regions can influence climate.

Applying

10 a **Calculate** the annual output of carbon dioxide in Australia, the United States, India and China from the data presented in Figure 6.3.6 on page 196 and Table 6.3.1 on page 197.

b **Identify** the country that is the highest emitter of carbon dioxide, then rank the others in order of decreasing production.

11 Use diagrams to **demonstrate** what happens as sea ice forms at the poles and water is added to a deep ocean current.

Analysing

12 **Compare** global warming and climate change.

13 a **Compare** carbon dioxide, methane and nitrous oxide as greenhouse gases.

b **Explain** why the focus of concern about greenhouse gases is on carbon dioxide, not on methane and nitrous oxide.

Evaluating

14 **Propose** reasons for why the data in Figure 6.3.6 are presented as carbon dioxide emissions per head of population, rather than for the total population.

15 It is over 100 years since people were made aware of the potential global warming effect of carbon dioxide. **Propose** reasons why people did not act earlier to reduce carbon dioxide emissions.

Creating

16 **Construct** a consequences wheel for global warming. Use Figure 6.3.14 as a guide to the layout. In the centre, write 'global warming'. In the next layer record the immediate consequences of global warming such as a rise in average world temperature. In the second layer add the consequences of these changes.

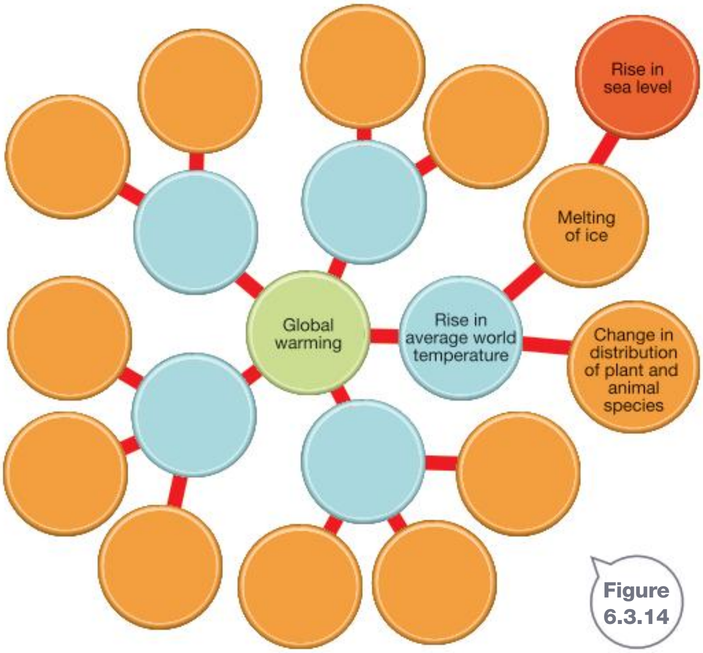


Figure 6.3.14

Inquiring

1 Research energy sources that are used as alternatives to fossil fuels. Discuss their efficiency as energy sources and the impact they have on the environment.

2 Investigate the scientific information used to demonstrate changes to the Earth's atmosphere in the 20th century.

3 Some scientists are sceptical (not convinced) about the degree to which human activity is responsible for climate change. Research some of the alternative views on climate change and discuss the points of view.

4 Design an experiment that investigates the effect of carbon dioxide on air temperature.

6.3 Practical activities

1 Freezing and density

Purpose

To investigate the effect of freezing on the density of salt water.

Materials

- 6 L container (such as a bucket or watering can)
- 2 large transparent containers (pneumatic trough, pie dish or aquarium)
- 2 L container that can be placed in the freezer
- 1 L plastic container
- 6 L water
- 60 g salt (sodium chloride)
- food colouring
- access to a fridge and freezer
- stirrer

Procedure

1. Mix 6 L of water with 60 g of salt and stir until all the salt is dissolved.
2. Add 2 L of the salt solution to each of the large transparent containers. Place the containers in the fridge.
3. Add a few drops of food colouring to the remaining 2 L of salt solution.
4. Pour off the coloured salt solution into the 2 L container and place in the freezer.
5. Leave the coloured salt solution in the freezer until two-thirds of it is frozen.
6. Pour the liquid that has not frozen from step 5 into the 1 L container and place it in the fridge.
7. Save the ice from the coloured salt solution and allow it to thaw in the fridge. Add a few more drops of colouring if there is not an obvious tint to the water.
8. When the coloured solution and thawed ice are at the same temperature as the solution in the large containers, remove all containers from the fridge.
9. Allow the water in the large containers to settle.
10. Gently pour the coloured salty water in a slow steady stream into one end of one of the large containers as shown in Figure 6.3.15. Observe where the coloured water goes. Record your observations in your workbook.
11. Using the same technique as step 10, gently pour the thawed ice water in a slow steady stream into one end of the other large container. Observe where the coloured water goes. Record your observations in your notebook.

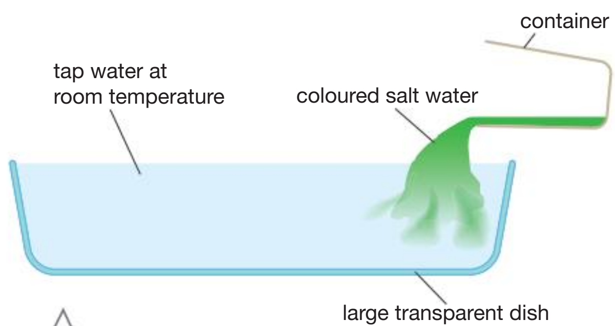
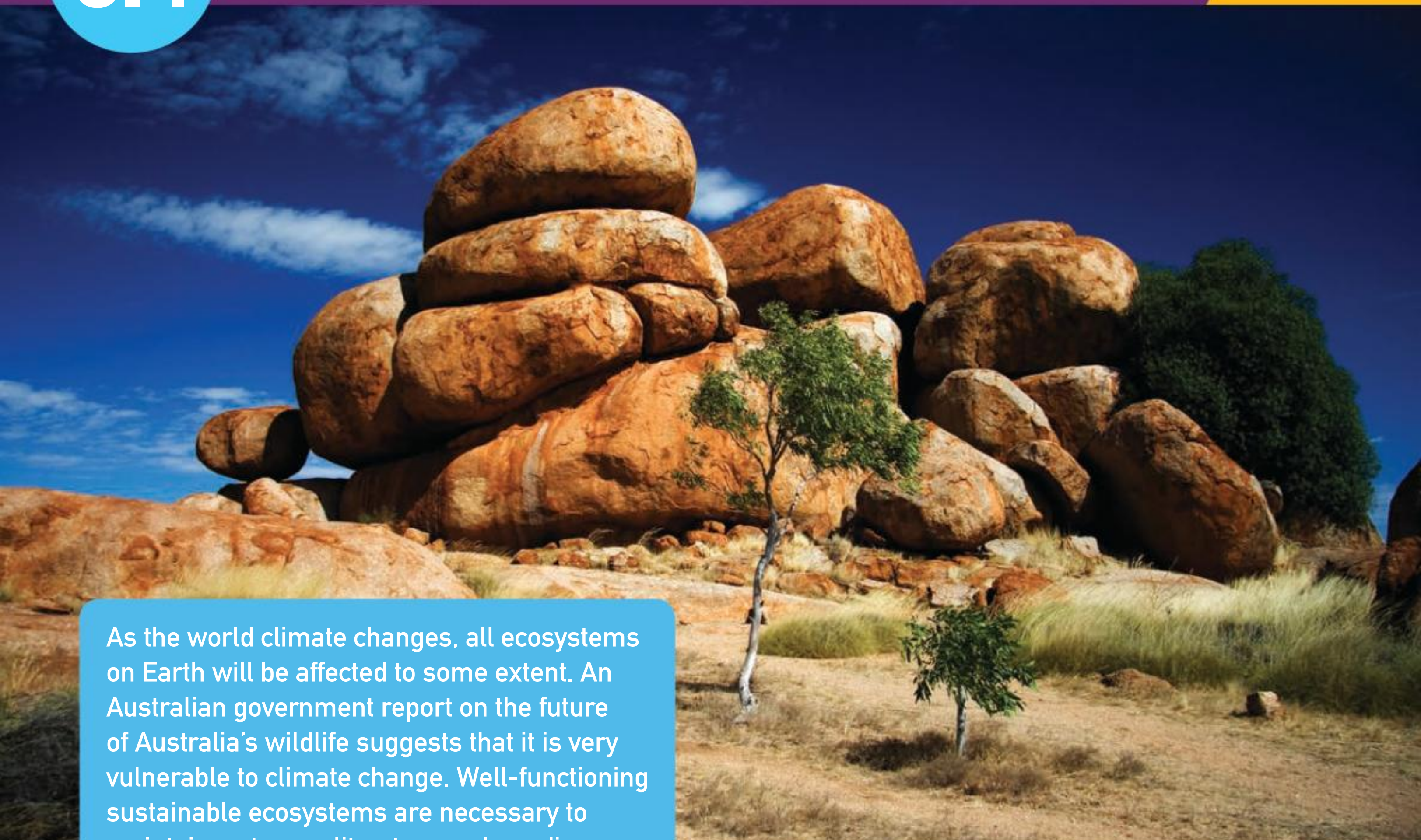


Figure 6.3.15

Discussion

1. **Describe** the behaviour of the coloured salt water when it was poured into the large container.
2. **Describe** the behaviour of the coloured water that came from thawing the ice when it was poured into the large container.
3. **Compare** ways that the solution and water from the ice behaved.
4. **Propose** why the two solutions behaved in this way.
5. **Explain** how this experiment is relevant to the effect of polar ice on the Arctic or Antarctic Oceans.

6.4 Changing environments



As the world climate changes, all ecosystems on Earth will be affected to some extent. An Australian government report on the future of Australia's wildlife suggests that it is very vulnerable to climate change. Well-functioning sustainable ecosystems are necessary to maintain water quality, store carbon, dispose of natural wastes, remove pollination and maintain genetic diversity.

Predictions

Many different computer models of climate change have been created. They produce different outcomes. However, they agree that not all parts of the world will be affected in the same way. The models predict that the oceans will not warm as much as land. The greatest increase in temperature will be in the northern parts of the northern hemisphere. Areas near the Antarctic and in the far north of the Atlantic Ocean are predicted to have the smallest temperature increase.

The area of land covered in snow will decrease and the amount of sea ice at both poles will be reduced. Satellite data have shown that the extent of Arctic sea ice has decreased by 2.7% each decade since 1978.

The number of extreme weather events such as heatwaves and tropical cyclones (such as the one in Figure 6.4.1) will increase.

Precipitation will increase towards the poles, but in subtropical areas such as the Mediterranean, parts of Queensland and Western Australia the rainfall will decrease.

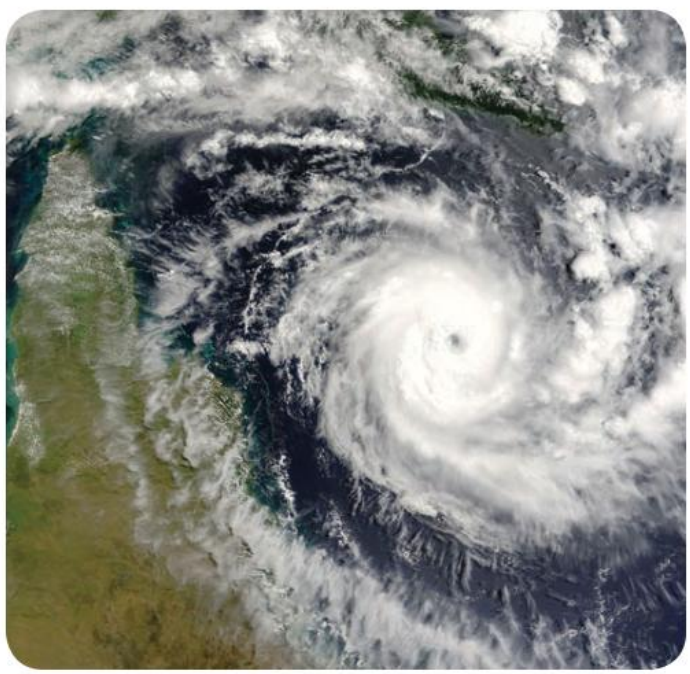


Figure 6.4.1 Computer modelling of climate change suggests that there will be more frequent cyclones in northern Australia.

6.5

> **Save the whales**
> A lack of iron in the waters of the Southern Ocean inhibits the growth of photosynthesising plankton. Twelve thousand sperm whales live there, releasing 50 tonnes of iron each year in their faeces. This iron means the plankton flourish and through photosynthesis use 400 000 tonnes of carbon dioxide—twice as much as the whales produce through respiration. The presence of the whales therefore helps take carbon dioxide out of the atmosphere.
>
> SciFile

Who will survive?

The history of the Earth reveals that climate change in the past has caused many species and entire ecosystems to become extinct. About 14 700 years ago, Earth's temperature rose by 10°C. At that time, many of the mega-mammals of North America such as mammoths, mastodons and giant sloths (Figure 6.4.2) began to disappear. There is debate about whether climate alone caused those extinctions or whether hunting by early humans was a contributing factor.

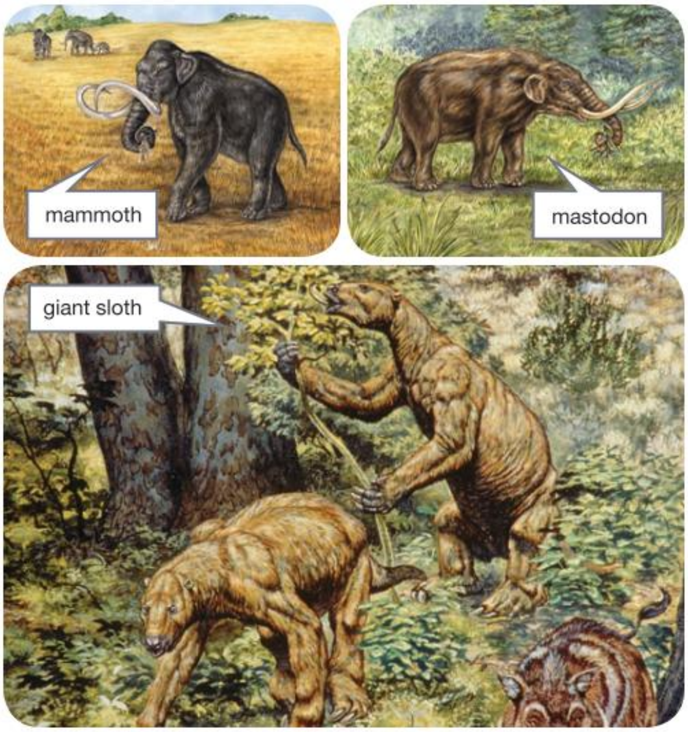


Figure 6.4.2 Extinction of the megafauna of North America may have been due to a rise in temperature as the last Ice Age came to an end.

Around 56 million years ago many large mammals disappeared due to a 7.2°C rise in temperature caused by a natural release of methane from marine sediments. Humans were not around at this time.

Not all plants and animals die out when the temperature changes. When the climate warms, species move towards the poles if they are able to. During a period of cooling, they move towards the equator.

Urban development and clearing land for agriculture have destroyed some natural ecosystems and divided others into small fragments. This makes it more difficult for organisms to move away from areas that are no longer suitable.

Climate change and the destruction of ecosystems by human activity has led to a decrease in biodiversity. **Biodiversity** is the variety of ecosystems in the biosphere, the variety of species within those ecosystems and the genetic variation within those species.

Australia is very biodiverse. It is one of 17 countries that together contain more than 70% of all species found on Earth. Many species found here are unique to Australia. About 85% of Australia's terrestrial mammals, 91% of flowering plants, and 90% of reptiles and frogs are found nowhere else in the world. More than 50% of the world's marsupial species occur only in Australia.

Great Barrier Reef

Corals are very sensitive to small changes in temperature. An increase in temperature of only 1–1.5°C above the summer average maximum can cause severe stress to the coral.

The health of coral reefs depends on the symbiotic relationship between the coral and unicellular, photosynthetic protists that live within their cells. As well as providing essential nutrition, these protozoans give corals their distinctive colour. An example is shown in Figure 6.4.3.

Figure 6.4.3 Healthy corals owe their colour to the protozoans that live within their cells.

When the coral is stressed, it expels the protists. The coral becomes lighter in colour—it is bleached. A bleached coral can be seen in Figure 6.4.4 on page 204. Once the bleaching has begun, it does not necessarily stop once the stress has reduced. Some corals take months to recover from a bleaching episode. Other corals never recover.

Bleached corals suffer from a lack of the nutrients that are normally provided by the protists. The corals can no longer compete with faster growing algae. The corals die and the reef is overtaken by algal growth.

Figure 6.4.4 Coral bleaching is occurring in coral reefs throughout the world. Not only are natural ecosystems affected by coral bleaching, fishing and tourism industries are adversely affected as well.

A great variety of organisms depend on corals for food and shelter. These organisms will be affected directly by any change in the health of the coral reefs. Many other organisms further along the food chain will be affected indirectly.

Kakadu

Changes to fire regimes, rising sea levels and increased storm activity are results of climate change. These could impact on Kakadu National Park in the Northern Territory.

There are large areas of wetland in Kakadu National Park. These wetlands support a large variety of species including many migratory species of bird such as magpie geese (*Anseranas semipalmata*) seen in Figure 6.4.5.

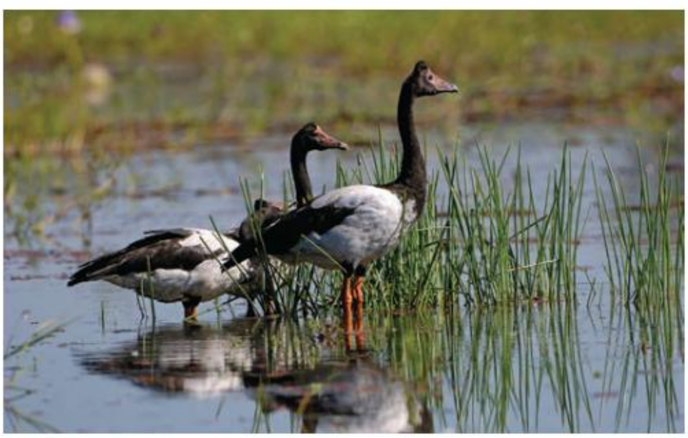


Figure 6.4.5 Late in the dry season, millions of magpie geese flock to Kakadu to feed.

Human activity has significantly reduced many populations of this bird in southern and south-eastern Australia. Looking after the population in Kakadu is a good opportunity to conserve the species. Kakadu wetlands are fresh water. However, many areas are very low lying. A rise in sea level combined with increased storm activity would allow salt water to flood into the area. Organisms that cannot live in saline conditions will disappear from the area. Organisms tolerant of salt will flourish and the ecosystems will change.

Extensive flooding also allows weed species and feral animals from surrounding areas to invade the wetlands. Feral animals such as pigs, cane toads and water buffalo (Figure 6.4.6) already pose problems in Kakadu. Water buffalo damage river banks, causing erosion. The water becomes muddy and unsuitable for the water plants and fish that normally live there. Water buffalo also eat so much that they are in direct competition with native wildlife.

Figure 6.4.6 Water buffalo (*Bubalus bubalis*) wallow in shallow waterholes in Kakadu National Park.

SciFile

More spiders

In West Greenland, higher average temperatures have led to spring arriving more than 20 days earlier than usual, giving wolf spiders more time to hunt. The average size of female spiders has increased and it is likely they will lay more eggs, leading to an explosion in the spider population in Greenland.

Species on the move

The long-spined sea urchin *Centrostephanus rodgersii* is shown in Figure 6.4.7. It is a very common species in the temperate waters of southeastern Australia. It appears to be moving down to Tasmania, where it could damage shallow reef ecosystems and the commercial abalone and rock lobster industries. Scientists believe that a strengthening of the East Australian Current resulting from climate change is carrying the larvae south.

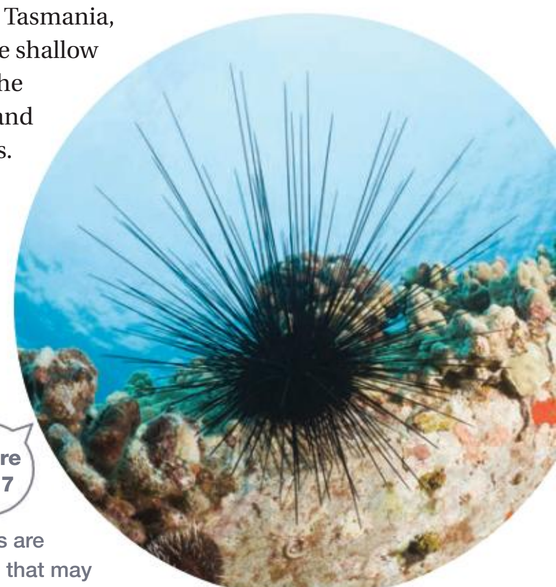


Figure 6.4.7 Long-spined sea urchins are moving south, a change that may be a response to rising sea temperatures.

In the Australian Alps kookaburras are hunting at higher altitudes and preying on alpine skinks. The alpine skinks do not recognise the kookaburras as predators and do nothing to avoid them. As a result, the alpine skink population will decrease.

Swamp wallabies and red-necked wallabies are also moving further up to graze on the herb fields high in the Australian Alps. Many plant species in the herb fields (Figure 6.4.8) will not survive continuous grazing, and biodiversity of the area will decrease.

Figure 6.4.8 Mountain ecosystems such as these herb fields survive under extreme conditions. They are very vulnerable to any added stress such as grazing.

SciFile

Early spring

A team of scientists in Europe's International Phenological Gardens records the date that each tree and shrub buds, blossoms and loses it leaves each year in the gardens. These data show that between 1959 and 1996 the growing season lengthened by eleven days with Spring coming earlier. Satellite tracking has confirmed this trend in other parts of the world. Changes to seasons could alter interactions between plants and animals in ecosystems.

In response to the earlier spring, some migratory birds are changing the time they start their migration.

Change in sea level

Geological history shows that sea levels have been both higher and lower than they are today. About 18 000 years ago, sea levels were about 120 metres lower. In the past 7500 years, sea levels have risen about 5.8 metres—that is about 2.5 cm every 30 years. This is a natural part of being in an interglacial warming period.

If all the ice on land on Earth were to melt, the sea level would rise about 70 metres. However, no climate change model has suggested that this could happen. Most cities are on the coast and therefore any rise in sea level is of concern. When sea levels rose in the past, cities like Sydney and Melbourne, London and New York did not exist. The industry, roads, houses, apartments and businesses you can see in Figure 6.4.9 were not in place then. As the water rose, animals moved out of the way and any early humans went with them. As the sea level fell again, they moved back to the newly exposed land. Skyscrapers, homes and businesses will not be able to be moved out of the way of the sea, so the economic impact will be huge.

1 p208 6.6 6.7 6.8

Figure 6.4.9 When sea levels rose in the past, animals just moved to higher ground. Development in coastal areas means that any future change in sea level will have a significant economic impact. The Gold Coast is at particular risk.

SCIENCE AS A HUMAN ENDEAVOUR

Use and influence of science

Reducing carbon dioxide

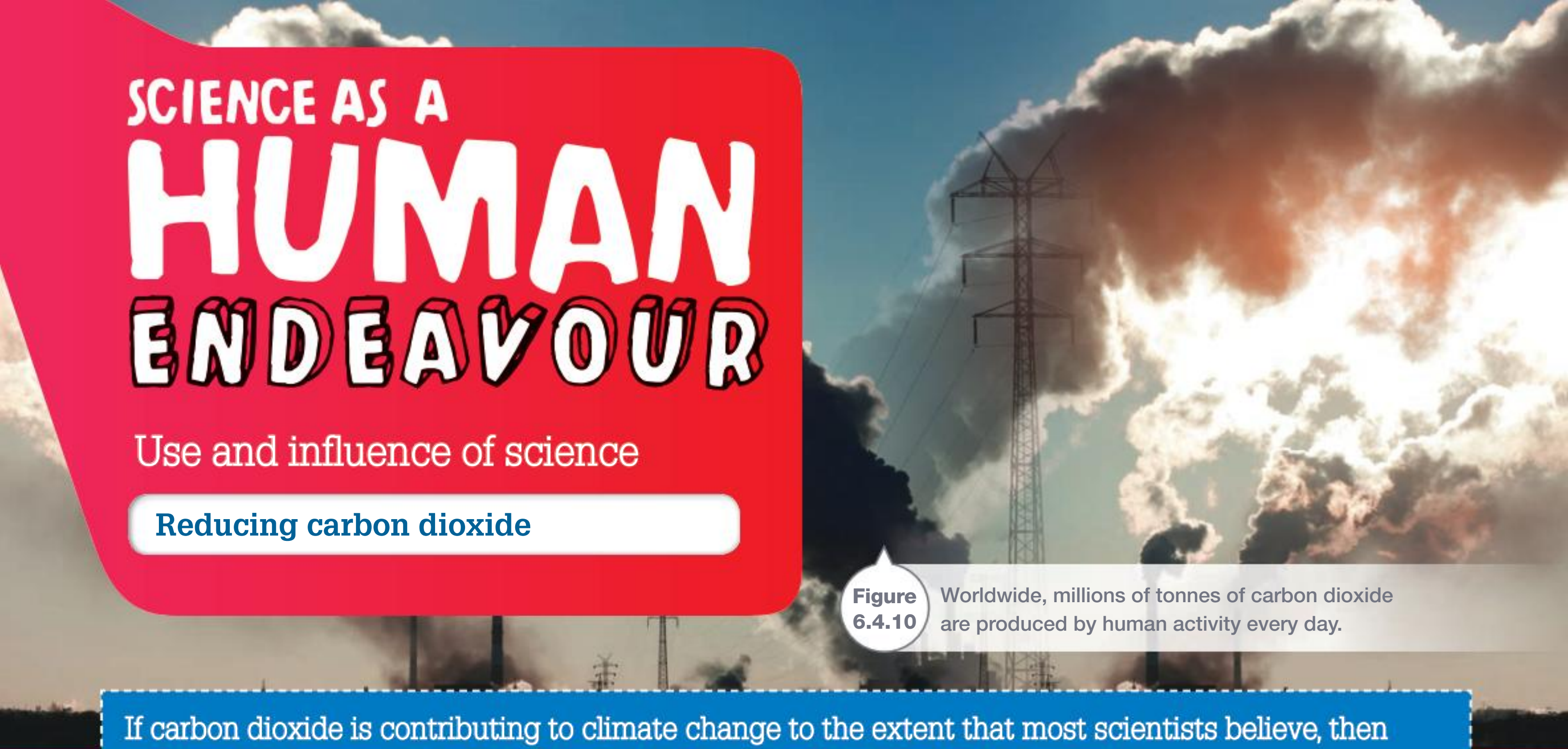


Figure 6.4.10 Worldwide, millions of tonnes of carbon dioxide are produced by human activity every day.

If carbon dioxide is contributing to climate change to the extent that most scientists believe, then reducing the amount of carbon dioxide in the atmosphere should be a priority.

The direct approach to reducing carbon dioxide is to reduce the amount entering the atmosphere from the burning of fossil fuels such as coal and oil (Figure 6.4.10). An alternative approach is to use a natural means of removing carbon dioxide from the atmosphere. Increasing the number of photosynthetic organisms in the environment will increase the amount of carbon dioxide being taken from the atmosphere and in some cases store it away for a long time.

About half of a tree's mass is carbon, so large amounts of carbon are stored in forests. The larger the tree, the more carbon is stored in it. For example, a small *Eucalyptus* tree with a trunk circumference of 100 cm stores about 320 kg of carbon. A tree of circumference 300 cm contains about 5540 kg of carbon. To store this much carbon, these trees would have absorbed about 1180 kg and 21 320 kg of carbon dioxide respectively. This is equivalent to the amount of carbon dioxide produced when 500–9035 L of petrol is burned. Just think how much carbon could be stored in some of the giant *Eucalyptus* trees in old-growth forests. Some of them have trunks with circumferences of 40 metres (Figure 6.4.11).

Governments are putting in place schemes in which people can buy carbon credits. In these schemes, people and industries plant trees for the sole purpose of reducing the amount of carbon dioxide in the atmosphere. One carbon credit is the equivalent of reducing the amount of carbon dioxide in the atmosphere by 1 tonne. That is enough carbon dioxide to fill a swimming pool 10 metres wide, 25 metres long and 2 metres deep.

In this way, an industry can balance the carbon dioxide it produces with the carbon it has stored. The effect is that no extra carbon has gone into the atmosphere.

The carbon is then stored in the trees and will remain there as long as the tree lives or as long as the wood in the tree is still intact, as in a building or furniture.

Figure 6.4.11 This *Eucalyptus* (*E. regnans*) is 79 metres tall and stores a large amount of carbon.

6.4 Unit review

Remembering

1 **List** the effects of climate change in the past.

2 **State** the source of evidence used by scientists to suggest that sea levels were higher in the past.

3 **List** the effects of climate change that are predicted to occur in Kakadu National Park.

Understanding

4 **Explain** how animals in natural ecosystems are likely to respond to rising sea levels.

5 **Explain** why it is difficult for animals to move to new areas when climate change makes their present habitat unsuitable.

6 **Describe** what happens to corals when they are bleached.

7 **Explain** why an unusually high rise in sea levels caused by onshore winds could have a negative impact on the Kakadu wetlands.

8 **Explain** the concept of carbon credits and how they could reduce the level of global warming.

Applying

9 Long-spined sea urchins have free-swimming larvae and these are carried south in currents. **Use** this information to suggest possible effects of climate change on the distribution of other organisms such as corals and starfish that also have free-swimming larvae.

Analysing

10 Think about climate change and **compare** the potential effects on it of planting large numbers of trees with the potential effects of destroying forests.

Evaluating

11 a For each case below, **propose** which organism is more likely to survive a change in climate.

b **Justify** your response.

i a plant with seeds that are dispersed by wind
OR
a plant that depends on animals for seed dispersal

ii an animal that produces a large number of offspring each year
OR
an animal that produces one offspring every two or three years

iii plants that have very specific environmental needs
OR
plants that survive in a wide range of habitats

iv plants or animals that live in very cold climates
OR
organisms that live in tropical regions

12 **Propose** possible effects on migratory birds if wetlands such as those in Kakadu National Park were to change significantly or disappear altogether.

13 A symbiotic relationship is one in which both organisms benefit from the relationship. **Deduce** the benefits for the symbiotic relationship between protozoans and corals for the:

a corals

b protozoans.

14 **Propose** what would control how far south the long-spined sea urchin shown in Figure 6.4.7 on page 204 could move and become established in large populations.

15 **Deduce** the effect on other predators of the movement of kookaburras up the slopes of the Australian Alps.

16 The short-term effect of wallabies moving up slopes in response to warmer temperature is increased grazing on the fragile herblands. **Propose** the long-term effects on the area.

Creating

17 **Construct** a consequence wheel for the global implications (potential results) of reduced biodiversity.

Inquiring

1 Identify a plant or animal species from your area that is endangered or vulnerable. Investigate the causes for it being vulnerable and propose the effect on this organism of predicted changes due to climate change.

2 Research the organisms that live on a typical coral reef.

a Use your findings to construct a food web for the reef.

b Describe the impact on the food web from the loss of coral due to bleaching.

3 Research technologies that are aimed at reducing carbon pollution. Carbon capture, sequestration and 'clean coal' are three possible starting points. Present your findings to the class in a poster or audio-visual presentation.

4 Access a map of your local area. The map should cover an area that is about 100 km by 100 km. Research the native animals that live in your local area. Use the map to identify where a colony of a particular animal might live.

a Investigate what could happen to this animal if conditions in its present habitat were no longer suitable.

b Design a scheme to help this animal survive changing conditions.

6.4 Practical activities

1 Where will the sea go?

Purpose

To investigate the effect on Australia of rising sea levels.

Materials

- access to Google Earth on a computer
- map of your state capital (alternatively you could look at your local area or choose an area from the map in Figure 6.4.12)

Figure 6.4.12

Procedure

1. Draw an outline of the map, showing the coastline.
2. List important features of the city such as commercial and administrative areas, centres for transport and shops, education centres and major housing areas.
3. Mark these on your map.
4. Using Google Earth, find the elevation of these features.

Results

Using the elevations, shade the map to show the areas that would be inundated by sea water if there was a 5 metre, 10 metre and 15 metre rise in sea level.

Discussion

1. **Propose** the changes to the function of your city that would be caused by an increase in sea level of:
   - a 5 m
   - b 10 m
   - d 15 m.
2. **Describe** the characteristics of the areas of the city that would be unaffected by the changes in sea level.
3. **Discuss** whether your city would be able to function if there was a rise in sea level.
4. **Propose** some wider effects of the changes to the capital city.
5. **Propose** strategies that would ensure that your state could continue to function.

Chapter review 6

Remembering

1 **Name** two substances that cycle through a natural ecosystem.

2 **State** where ozone is found in the atmosphere.

3 **Name** two major natural cycles that keep matter cycling through the environment.

Understanding

4 **Explain** why there is concern about chemicals that destroy ozone in the atmosphere.

5 **Describe** the most common effect an El Niño event has on Australia.

6 **Explain** how salinity and temperature affect deep ocean currents.

Applying

7 **Identify** two ways in which greenhouse gases can be reduced.

8 A suggested strategy for reducing the impact of carbon emissions is to plant trees. **Demonstrate** why this is a useful strategy.

Analysing

9 A single cow produces over 250 litres of methane every day. The number of cattle in Australia varies with conditions of rain and drought. Using 22 million as the cattle population, **calculate** the amount of methane produced by Australian cattle in:

a 1 day

b 1 year.

10 **Compare** the greenhouse effect and the enhanced greenhouse effect.

11 An Australian scientist was told by a person with no knowledge of climate science that 'Studying ocean currents seems pointless because they could not affect us.' **Analyse** this statement.

Evaluating

12 **Propose** a response to someone who says that humans are totally responsible for the global warming experienced by the world today.

13 a **Analyse** the nitrogen cycle, identifying areas where human activity may have an impact on it.

b **Propose** possible effects these human activities may have.

14 **Use** the information in Figure 6.2.2 on page 184 to **deduce** how the diagram would change as the Earth warms. Take into account changes in the patterns of reflection and absorption of solar radiation.

15 Round-the-world sailors usually follow the route shown in Figure 6.5.1. The loop in the Atlantic Ocean is to make the total distance equal to sailing around the equator, which is obviously impossible because of the land. **Propose** why sailors sail from west to east and not the other way around.

Figure 6.5.1

Creating

16 **Construct** a diagram of the carbon cycle. Label the diagram to show where:

a the carbon moves quickly from one part of the cycle to the next

b carbon moves more slowly

c there are carbon sinks.

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

greenhouse effect
enhanced greenhouse effect
global warming
nitrogen cycle
El Niño
La Niña
carbon cycle
climate change
Southern Oscillation
Indian Ocean dipole

6.9

Thinking scientifically

Q1 Table 6.6.1 presents data on changes in water consumption in different sectors of Australian society for the years 1996–97 and 2000–01.

Table 6.6.1 Water consumption by selected industries and sectors, 1996–97 and 2000–01

Sector	Annual water consumption (GL)	
	1996–97	2000–01
Forestry and fishing	19	23
Mining	570	401
Manufacturing	728	866
Electricity and gas supply	1308	1688
Household	1829	2181

Calculate the percentage increases in water consumption and decide which two sectors had the greatest increase in water consumption over this time.

A manufacturing and household
B mining, and electricity and gas supply
C electricity and gas supply, and household
D forestry and fishing, and manufacturing

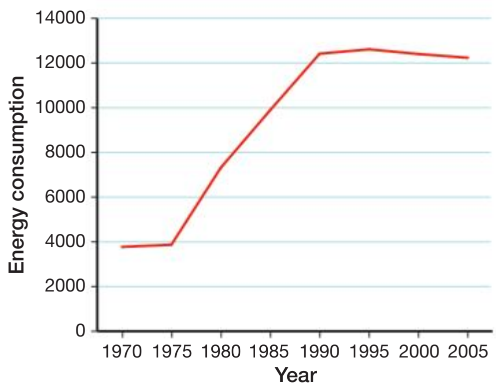
Q2 Table 6.6.2 provides data on energy use per head of population for the United Arab Emirates, one of the major oil-producing nations of the world.

Table 6.6.2

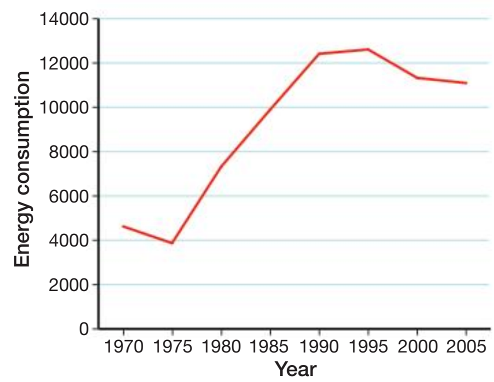
Year	Energy consumption per head of population (kg oil equivalent)
1971	3774
1975	3871
1980	7315
1985	9892
1990	12416
1995	12611
2000	11401
2005	11133

Which graph best represents the data in the table?

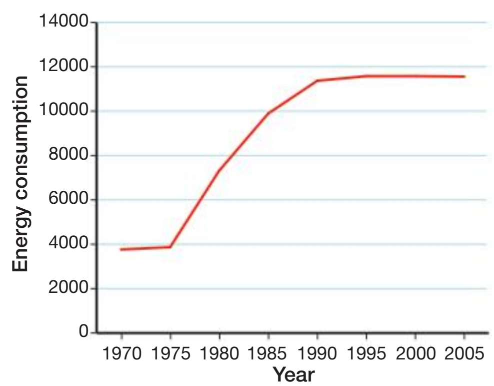
A



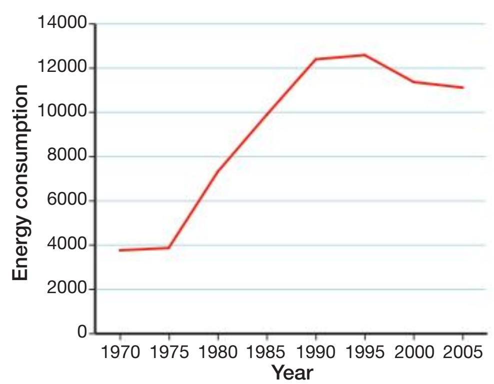
B



C



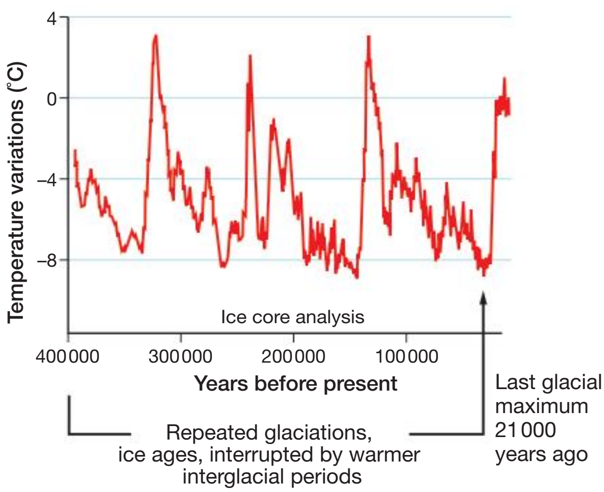
D



Q3 Use the data in Table 6.6.2 to determine the 10-year period that saw the greatest change in energy use.

A 1975–85
B 1980–90
C 1985–95
D 1990–2000

Q4 The graph below shows the variation in average world temperature for the past 400 000 years.



Based on the information in the graph, which of the following is *not* a true statement?

A The Earth is currently in a period of global warming that started about 20 000 years ago.

B There have been four periods of glaciation in the past 400 000 years.

C The current period of global warming has had the greatest increase in temperature of those experienced in the past 400 000 years.

D The longest period of low average temperatures was in the ice age preceding the current period of global warming.

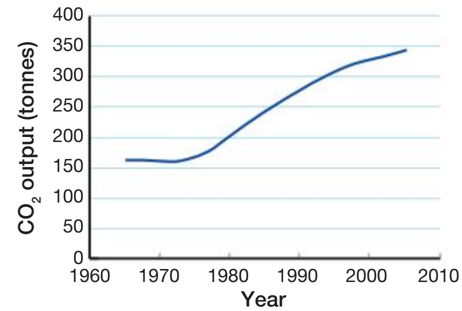
Q5 Table 6.6.3 shows the population and carbon dioxide output per head of population in Australia from 1965 to 2005.

Table 6.6.3

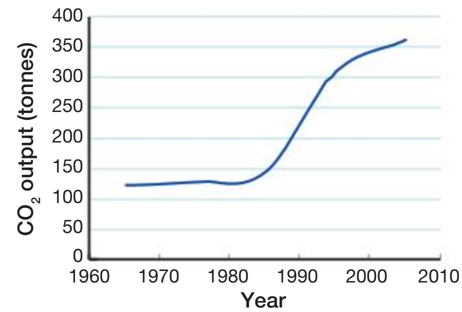
Year	Population (millions)	CO_2 output (metric tonnes per head of population)
1965	11.5	10.6
1975	14	11.9
1985	16	15.2
1995	18	17.1
2005	20	18.1

Which of the following graphs best represents the change in total carbon dioxide output for the nation?

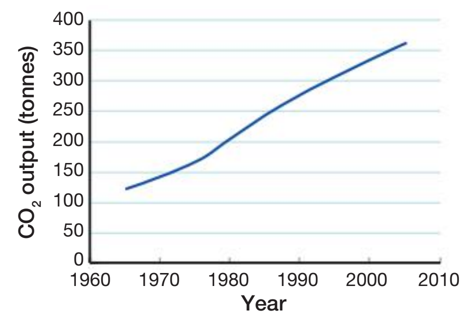
A



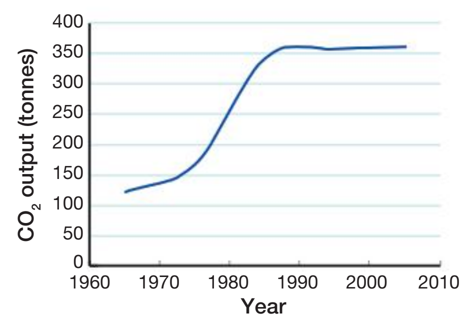
B



C



D



Q6 Use the data in Table 6.6.3 to calculate the decade in which Australians had the largest increase in carbon dioxide output per head of population.

A 1965–75
B 1975–85
C 1985–95
D 1995–2005

Glossary

Unit 6.1

Atmosphere: the layers of gases surrounding the planet

Biosphere: all living things on Earth

Carbon cycle: the process by which carbon is recycled through the soil, water, living things and the atmosphere

Denitrifying bacteria: bacteria that convert nitrates back into gaseous nitrogen (N_2), which is then released back into the atmosphere

Fossil fuels: fuels that contain the carbon of plants and animals that died and were preserved millions of years ago

Fossils: the preserved remains of once-living organisms

Hydrosphere: all the liquid water on the Earth's surface

Leguminous plants

Leguminous plants: plants that can take nitrogen from the air and fix it in their tissues

Lithosphere: the land masses on Earth

Nitrogen cycle: the process by which nitrogen cycles between the living and non-living environments

Nitrogen-fixing bacteria: bacteria that absorb nitrogen from the air and convert it into ammonia and then into nitrates

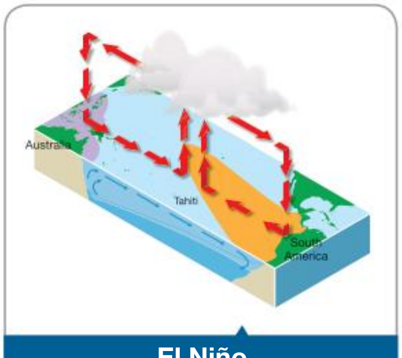
Sustainable ecosystems: ecosystems that are diverse and provide for the needs of the organisms that live there

Unit 6.2

Climate: the long-term averages of weather conditions

Climate change: change to the averages of aspects of climate that persist for decades or longer

El Niño: an extreme of the Southern Oscillation that causes drought in parts of Australia



El Niño

Global conveyor belt: common name for the thermohaline circulation

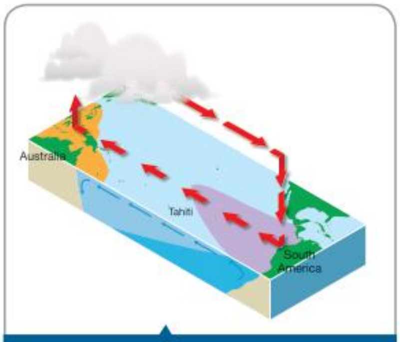
Global warming: a time when the average world temperature is increasing

Greenhouse effect: the warming of Earth caused by greenhouse gases

Greenhouse gases: gases that trap heat close to the Earth's surface

Gyres: the circular patterns shown by the ocean currents in the major ocean basins

Indian Ocean Dipole (IOD): a variable and irregular cycle of warming and cooling of waters in the equatorial area of the Indian Ocean



La Niña

Interglacials: periods between glaciations

La Niña: an extreme of the Southern Oscillation that causes significant rainfall in parts of Australia

Ocean currents: continuous movements of ocean water

Southern Oscillation: a sequence of changes to the atmosphere and ocean circulation across the Pacific Ocean and Indonesian Islands

Southern Oscillation Index (SOI): a measure of the Southern Oscillation calculated using the difference in air pressure between Tahiti and Darwin

Thermohaline circulation: scientific term for the *global conveyor belt*, a continuous circulation of water that can be tracked around the whole Earth

Weather: the conditions in the atmosphere

Unit 6.3

Enhanced greenhouse effect: an increase in the natural greenhouse effect caused by human activity

Permafrost

Permafrost: areas on Earth where the temperature in layers of soil or rock beneath the surface never rises above freezing point

Unit 6.4

Biodiversity: the variety of ecosystems in the biosphere, the variety of species within those ecosystems and the genetic variation within those species

SCIENCE TAKES YOU PLACES

Look who is using science

COMPETITION SAILOR

My name is Cam Parsons and I am a competition sailor. I've represented Australia in a Youth World Title in Croatia and competed in a number of national events.

Competition sailors rely heavily on physics concepts. To keep the boat upright, we must counterbalance the force of the wind with our body weight. To turn the boat, we have to change the angle that the blades of the boat cut through the water. We can also turn by changing how the boat is sitting in the water. For example, if we lean the boat over, then it will change direction. Moving our weight back and forth also changes the speed that the boat moves.

I like sailing because I travel to different places. Every time I go out it is different, every time a new experience. I also have many friends within the sailing community from all over Australia and the world.

ASTRONOMER

I am Dr John O'Sullivan. In 2009, I won the Prime Minister's Prize for Science. After I completed a double degree in physics and electrical engineering, I went on to study for a PhD in radio astronomy. This is the field of science that uses radio waves to learn about stars and galaxies.

In the 1980s, while I was working with a team that was searching for exploding black holes, I started working on a technique that allowed complex radio signals to be split up, transmitted and recombined. About 10 years later, we discovered that this same idea could be used to greatly speed up radio signals between computers, mobile phones and other electronic devices.

Today, almost every wireless (WiFi) network system in the world uses the technology that was originally inspired by a search for exploding stars. One estimate has suggested that almost a billion people around the world use our invention every day!

These days I am working on Australia's attempt to build the largest telescope ever constructed—the Square Kilometre Pathfinder Telescope.

CIVIL ENGINEER

My name is Melanie Mindum and I am a civil engineer. A civil engineer puts structures in place that help people move around. We design bridges, plan road and railway links and map drainage systems so that our streets don't flood.

Recently I worked on a project that recommends where power and water services will be positioned in a new housing area. I have also designed railway lines and tram super stops that allow better access for people in wheelchairs, and upgraded railway level crossings to make them more obvious to drivers.

A civil engineer focuses on the needs of today's society, but must also ensure that what is designed now will be sustainable for the future. I enjoy my work because I like dealing with numbers and budgets and thinking logically about how to solve a problem.

7 The universe

HAVE YOU EVER WONDERED…

- how far away the stars are?
- how the universe began?
- whether the universe will ever end?
- how old the solar system is?
- when the Earth was formed?

After completing this chapter students should be able to:

- identify the evidence supporting the Big Bang theory
- recall that the age of the universe can be derived using knowledge of the Big Bang theory
- describe how the evolution of the universe has continued since the Big Bang
- recall that the study of the universe involves teams of specialists from different branches of science, engineering and technology
- describe the formation of galaxies and stars.

7.1 Stars

Astronomy is the study of stars (*astra* means stars, *onomy* means study of). Not all stars are like our Sun. Like people, stars can vary in age, size and appearance. Stars can also change over time. Understanding the reasons for the differences between stars will help us understand our universe. It will also show how the beginnings of life were created in a star.

Brightness

Look up at the night sky and you will see that stars differ from one another in two very obvious ways—brightness and colour. Astronomers refer to the brightness of a star as its **magnitude**. The colour of a star is due to its temperature.

A star's **apparent magnitude** is a measure of how bright it will appear to an observer on Earth. Although confusing, the brightest stars are given the lowest magnitudes, while dimmer stars are given higher magnitudes. The very brightest stars are given negative magnitudes. For example, Alpha Centauri (the brighter of the two Pointers to the Southern Cross) has an apparent magnitude of –0.27. In most cities, the dimmest stars that can be observed with the naked eye have a magnitude of 3.5. Under ideal conditions, the human eye can see stars down to a magnitude of 6.5.

Apparent magnitude is measured on a logarithmic scale. On this scale, a change of one unit changes the brightness of the star by a factor of about 2.5. For example, two of the brightest stars in the constellation Orion are Betelgeuse and Bellatrix (Figure 7.1.1). Betelgeuse is the bright red star that makes the

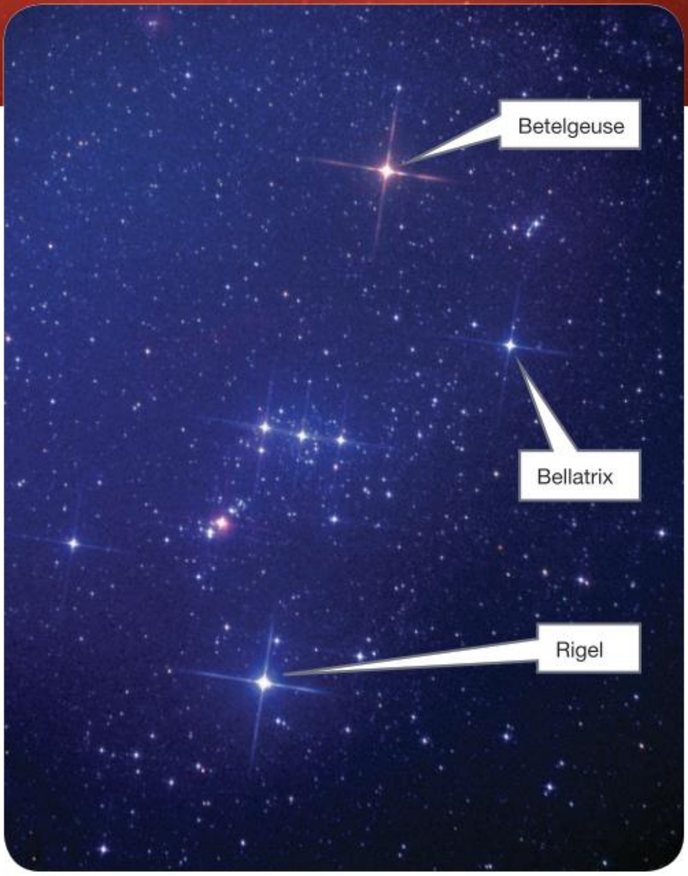


Figure 7.1.1 The constellation Orion (the hunter) contains stars of different brightness and colour.

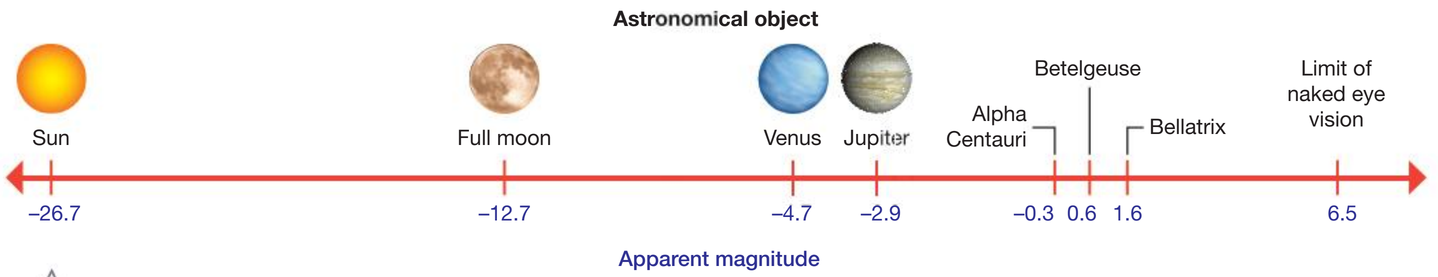


Figure 7.1.2 The apparent magnitudes of various astronomical objects. The magnitude of planets such as Venus changes over time and so the values given here are their maximum values.

right shoulder of the hunter in the constellation and Bellatrix is its left shoulder. Betelgeuse has an apparent magnitude of 0.6 and Bellatrix has an apparent magnitude of 1.6 (Figure 7.1.2). Since Betelgeuse's apparent magnitude is one unit lower than that of Bellatrix, it appears about two and a half times brighter than Bellatrix.

There are two main factors that determine a star's apparent magnitude. One is how much light the star emits. The other is the distance between the star and Earth—the greater the distance, the dimmer the star will appear. In order to study stars, it is important to eliminate the effect of distance on our measurements.

7.1

The distances between stars

Given the enormous distances between stars, the kilometre is not a convenient unit of length in astronomy. Astronomers often measure interstellar distances (the distances between stars) in **light-years (l.y.)**. One light-year is the distance that light will travel in one year. This distance is a little under 9.5 trillion kilometres. The distance to Betelgeuse is 650 l.y. This means that the light you see when you look at Betelgeuse was emitted by the star nearly 650 years ago. Looking at stars is like looking backwards in time!

Another commonly used astronomical unit of length is the **parsec** (pc), which is equivalent to 3.26 light-years.

SKILL BUILDER

Converting between light-years and parsecs, l.y. → pc

To convert from light-years into parsecs, divide by 3.26:

$$\text{distance in parsecs} = \frac{\text{distance in light-years}}{3.26}$$

To convert from parsecs to light-years, multiply by 3.26:

distance in light-years = distance in parsecs × 3.26

WORKED EXAMPLE

Converting light-years to parsecs

Problem

Betelgeuse is 650 light-years away. Calculate how many parsecs this represents.

Solution

$$\text{Distance in parsecs} = \frac{650}{3.26} = 199 \text{ pc}$$

INQUIRY science 4 fun

Eye parallax

Yes

Do this ...

1. Place an object on a table about arm's length in front of you.
2. While looking at the object, close or cover your left eye. Note the position of the object relative to its background.
3. As quickly as possible, close or cover your right eye while you open your left eye. Note how the position of the object changes.
4. Quickly swap back to looking with just your right eye. Swap from one eye to the other as quickly as possible. Note how the position of the object changes against its background as you change from one eye to the other. This apparent change in position is parallax.
5. Repeat this process with an object about 2 metres away.
6. Repeat the process with an object at the other side of the room and then with a distant object (for example, through a window).

Record this ...

Describe what happened. Was the effect for more-distant objects greater or smaller than for closer objects?

Explain why you think this happened. Use a diagram to help you

Definition of a parsec

A parsec is defined as the distance a star would need to be from our Sun if it was to have a stellar parallax of exactly 1 arcsecond (1 arcsecond = $\frac{1 \text{ degree}}{3600}$). The closest star to our Sun is Proxima Centauri. Its parallax is 0.768 arcsecond, giving it a distance 1.3 parsecs or 4.2 light-years.

SciFile

The parsec is based on a phenomenon known as **parallax**. Parallax causes you to see different views of the same object. Shut one eye, open it, then shut the other and you will see slightly different views of the same scene. This is parallax! Parallax can be used to measure the distance between the Sun and other stars. As the Earth moves around the Sun, our changing point of view means that the positions of stars in the sky change very slightly over the course of the year. This is shown in Figure 7.1.3.

p227

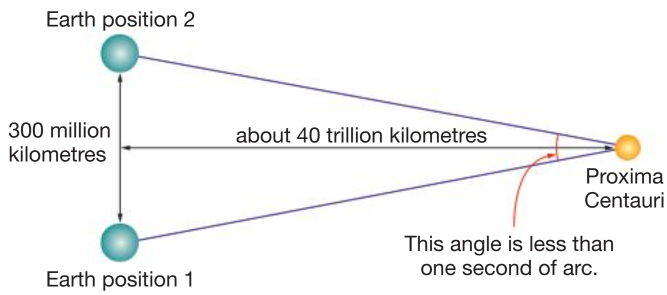


Figure 7.1.3 The position of Proxima Centauri in the sky changes slightly due to the Earth's movement around the Sun. This diagram is not to scale.

Even for the closest stars, this shift in position (known as **stellar parallax**) is tiny—less than one-thousandth of 1 degree. It is only since the 19th century that astronomers have had instruments sensitive enough to reliably measure stellar parallax and calculate the distance to the nearest stars. Many stars are so far away that their stellar parallax is too small to be measured. Astronomers need to use more indirect methods to measure the distances to these stars.

Absolute magnitude

As a way of measuring a star's actual brightness, scientists use a measurement called **absolute magnitude**. This measures how bright a star would appear to us if it was a distance of 10 parsecs from Earth. Using absolute magnitudes allows the brightness of stars from different parts of the galaxy to be meaningfully compared.

Betelgeuse is almost 200 pc from Earth whereas Bellatrix is only 75 pc away. Betelgeuse has an absolute magnitude of –5.14. This means that if it was only 10 pc from Earth, it would be almost 200 times brighter than it currently appears. In comparison, the absolute magnitude of Bellatrix is –2.72, meaning that even if Betelgeuse and Bellatrix were the same distance from Earth, Betelgeuse would still be the brighter of the two stars. (Remember that brighter stars have lower magnitudes.)

SciFile

Seeing the colour of stars

The colours you see in Figure 7.1.4 will probably seem much clearer than those you see when you look at stars in the night sky. One reason for this is that your eyes have two different types of light receptors called rods and cones. Cones are responsible for colour perception. They require a lot of light to be activated and do not work well at night. Also, our eyes suffer from an effect called small-field tritanopia. This means that we have difficulty detecting the colour of small points of light. The long exposure time used in taking the photo in Figure 7.1.4 makes many of the stars small disks rather than points. This allows our eyes to perceive their colour easier than with normal stars.

Figure 7.1.4 This is a photo taken by the Hubble Space Telescope of a section of sky in the constellation Sagittarius. It shows some of the variety in the colour of stars in our galaxy.

Colour

Each star emits light at a range of different wavelengths. Some of this light is in the visible part of the **electromagnetic spectrum** (Figure 7.1.5), while some of it will be in the invisible infrared or ultraviolet range. Your eyes collect the visible light from stars and your brain performs a complex averaging process that results in you perceiving the star as a particular colour.

Rather than rely on the human eye and the brain to interpret the colour, scientists analyse the light from a star by using filters. By comparing the magnitude of the star when viewed through coloured filters, its colour can be precisely measured.

A star's spectrum is mainly determined by its surface temperature. Cooler stars emit most of their energy in the infrared and red parts of the spectrum and therefore appear red to your eyes. Very hot stars emit a lot of energy in the violet and ultraviolet part of the spectrum and appear blue. Stars with temperatures in between these extremes emit light across a range of wavelengths and can appear orange, yellow or white.

Another device that is used to analyse starlight is a **spectrometer**. This is a device that splits light into a spectrum to reveal its component colours.

Scientists can determine what chemical elements are present in a star from distinctive lines that appear in its spectrum. Particular elements emit colours of particular wavelengths. These can be measured precisely to determine the elements in the star.

2 p228

When studying the spectra from stars, scientists also see dark lines showing missing colours. The Sun has dark lines called Fraunhofer lines in its spectrum. You can see them in Figure 7.1.6. The lines are due to light interacting with atoms in the outer layers of the star. The light energy is absorbed by electrons in atoms of all the elements in the outer gas layers. These electrons absorb light energy of particular wavelengths. The absorption occurs at exactly the same wavelength that the same element would emit when it is extremely hot.

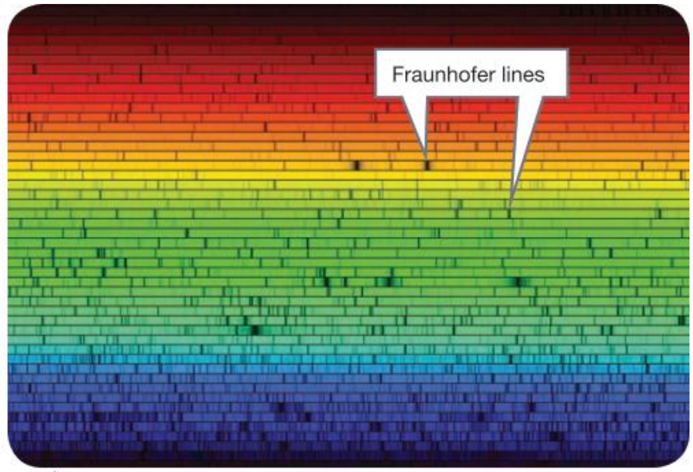


Figure 7.1.6 The spectrum of the Sun, showing dark vertical lines called Fraunhofer lines

From the spectra, scientists have created a classification system called **spectral class**. Spectral class indicates the elements present in the star, the temperature and colour of a star. This is shown in Table 7.1.1. Our Sun has a surface temperature of just under 6000°C so it is classified as a G-type star. It has a yellow-white colour.

The source of energy that keeps stars at these extraordinarily high temperatures is a process known as **nuclear fusion**.

Table 7.1.1 Spectral classes and their associated temperatures and colours

Spectral class	Temperature (°C)	Colour of star
O	50 000–28 000	Blue
B	28 000–10 000	Blue-white
A	10 000–7500	White
F	7500–6000	White-yellow
G	6000–4900	Yellow
K	4900–3500	Orange
M	3500–2000	Red

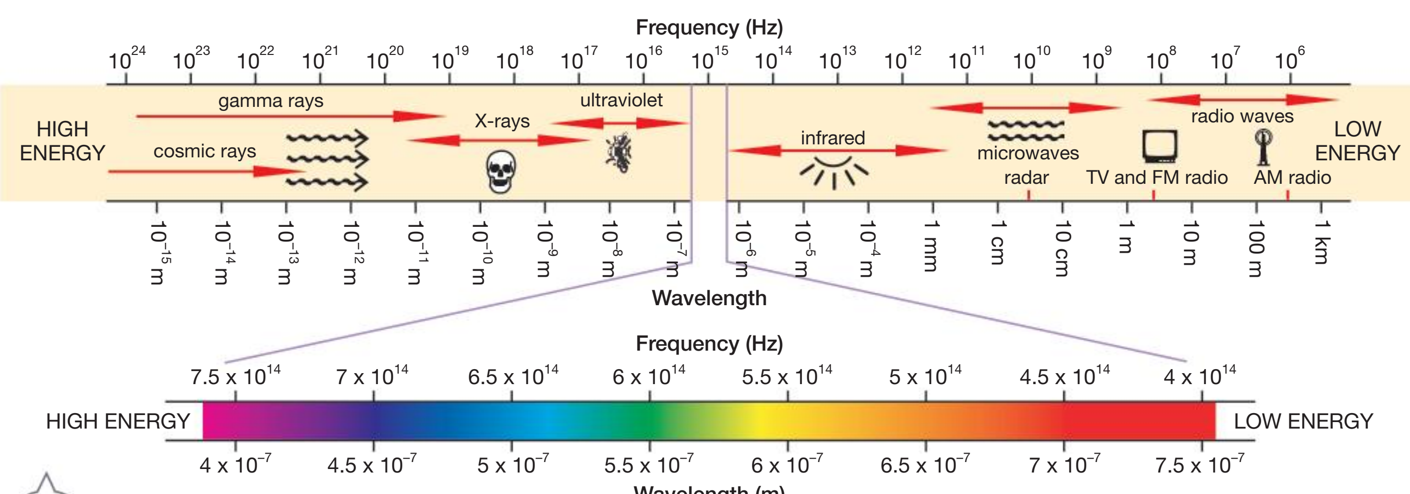


Figure 7.1.5 The visible part of light is just a small part of the electromagnetic spectrum.

Nuclear fusion

Data from spectral analysis has indicated that three-quarters of the material in a typical star is hydrogen. Most of the remaining quarter consists of helium and small amounts of iron and other heavy elements.

The enormous gravitational forces within a star can heat the material at its centre to a temperature of almost 15 million degrees Celsius. Hydrogen is the simplest element in the periodic table, consisting usually of a single proton and an electron. At the enormous temperatures inside a star, the electrons have too much energy to stay bound to the protons so the material takes the form of **plasma**. Plasma is a state of matter consisting of a 'soup' of positively charged ions and free electrons.

Protons are positively charged and so they strongly repel each other. However, in the centre of a star, the massive gravitational force is enough to bring individual protons close enough so that they will fuse together into a new nucleus. This is shown in Figure 7.1.7.

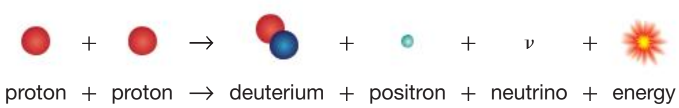


Figure 7.1.7 In the centre of a star, protons join to form a new nucleus called deuterium (a proton and neutron joined), a positron and a neutrino.

During the fusion process, one of the protons is converted into a neutron and two tiny particles are released—a small positively charged particle called a **positron** and a tiny, neutral particle called a **neutrino**. A positron is the antimatter particle for an electron. It is identical to an electron except that it has a positive charge. The positron does not stay in existence for long. As it is positively charged, it will be attracted to any electrons in the plasma. When a positron collides with an electron, the two particles annihilate (destroy) each other and become two high-energy **gamma rays**. As these gamma rays make their way out from the core of the star, their wavelengths increase and they are stretched into the heat, light and ultraviolet radiation that we can observe from Earth.

The new nucleus formed in this fusion reaction consists of a proton and a neutron. This is still the nucleus of a hydrogen atom, but it is an **isotope** of hydrogen known as deuterium.

Neutrinos

Neutrinos are extremely difficult to detect. They have almost no mass and, since they have no charge, they are not affected by electric or magnetic fields. It is suspected that trillions of neutrinos produced by the Sun pass through your body each second without having any effect on you at all!

SciFile

The deuterium can undergo further fusion reactions as shown in Figures 7.1.8 and 7.1.9.

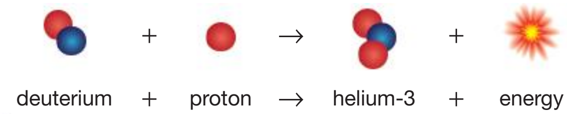


Figure 7.1.8 Hydrogen fusion reaction

Figure 7.1.9 Helium–helium reaction (protons shown in red, neutrons in blue)

The overall result of all these reactions is that hydrogen is converted into helium and energy.

The life cycle of stars

Hertzsprung–Russell diagrams

In the early part of the 20th century, two astronomers, Ejnar Hertsprung of Denmark and Henry Norris Russell of the United States, independently came up with the idea of plotting stars on a diagram. Absolute magnitude (brightness) was placed on one axis and spectral class (colour) on the other. When they did this, they noticed that the stars fell into a number of clearly defined groups. This type of diagram became known as the Hertzsprung–Russell or H–R diagram. A typical H–R diagram is shown in Figure 7.1.10 on page 220.

The H–R diagram revolutionised astronomy because it showed that there was a relationship between the brightness and temperature of stars. H–R diagrams were also interpreted as showing that stars were changing from one 'type' to another. These changes became known as the 'life cycle' of a star. Using an H–R diagram is a bit like going into a forest and seeing all the trees at different stages of growth and concluding that the stages represent different life stages of the species. You can't actually see a tree at one stage grow into the other, but it is clear that they must. It became apparent that as stars develop and change, they move from one section of the H–R diagram to another. Thus the H–R diagram acts as a map of the life-cycle of a star.

7.2

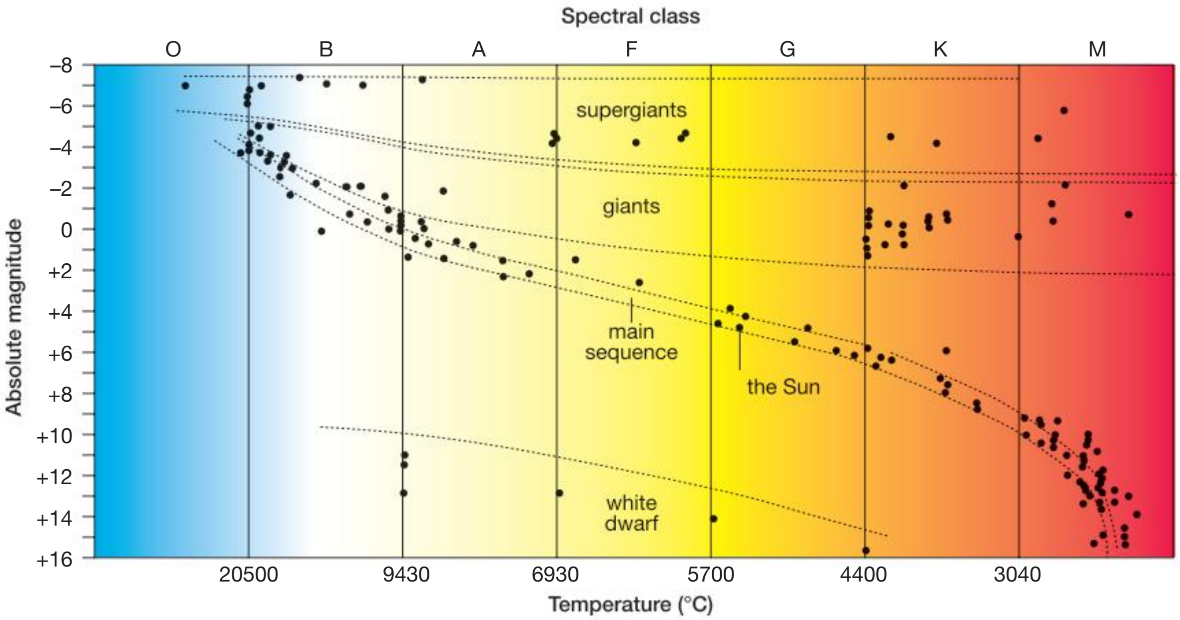


Figure 7.1.10 Hertzsprung–Russell diagram

Main sequence

On an H–R diagram, most stars fall on a broad line running from the top left-hand corner to the bottom right-hand corner. This line is known as the **main sequence**.

The structure of any star is determined by the balance of two opposing forces. One of these forces is **gravity**, which causes the material within the star to fall in towards the centre of the star. Opposing gravity is the **radiation pressure**, which is produced by the heat generated by nuclear fusion.

In a main sequence star, gravity and radiation pressure are in equilibrium—they balance each other out, giving the star a constant radius and brightness. This equilibrium can last for millions or even billions of years until the hydrogen in the core of the star starts to run out.

For main sequence stars, there is a simple relationship between the mass of the star and its temperature and brightness—the heavier the star, the hotter and brighter it will be. This is because more mass results in a greater gravitational force. The greater gravity from the large mass causes the core of the star to be more tightly compressed and therefore nuclear fusion occurs more rapidly. Hydrogen is converted into helium more quickly and produces more heat and light. This also means that more massive stars burn up their fuel more quickly.

Our Sun is a medium-sized star on the main sequence. At a temperature of around 6000°C. Our Sun's nuclear fuel will last for about 10 billion years. In comparison, a star ten times as massive as the Sun will be 10 000 times brighter, have a temperature of 22 000°C and burn out in 20 million years.

On an H–R diagram, the stars in the top left-hand corner are brighter, hotter and larger. Stars in the bottom right-hand corner are dim, cool and small.

Typical stars in the main sequence start their lives at the bottom right-hand corner of the main sequence and move towards the top left of the H–R diagram. When the hydrogen in the core of a main sequence star runs out, it undergoes a dramatic transformation and moves off the main sequence. Where it goes next on the diagram depends on its mass.

Red giants

When the hydrogen in the core of a medium-sized star runs out, fusion stops and the outward radiation pressure also stops. Gravity causes the star to collapse inwards and the outer layers of the star to start to fuse. Heat from this fusion produces radiation pressure, which causes these outer layers to expand and cool. The star becomes a **red giant** with a small dense core and a large, relatively cool outer atmosphere.

Fusion in the outer layers of a red giant occurs at a lower temperature than in a main sequence star. Therefore, a red giant produces more light in the red part of the spectrum, giving the star its distinctive colour. As the hydrogen in the outer layers of the red giant fuses, the helium produced sinks into the core of the star. As more and more matter is added to the core, its gravitational force and temperature increase until helium atoms start to fuse into heavier elements such as beryllium and carbon. This is shown in Figure 7.1.11.

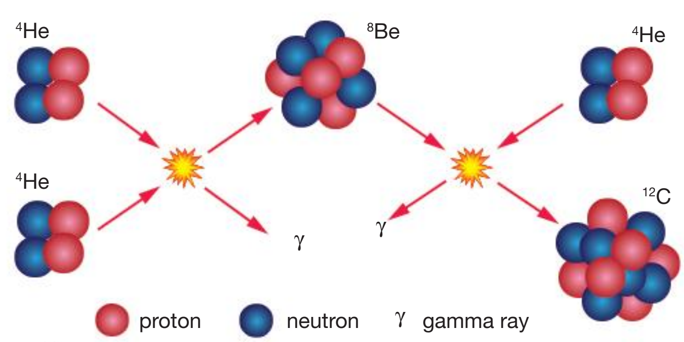


Figure 7.1.11 Fusion can create heavier elements from helium (He). This example shows how beryllium (Be) and carbon (C) form.

Typically, a red giant that has formed from a medium-sized star has enough helium fuel in its core to last for around 100 million years. When this runs out, the star collapses further

Figure 7.1.12 Planetary nebulae form spectacular shapes and patterns.

and the outer layers escape to become a cloud of gas known as a **planetary nebula.** Almost half of the mass of the original star is lost into this planetary nebula. The remaining core of the red giant is extremely hot and emits ultraviolet light. This causes the planetary nebula to glow in spectacular patterns. You can see some in Figure 7.1.12.

'Planetary' nebula

SciFile

The name *planetary nebula* was first used in the late 18th century by William Herschel, the discoverer of Uranus. Through the low-power telescopes available at the time, these clouds of gas looked like Uranus and other gaseous planets. The name is misleading since scientists now know that these phenomena have nothing to do with planets.

Over a 'short' period of 20 000 years, a planetary nebula will disperse to reveal the hot, dense sphere of carbon and hydrogen that is the remains of the red giant (its core). This fades to become a very dense star called a **white dwarf**. White dwarfs are so dense that if our Sun became a white dwarf, its mass could be packed into a sphere only slightly larger than the Earth. While a white dwarf is very hot, it is much dimmer than the red giant from which it forms. The lower brightness now places it off the main sequence and this means that the white dwarf drops to the bottom of the H–R diagram.

Nuclear fusion has ceased on a white dwarf, so the star will fade to become a cold, dark ball of inert matter known as a **black dwarf**.

Do black dwarfs really exist?

SciFile

Since white dwarfs are very small and have a relatively small surface area, they radiate heat very slowly. It would take hundreds of billions of years for a white dwarf to turn into a black dwarf. Scientists currently believe that the universe is less than 20 billion years old, so it is possible that black dwarfs exist only in the imaginations of astrophysicists!

Supergiants

Stars that are ten or more times as massive as our Sun follow quite a different life-cycle from the stars on the main sequence. These massive stars start at the top left-hand corner of the H–R diagram and are known as **blue supergiants**. Being much larger than main sequence stars, they have much higher gravitational forces and consume their hydrogen much more quickly—in millions rather than billions of years.

When the hydrogen runs out and helium fusion begins, the star's brightness stays approximately the same but it slowly cools down. On the H–R diagram, this is seen as movement from left to right. Once all the helium has been fused into carbon and oxygen, the temperature in these massive stars is hot enough to cause these atoms to fuse into even heavier and heavier elements. Eventually though, even this fuel will have to run out and then the results are nothing short of spectacular—a supernova occurs!

Supernovae

Once all the material in the core of a supergiant has been fused into iron, it cannot fuse any further. Creating heavier elements than iron absorbs more energy than it releases. If the core of the star stops producing energy, there is no force to act against gravity and all of the material in the outer layers collapses inwards at incredible speeds. When this material reaches the solid core, it rebounds in a massive explosion called a **supernova**. The star will become over 100 million times brighter than it was originally, outshining the rest of the stars in its galaxy combined! In 1987, astronomers were fortunate enough to capture this process occurring in a star in the Large Magellanic Cloud. The black and white images in Figure 7.1.13 on page 222 show how dramatically the brightness of the star increased.

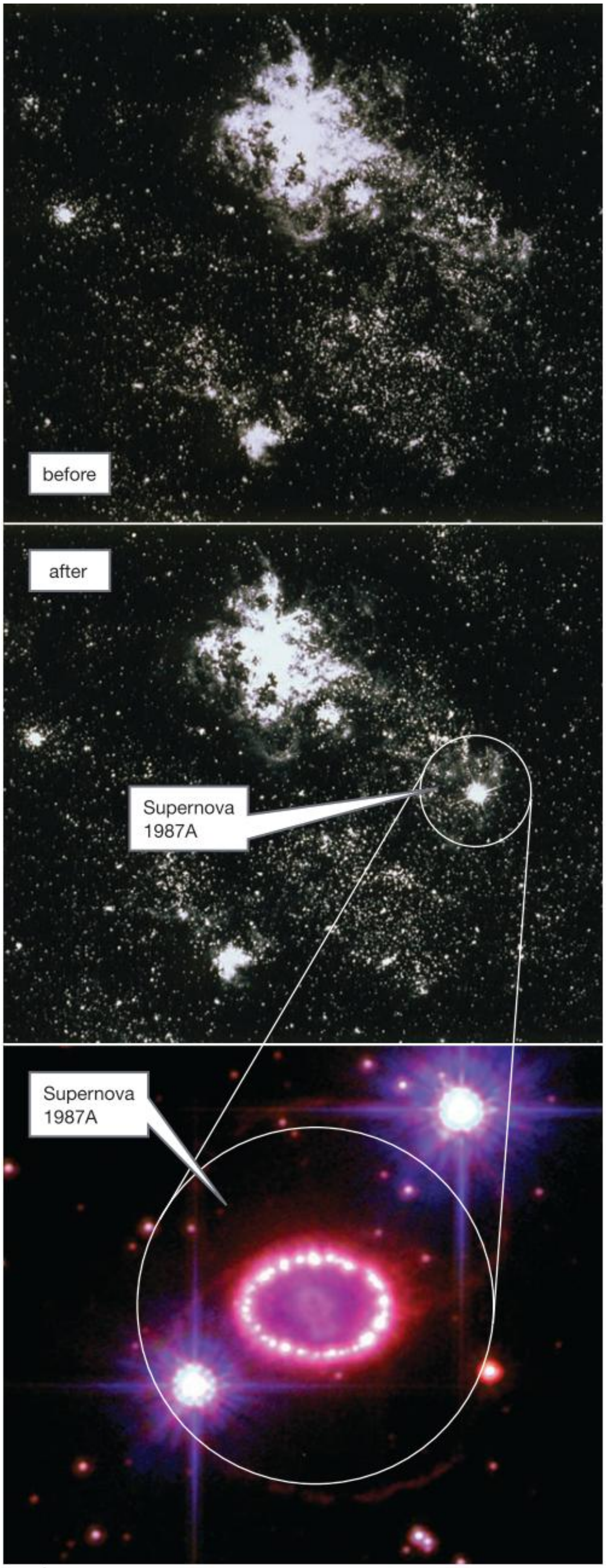


Figure 7.1.13 Before and after photos of Supernova 1987A.

SciFile

Supernova—'big, new star'

In Latin, the word *nova* means 'new'. This term was originally used by the earliest astronomers because it seemed that a 'new' star was being born. A nova would appear, burn brightly for a few weeks or months and then fade dramatically. If a nova was particularly spectacular, it came to be known as 'supernova'. Scientists now understand that a nova or supernova is not a new star at all. The star that exploded into the supernova was always there, it may just have been too dim for astronomers to notice it.

When a star explodes this violently, much of its mass is blown in to space. You can see this in the bottom photo of Figure 7.1.13 and in Figure 7.1.14. This material is mostly in the form of neutrons, which collide with other atomic nuclei as they are flung outwards. Many of the neutrons are captured by these nuclei to form heavy elements such as gold and silver.

What happens to the material left behind by this explosion depends on the size of the star.

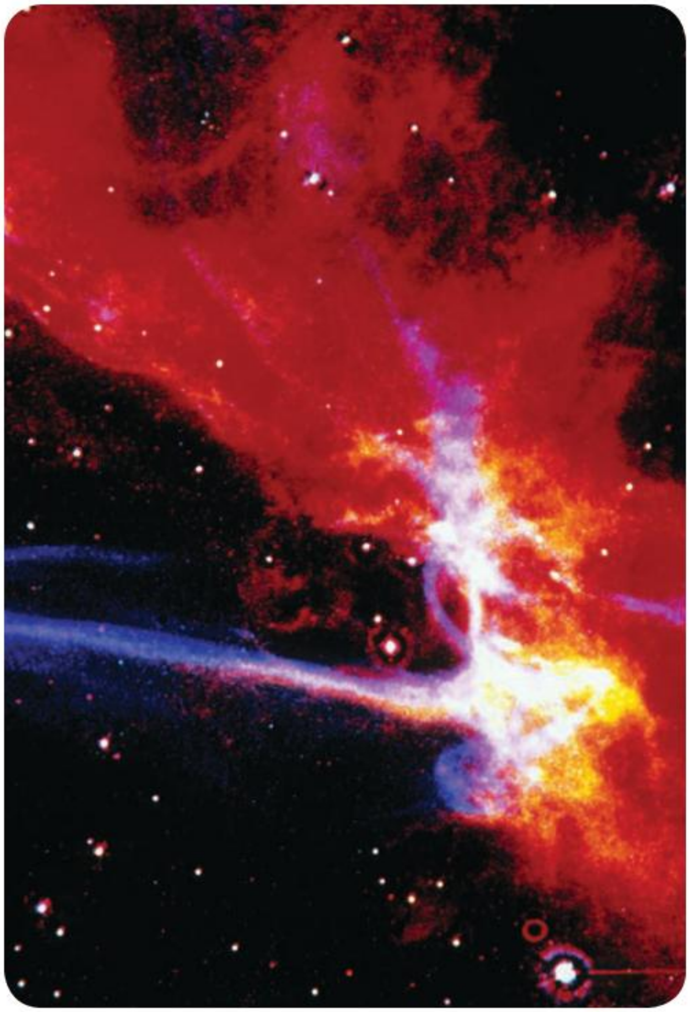


Figure 7.1.14 This image shows a section of the Cygnus loop, a cloud of gas produced in a supernova explosion. The bright colours indicate the presence of elements such as oxygen.

Calculating density

Density is defined as mass per unit volume.

Density = $\frac{\text{mass}}{\text{volume}}$

Density is commonly measured in units of either grams per cubic centimetre (g/cm^3) or kilograms per cubic metre (kg/m^3).

WORKED EXAMPLE

Calculating Earth's density

Problem

The planet Earth has a mass of 6.0×10^{24} kg and a volume of 1.1×10^{21} m^3. Calculate its average density.

Solution

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

$$= \frac{6.0 \times 10^{24}}{1.1 \times 10^{21}} = \frac{6.0}{1.1} \times \frac{10^{24}}{10^{21}}$$

$$= 5.5 \times 10^3 = 5.5 \times 1000$$

$$= 5500\ kg/m^3$$

Neutron stars

If the amount of material left behind by a supernova is 1.4–3 times the mass of our Sun, then gravitational forces are strong enough to cause the structure of the atoms within it to break down. Electrons and protons combine to form neutrons. The resulting **neutron star** has an enormous **density** since its entire mass can be compressed into a sphere about 10–15 km across.

3 p229

Black holes

For supernova remnants that are more than three times the mass of our Sun, the process of collapse after a supernova does not end with the formation of a neutron star. The immense gravitational forces cause the star to shrink even further into what scientists refer to as a **singularity** or **black hole.**

The gravitational field of a black hole is so strong that not even light is fast enough to escape from it. This makes black holes very hard to detect as they do not emit any visible light. However, it is possible to find black holes indirectly by the effect they have on other stars. One method of detection occurs when a black hole is part of a **binary star system** (Figure 7.1.15). This occurs when two stars form close to one another and orbit a common centre of mass between them. If one of these stars becomes a black hole, its enormous

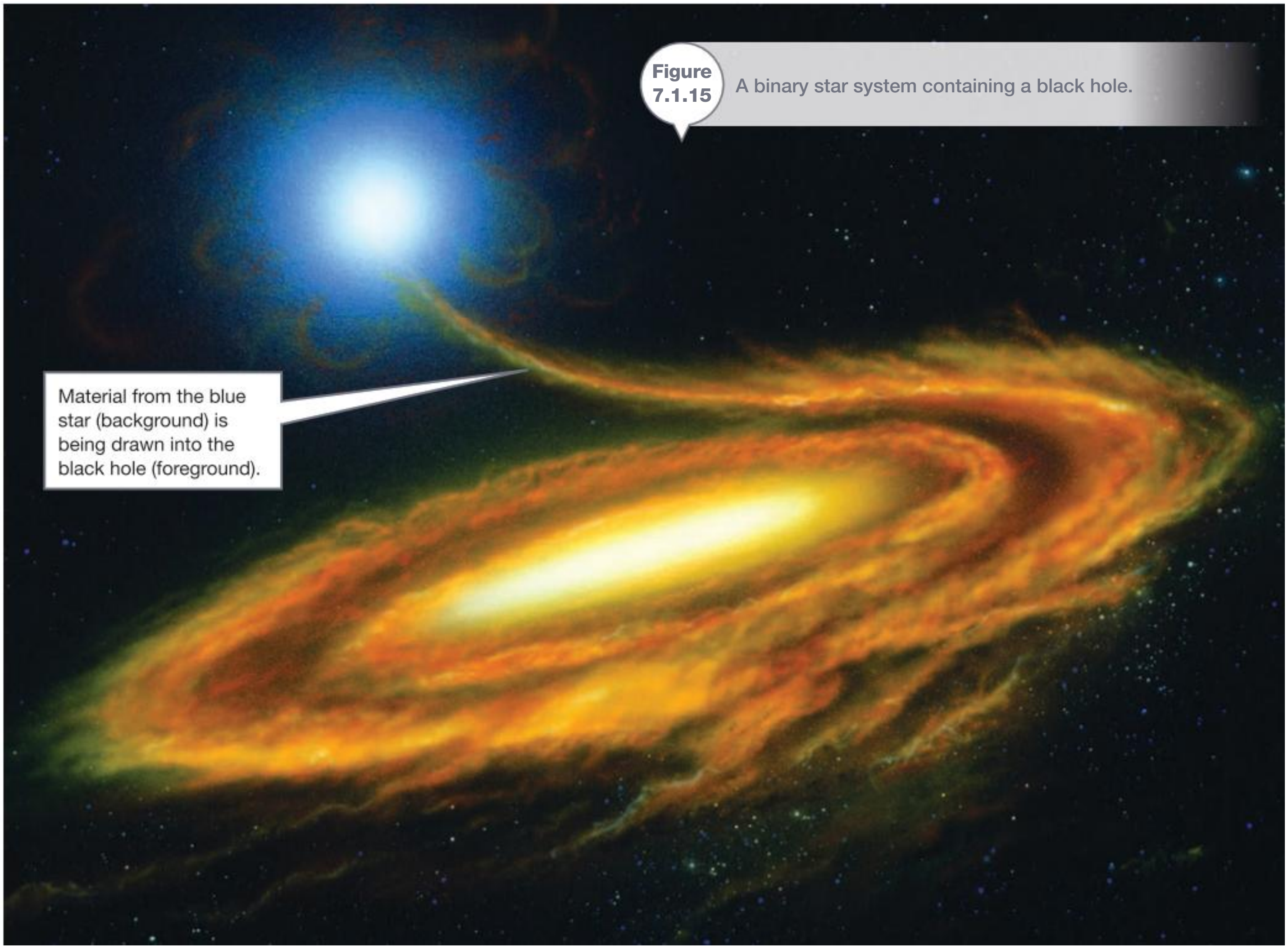


Figure 7.1.15 A binary star system containing a black hole.

gravitational field will start to strip material from the other star. As this material spirals into the black hole, it emits a distinctive high-energy X-ray signal, which indicates the presence of the black hole.

Another way to detect a black hole is by a process called **gravitational lensing**. According to Einstein's theory of relativity, the gravitational field around a black hole is so strong that it can actually distort the shape of space itself. This means that light from a distant star passing either side of the black hole can be bent back towards an observer on Earth. Due to this lensing effect, the observer sees identical stars on either side of the black hole (Figure 7.1.16).

Scientists now believe that most galaxies have an enormous black hole at their centre. These **supermassive black holes** may have masses equivalent to millions or billions of stars the size of our Sun. Evidence suggests that the black hole at the centre of the Milky Way galaxy lies in the constellation Sagittarius.

The initial size of a star is critical in determining its life cycle and the type of star it will eventually become. The various possibilities are summarised in Figure 7.1.17.

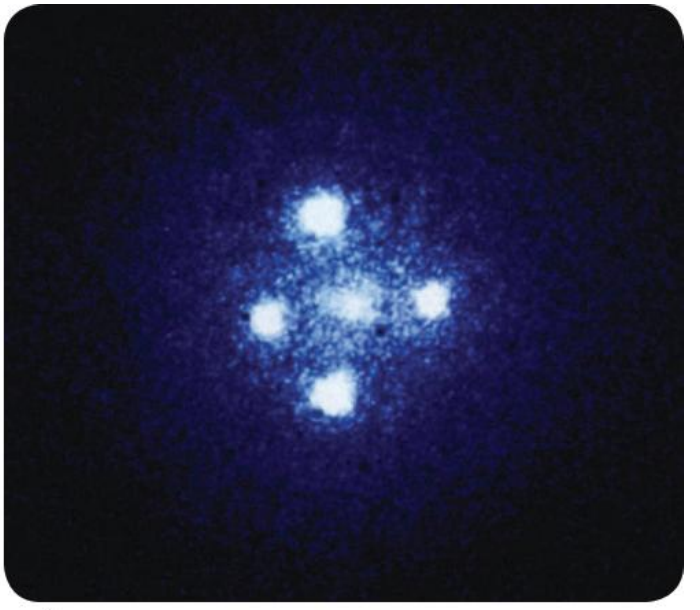


Figure 7.1.16 This image taken by the Hubble Space Telescope shows five different images of the same star. These images are caused by gravitational lensing.

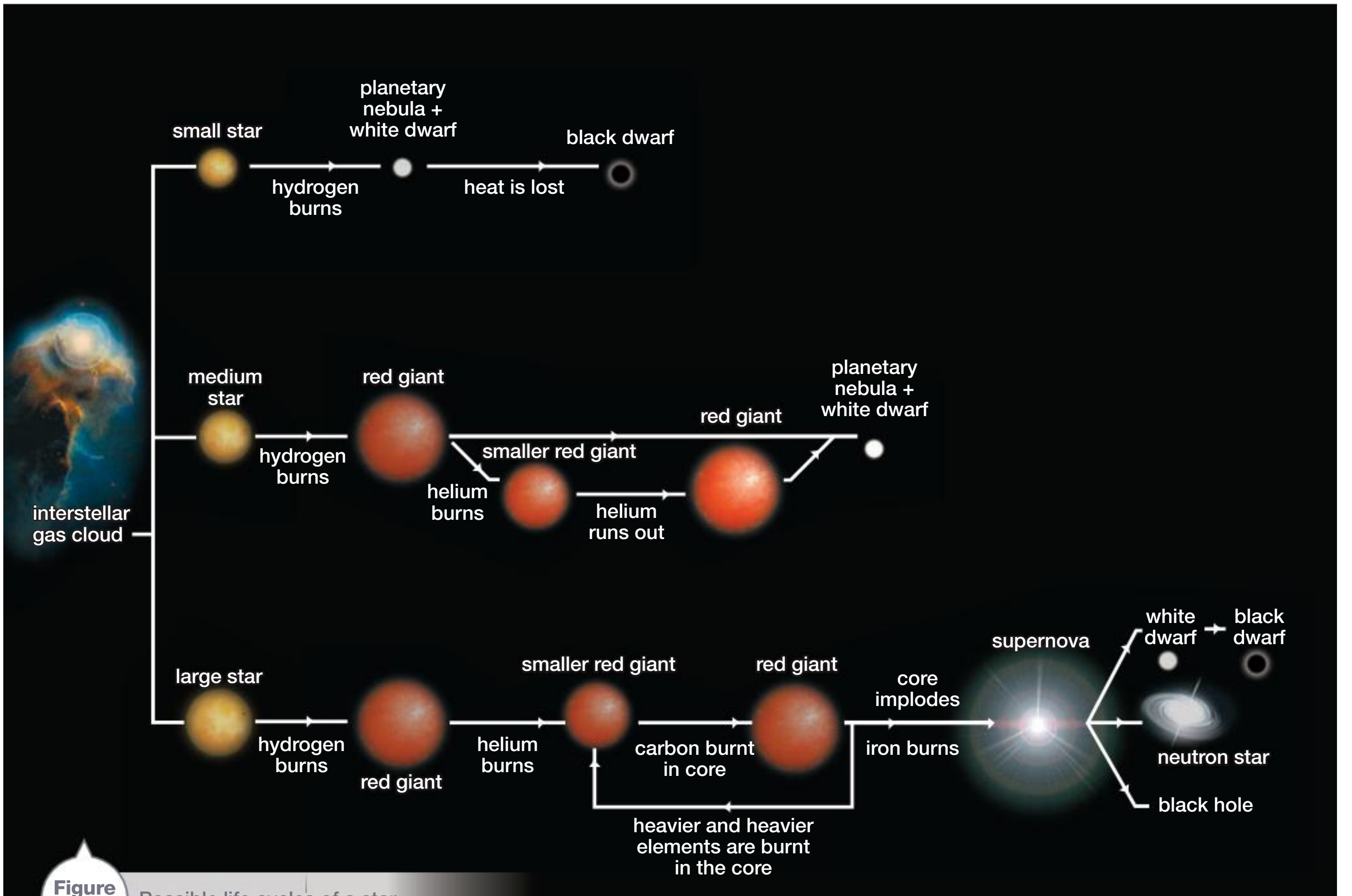


Figure 7.1.17 Possible life cycles of a star

SCIENCE AS A HUMAN ENDEAVOUR

Nature and development of science

Magellanic Clouds

Figure 7.1.18 Ferdinand Magellan, the Portuguese explorer after whom the Magellanic Clouds are named

In 1519, Ferdinand Magellan was sent by the king of Spain to make the first circumnavigation (trip around the circumference) of the world. He set out with 237 men and five ships. Three years later, just 18 men and one ship returned. While on his travels through the Philippines, Magellan had been killed in a battle with native tribes.

Fortunately for science, one of the survivors was Antonio Pigafetta, a scholar from Venice, who took detailed notes on the flora, fauna, geography and languages encountered on the trip. He also recorded the first Western observations of the astronomical objects now known as the Magellanic Clouds. These are two of the closest galaxies to the Milky Way (Figure 7.1.19).

However, this was not the first human observation of these cloud-like objects. In 964 CE, a Persian astronomer known as Al-Sufi observed the Large Magellanic Cloud and named it the White Ox.

Perhaps the earliest references to the Magellanic Clouds come from the myths (stories) of Australian Aborigines, who refer to the clouds as an old man and woman and as two 'lawmen' whose fire sent sparks into the sky to form the clouds.

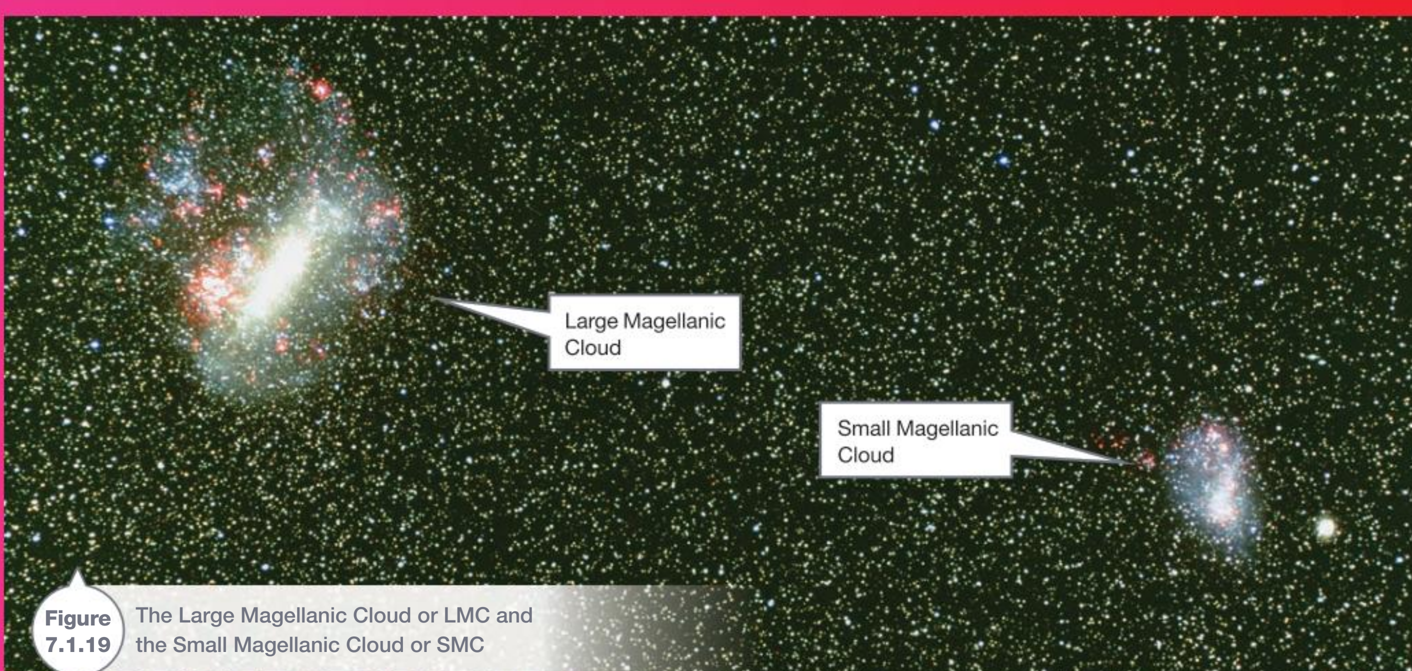


Figure 7.1.19 The Large Magellanic Cloud or LMC and the Small Magellanic Cloud or SMC

7.1 Unit review

Remembering

1 **Name** the type of nuclear reaction that produces energy stars.

2 **Recall** the type of star produced by the collapse of a star that is the same size as our Sun.

Understanding

3 a **Define** the term *spectral class*.
  b **Name** the device used to measure it.

4 The 'twins' of the constellation Gemini are the stars Castor and Pollux. **Explain** how these two stars can have almost identical apparent magnitudes when Castor (50 l.y.) is almost 1.5 times further away than Pollux (33 l.y.).

5 **Explain** why stars on the main sequence get brighter as they get bigger.

6 **Predict** what will happen to a star 15 times the size of our Sun when the hydrogen fuel in its core runs out.

Applying

7 a Betelgeuse is a star that is 640 light-years away. **Calculate** this distance in parsecs.
  b Bellatrix is 75 pc from Earth. **Calculate** this distance in light-years.

8 Rigel and Betelgeuse are the two brightest stars in the constellation Orion. Rigel has an apparent magnitude of 0.18 and an absolute magnitude of –6.8. Betelgeuse has an apparent magnitude of 0.6 and an absolute magnitude of –5.1.
  a **Identify** which of the two stars appears brighter.
  b **Identify** which of the two stars produces more light.

9 **Calculate** the density of:
  a the planet Jupiter, mass = 1.9×10^{27} kg, volume = 1.4×10^{24} m^3
  b the Sun, mass = 2.0×10^{30} kg, volume = 1.4×10^{27} m^3
  c a red giant, mass = 3.6×10^{31} kg, volume = 1.2×10^{36} m^3.

Analysing

10 **Contrast** the terms *absolute magnitude* and *apparent magnitude*.

11 Just as a year can be broken up into 365 days, a light-year can be broken up into 365 'light-days'. A light-year is 9.5×10^{12} km (9.5 million million kilometres).
  a **Calculate** the length of 1 light-day.
  b **Calculate** the length of:
    i 1 light-hour
    ii 1 light-minute.
  c Given that the Earth is, on average, 150 000 000 km from the Sun, **calculate** this distance as a value in light-minutes.
  d **Interpret** the answer to part c to give the time it takes for light from the Sun to reach Earth.

Evaluating

12 The term *supernova* literally means 'big, new star'. Modern astronomers now understand that supernovae are not 'new' stars but stars that have suddenly become much brighter, so this term is misleading. **Propose** a more scientifically accurate name for this type of star.

13 a **Critically analyse** the accuracy of the term *planetary nebula*.
  b **Propose** a more appropriate term.

Creating

14 **Construct** a physical model that shows how two stars that are a long way apart might appear close together when viewed from Earth.

15 **Construct** an instrument that uses parallax to accurately measure the distance to objects up to 100 metres away.

Inquiring

1 Design an investigation to test the instrument you constructed in Question 15.

2 Research methods other than stellar parallax that can be used to measure the distances to astronomical objects.

3 Research pulsars, stating how these are related to the types of stars discussed in this unit and why Australia is a leader into research on pulsars.

4 Use the internet to research and design your own spectrometer using an old CD.

7.1 Practical activities

1 Distances and parallax

Purpose

To measure the distance to an object by parallax.

Materials

- wooden metre ruler
- 10 m of string
- drawing pins
- protractor
- scissors
- tape measure

Procedure

1. Copy the table from the results section into your workbook.
2. Cut the piece of string into two equal lengths.
3. Pin one end of one piece of string to the 20 cm mark of the metre ruler. Pin the end of the other piece of string to the 80 cm mark of the metre ruler. This gives a measurement baseline of 60 cm (i.e. 80 cm – 20 cm).
4. Identify a distant object. A tree or wooden post would be ideal. Pin the free ends of both pieces of string to the object.
5. Face the object that the string is pinned to and walk backwards away from it, holding the ruler horizontally in front of you. Continue walking away until both strings are tight and form an isosceles triangle with the ruler (Figure 7.1.20).
6. Use the protractor to measure the angle formed between each string and the ruler. Ideally, the angle should be the same for each string. If the two angles are slightly different, take the average of the two. If there is a big difference, reposition yourself to make them closer. Record the values in your results table.
7. Calculate the distance to the object, d, using the formula:
   $d = \frac{1}{2}b\tan\theta$
   where b is the length of the baseline (i.e. 60 cm or 0.6 m) and θ is the parallax angle measured between the string and the ruler.
8. Change the length of the baseline by changing the positions of the pinned ends of the string on the ruler.
9. Repeat the measurement using this new baseline.
10. Repeat the measurements using a number of different baselines.
11. Measure the distance to the object directly using a tape measure.

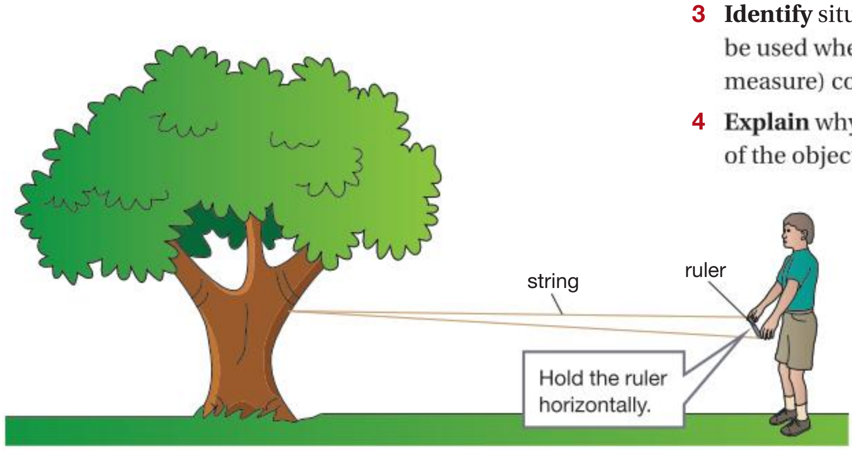


Figure 7.1.20

Results

1. Copy and complete the following table.
2. Calculate the distance to the object for each baseline.

Baseline, b (m)	Parallax angle, θ (°)			Distance to object, d (m)
	1	2	Average	
0.6				
Distance using tape measure				

Discussion

1. **Compare** distances measured by parallax with the distance measured with the tape measure.
2. **List** the advantages of using a longer baseline for parallax measurements.
3. **Identify** situations where parallax measurements could be used where direct measurements (such as with a tape measure) could not.
4. **Explain** why the formula $d = \frac{1}{2}b\tan\theta$ gives the distance of the object.

7.1 Practical activities

2 Using a spectrometer

Purpose

To compare the spectrum of light produced by different sources.

Materials

- spectrometer (spectroscope)
- light globe and coloured filters (a Hodgson's light box or similar would be suitable)
- fluorescent light tube
- coloured pencils

SAFETY

Never look directly at the Sun, whether using a spectroscope or not.

Procedure

1 Use a spectrometer to study the spectrum of light from a light globe. Sketch this spectrum.

2 Use a red filter to change the colour of the light. Observe and sketch this spectrum.

3 Use a blue filter to change the colour of the light. Observe and sketch this spectrum.

4 Use the spectrometer to study the spectrum of light from a fluorescent tube. Sketch the spectrum from the fluorescent tube, clearly showing the differences between it and the one produced by the light globe.

5 Looking through a window, observe and sketch the spectrum of light reflected off the ground or a building. (Do *not* point the spectrometer directly at the Sun!)

Discussion

1 **Identify** the differences in the spectrum observed for:
   a light seen through the red filter and light seen through the blue filter
   b sunlight and light from a fluorescent tube
   c light from a fluorescent tube and from an incandescent light globe.

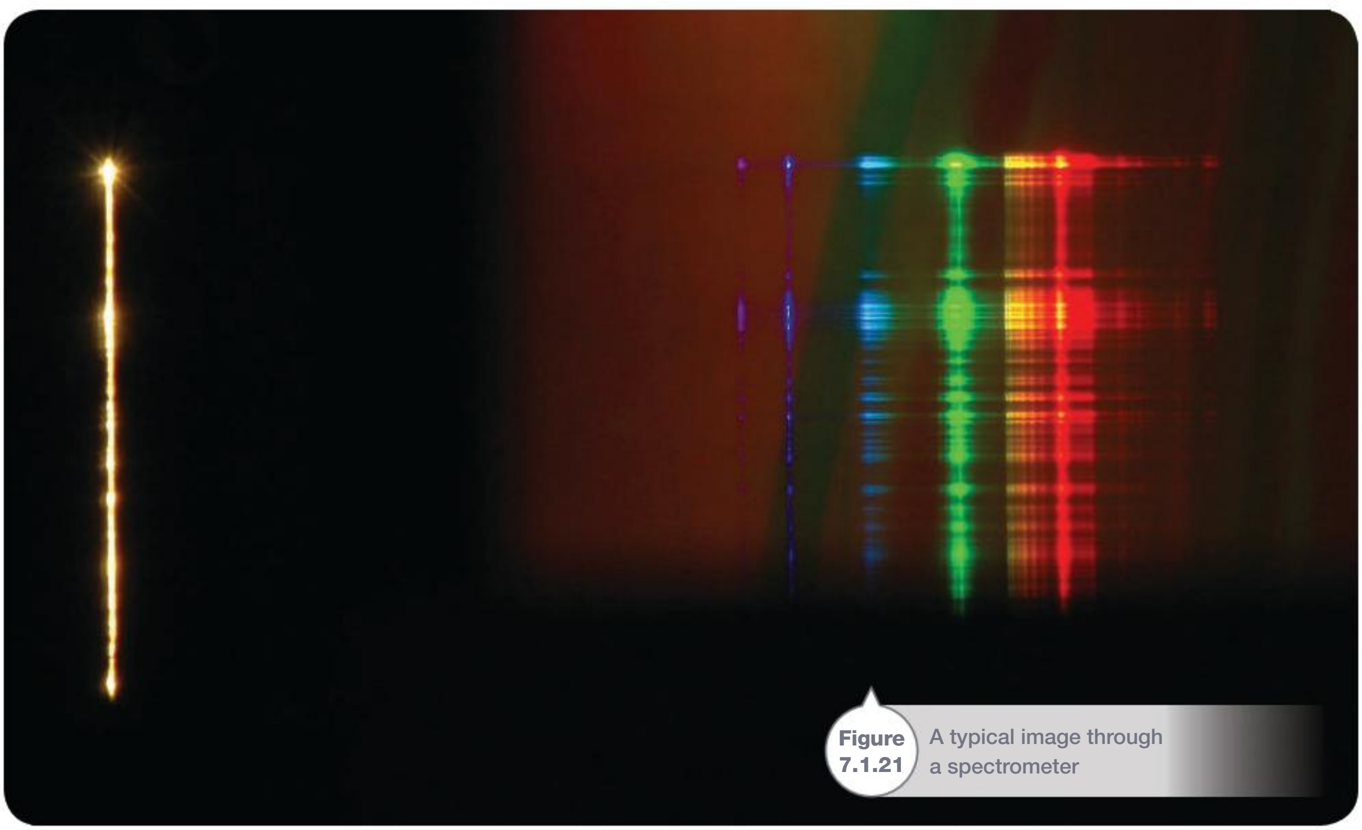


Figure 7.1.21 A typical image through a spectrometer

3 Modelling the collapse of a neutron star

Purpose

To model the change in density that occurs when a star collapses to form a neutron star.

Materials

- round balloon
- tape
- 2–3 metres of aluminium foil
- electronic balance
- metre rule
- pin

Procedure

1 Copy the table from the results section into your workbook.

2 Inflate the balloon to a diameter of about 15 cm. Tie the balloon so it remains inflated.

3 Cover the outside of the balloon with aluminium foil. Leave no gaps. Use tape to fix the foil to the balloon if necessary. This model represents the original star.

4 Measure the diameter of the model with the ruler. Halve this measurement to get the radius. Record this measurement in your table.

5 Measure the mass of the foil covered balloon with the electronic balance. Record this in your table.

6 Prick the balloon with a pin so that it bursts. Crumple the foil into a very loose ball. This model represents the star as it starts to collapse. Repeat steps 4 and 5 for this model.

7 Crush the foil into the smallest ball possible. This model represents the neutron star. Repeat the measurements for this model.

8 Calculate the volume and density of each model.
For a sphere, $V = \frac{4}{3}\pi r^3$ and density = $\frac{\text{mass}}{\text{volume}}$

Results

Copy and complete the following table.

Model	Mass (g)	Radius (cm)	Volume (cm^3)	Density (g/cm^3)
Original star				
Collapsing star				
Neutron star				

Discussion

1 **Discuss** the changes (if any) in the following quantities as the 'star' collapses:
- mass
- volume
- density.

2 **Assess** the ways in which this model is like a collapsing star.

3 Scientists estimate that a neutron star is 100 000 000 000 000 (i.e. 10^{14}) times more dense than the star that formed it. If you wanted to crush your model enough to make it 100 000 000 000 000 times more dense than the original model, **calculate** the volume and radius it would need to be.

7.2 Cosmology

Cosmology is the study of the entire universe, its origin and future. Many cultures and religions provide their own answers to the questions such as 'Where did the universe come from?' and 'How will the universe end?' The answers given by scientists must match observable evidence such as the composition and structure of the universe around us.

Galaxies

Our modern understanding of the structure of the universe began with the Ancient Greek philosopher Democritus. In the fourth century BCE, he suggested that the **Milky Way** could be made up of many distant stars. This idea was rejected by other philosophers of his time, who believed the Milky Way was an atmospheric phenomenon. It was not until the 17th century CE, when the astronomer Galileo Gallilei turned his newly invented telescope onto the Milky Way, that Democritus' theory was confirmed.

7.3

Astronomers now know that the Milky Way is just one of billions of galaxies in the observable universe. Some of the shapes galaxies can take are shown in Figure 7.2.1. This has caused scientists to dramatically reassess our understanding of the size of the universe. The Milky Way is estimated to contain between 200 and 400 billion stars and be about 100 000 light-years across. The Canis Major Dwarf galaxy is the closest galaxy to us and 25 000 light-years away from the Milky Way. Only four galaxies are closer than 2 million light-years away. Most galaxies are many millions of light-years away. Recent estimates put the number of observable galaxies at around 500 billion. This makes the universe unimaginably large.

Measuring distances to galaxies

The distances to other galaxies are far too big to be measured by parallax methods. One of the best techniques for measuring the distance to another galaxy uses a special type of star known as a Cepheid variable. A Cepheid is a type of star that has variable brightness—over a certain period of time, it changes from bright to dark and back to bright again (Figure 7.2.2). The period of this variation is directly related to the absolute magnitude of the star.

To measure the distance to another galaxy, an astronomer must first identify a Cepheid variable inside the galaxy. Then, by measuring the period of variation of the Cepheid, the absolute magnitude of the star can be determined. By comparing this to the star's apparent magnitude, the distance to the star (and the galaxy that contains it) can be calculated.

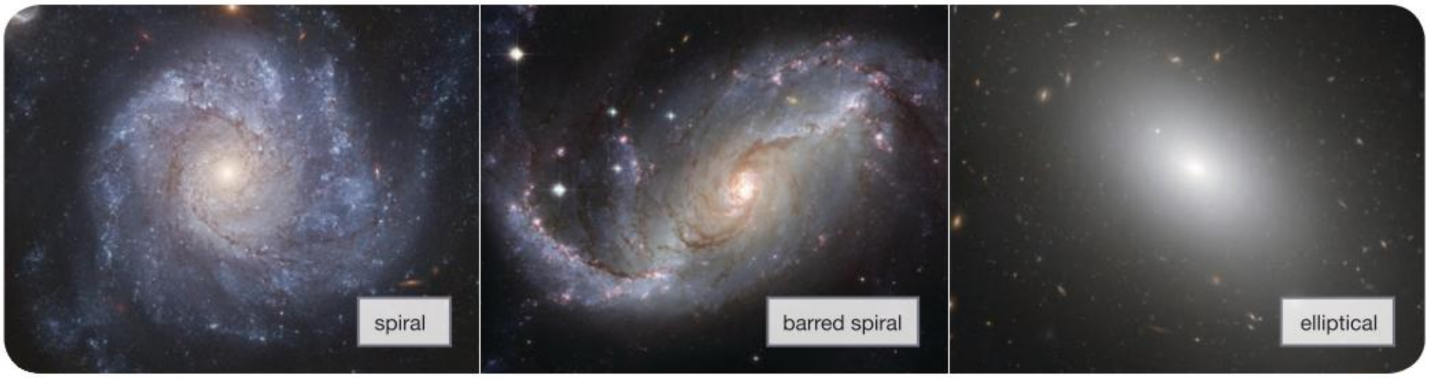


Figure 7.2.1 Galaxies can take various shapes including spiral, barred spiral and elliptical.

p236

Figure 7.2.2 This series of images shows the change in brightness of a Cepheid variable over a period of almost 40 days. (The variable star is in the centre of each frame.)

Steady state model

Fifty years ago, the most popular cosmological model was the **steady state** or infinite universe theory. This theory suggested that the universe is infinite in extent and has always existed in roughly the same form as observed today. This theory matches the fact that galaxies seem to be spread relatively evenly across the sky, as shown in Figure 7.2.3. This theory was expressed in its most complete form by English astrophysicist Sir Fred Hoyle in 1948 (Figure 7.2.4 on page 232). Although it enjoyed great favour through the 1950s and early 1960s, by the 1970s most scientists had rejected it.

Figure 7.2.3 Galaxies appear to be relatively evenly distributed throughout space. This was used as evidence of a steady state universe.

Big Bang

The term *Big Bang* was actually first used by Fred Hoyle, a key defender of the steady state theory. He meant it negatively, as term of ridicule, but the name caught the imagination of the public and has been linked closely with cosmology ever since.

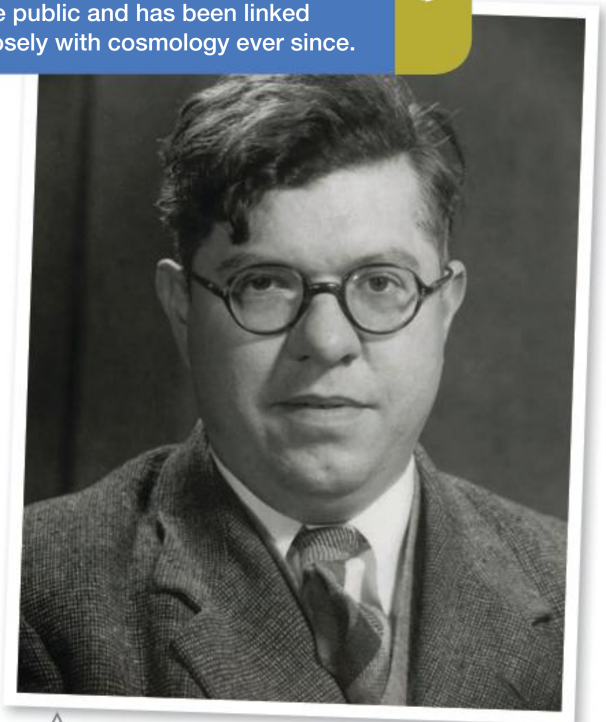


Figure 7.2.4 Astrophysicist Sir Fred Hoyle

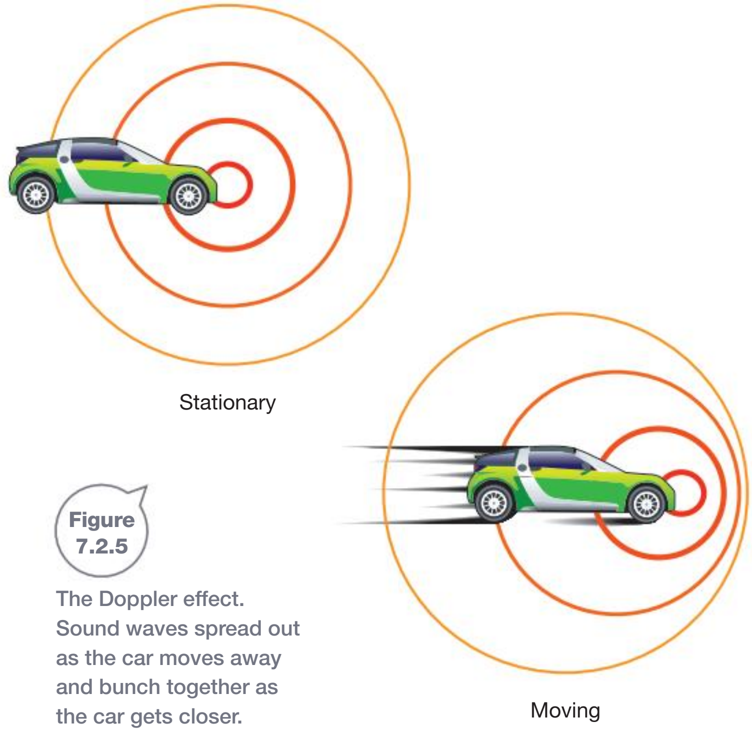


Figure 7.2.5 The Doppler effect. Sound waves spread out as the car moves away and bunch together as the car gets closer.

Cosmological red-shift

Cosmological red-shift is *not* caused by the Doppler effect since light waves do not travel through a medium as sound waves do through air. The expansion of the universe should not be visualised as stars expanding out into empty space. Instead, it is the space between stars that expands. It is the expansion of space itself that causes electromagnetic radiation to be stretched and, therefore, red-shifted.

Big Bang theory

Red-shift

The first evidence to undermine the steady state model was American astronomer Edwin Hubble's discovery that the universe is expanding. Hubble used Cepheid variables to measure the distance to a number of galaxies. He then carefully observed the spectrum of light from these galaxies and discovered that, in almost every case, it was distorted in a manner known as **red-shift**. This means that wavelengths of the light rays were all lengthened slightly, making the light appear redder than it should.

Red-shift is similar to a phenomenon known as the **Doppler effect**, in which waves produced by a moving source are either lengthened or shortened due to the motion of the source.

Consider the stationary car in Figure 7.2.5. As it is not moving, the sound waves produced by the engine extend out in all directions. Now consider the moving car. For an observer in front of the car, the sound waves produced by the engine will be compressed by the motion of the car. This means that the wavelength of the waves will be shorter than usual and the engine will sound as though it has a higher pitch. However, for an observer behind the car, the sound waves will be lengthened and the engine's pitch will sound lower and deeper.

A similar effect can be observed with light waves emitted by stars and nearby galaxies. Light from stars moving towards us will be compressed (**blue-shifted**). Light from stars moving away from us will be shifted towards the red end of the spectrum.

Hubble's measurement of the red-shift of light from distant galaxies contained two important observations:

- Almost all galaxies in the universe are moving away from the Milky Way galaxy.
- The further away a galaxy is, the more its light is red-shifted. This means that the more distant galaxies are moving away from the Milky Way faster than the closer galaxies are.

Taken together, these observations suggested that the universe is expanding.

This conclusion has important implications. If the universe is expanding, then it is reasonable to assume that at some point all the matter in the universe was condensed into one point. This represents the birth of the universe, the moment of an enormous explosion of energy now known as the 'Big Bang'.

7.4 | 2 p236

Einstein's big mistake

When Albert Einstein was working on his theory of general relativity, he realised that it suggested that the universe was expanding. He disliked the idea of an expanding universe so much that he added a 'cosmological constant' to his theory to ensure that it matched the steady state model. Einstein later described this as the 'biggest blunder' (mistake) of his life.

SciFile

Cosmic microwave background radiation

In 1965, two American astronomers, Arno Penzias and Robert Wilson, were trying to study radio signals from the Milky Way. They kept finding an annoying background signal coming from all directions in the sky that interfered with their measurements. By chance, they called a cosmologist, Bob Dicke, who realised that this background signal was the 'afterglow' of the Big Bang. It was radiation emitted approximately 400 000 years after the Big Bang.

This afterglow is now known as the **cosmic microwave background radiation**. You can see an image of the cosmic background radiation in Figure 7.2.6. It is consistent with predictions that radiation from the early universe should have been red-shifted into the microwave part of the spectrum by the expansion of the universe since the Big Bang.

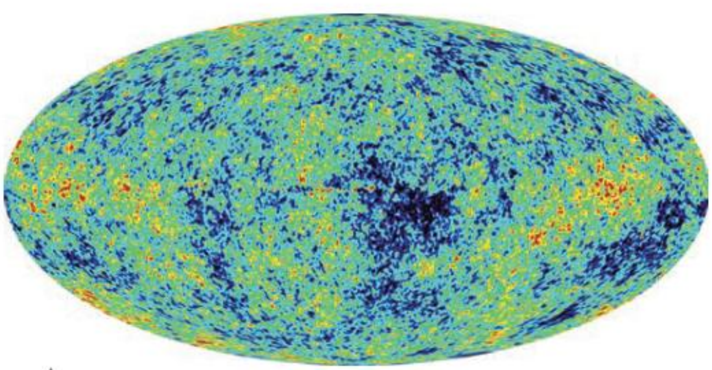


Figure 7.2.6 This image taken by the Wilkinson Microwave Anisotropy Probe (WMAP) maps the cosmic microwave background radiation. Different colours show slight variations in the temperature of the universe.

It was this discovery, in conjunction with Hubble's demonstration of the expansion of the universe, that convinced most scientists to accept the Big Bang model.

A brief history of the universe

Once the rate of expansion of the universe is accurately measured, it is possible to extrapolate back through time to the Big Bang. Astronomers currently estimate that the Big Bang occurred just under 14 billion years ago. They have also been able to suggest a rough outline of the history of the universe, as shown in Table 7.2.1 and Figure 7.2.7.

Table 7.2.1 History of the universe

Time from the Big Bang	Events
0	Big Bang—space and time come into existence along with all the energy that will ever exist. The universe undergoes a period of rapid inflation.
0.000 001 s	The universe expands and cools. Basic forces of nature come into existence. Protons, neutrons and electrons come into existence.
3 s	Protons and neutrons start to combine to form the nuclei of simple atoms—hydrogen (75%), helium (25%) and lithium (trace amounts).
10 000 years	The universe cools as high energy forms of electromagnetic radiation (X-rays and gamma) stretch into light and microwaves.
300 000 years	Electrons start to be captured by atomic nuclei to form simple atoms.
300 million years	Pockets of gas start to condense into the earliest stars and galaxies.
9 billion years	Our solar system begins to form.
13.7 billion years	Today's universe

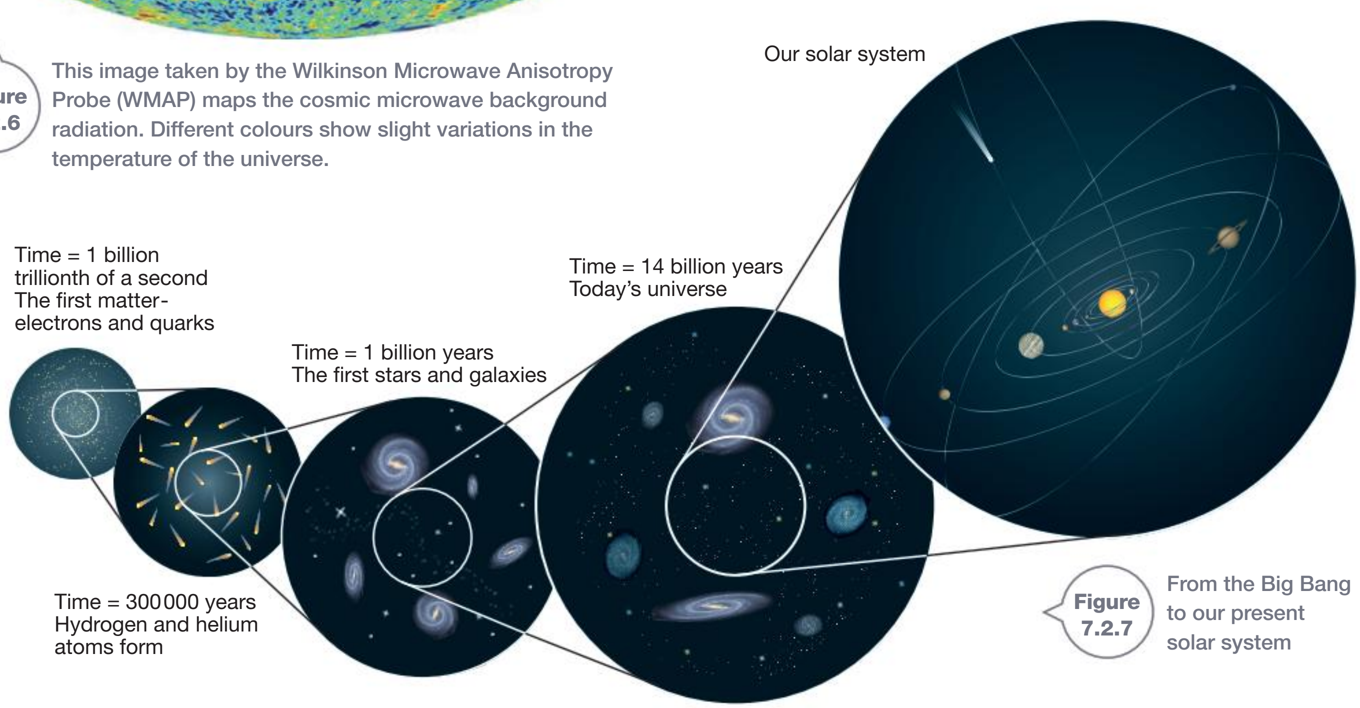


Figure 7.2.7 From the Big Bang to our present solar system

SCIENCE AS A

HUMAN ENDEAVOUR

Use and influence of science

The Large Hadron Collider

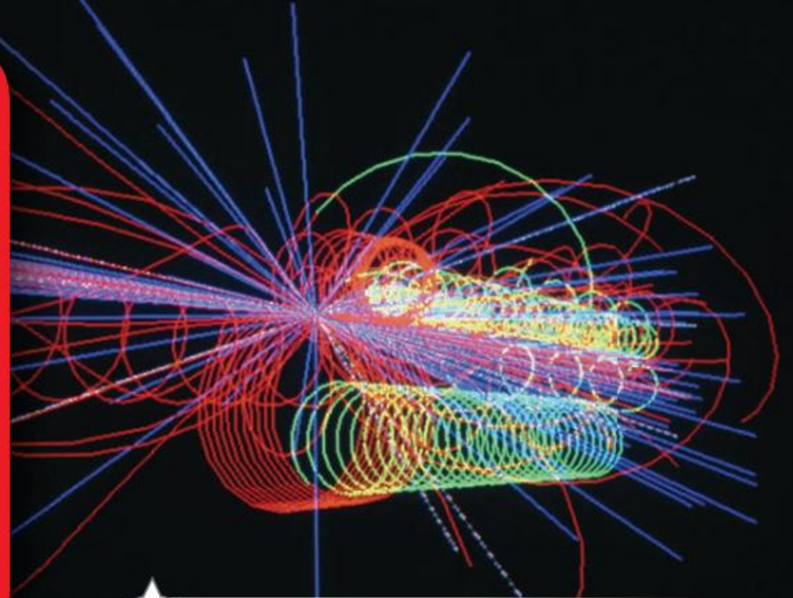


Figure 7.2.8 A computer simulation of a subparticle collision

One of the challenges faced by cosmologists is that many of the objects and processes they study are very different from those found in a standard laboratory. The conditions in the centre of a star or in the early moments of the Big Bang involve extremes of pressure and temperatures that are hard to physically recreate on Earth.

One way to explore the extraordinary conditions of the Big Bang on a microscopic scale is to use an instrument known as a particle accelerator. This takes tiny subatomic particles such as protons and electrons and uses magnetic fields to accelerate them to within 0.01% of the speed of light. Two beams of these particles can then be made to collide with each other (Figure 7.2.8). Scientists study the debris produced by these collisions, hoping to observe the sort of particles and interactions that might have occurred in the very early moments of the universe's existence.

Particle accelerators are also fundamental to scientists' pursuit of a grand unified theory, sometimes known as a 'theory of everything'. One of the great puzzles of science is that the theory used to explain the universe on the smallest scale (called *quantum mechanics*) and the theory used to explain the structure of the universe as a whole (*general relativity*) are very different and incompatible. Scientists hope that by studying the high-energy systems generated inside a particle accelerator, they can find a single mathematical model that will fit any situation, large or small.

By far the biggest particle accelerator ever built is the Large Hadron Collider or LHC (Figure 7.2.9). (Hadrons are the group of particles that include protons and neutrons.) Completed in 2008, it is not only one of the most complex scientific instruments ever constructed, but it is also one of the most significant examples of international scientific cooperation and collaboration.

The LHC consists of a ring-shaped tunnel 27 km long buried beneath the border between France and Switzerland. It has a staff of over 1800 scientists from 35 countries, including Australia. Collaboration is required at every stage of the LHC's operation, even to process the 1.7 million DVD of data it produces each year. Rather than try to process this on a single computer, the Worldwide LHC Computing Grid consists of a network of over 100 000 computers in 34 different countries.

A venture of this size and complexity could not operate without challenges. Shortly after the first beam was circulated on 10 September 2008, researchers were disappointed to discover a problem in two of the giant superconducting magnets that accelerate and guide the charged particles. It was over a year before the beams could be successfully circulated again. In the lead-up to the first particle collision there were also suggestions from some people that the high energies of the LHC might create a microscopic black hole that would eventually grow in size until it destroyed the Earth. These fears were shown to be incorrect when the first collisions took place on 30 March 2010.

7.5

Figure 7.2.9 A section of the Large Hadron Collider

7.2 Unit review

Remembering

1 **Name** the first person to suggest that the Milky Way was made up of stars.

2 **Name** the type of star used by Hubble to measure the distance to other galaxies.

3 **State** two pieces of evidence that support the Big Bang theory.

Understanding

4 **Define** the term *cosmology*.

5 a **Outline** the two main characteristics of Hubble's red-shift data.
  b **Explain** why these are significant.

6 **Describe** the cosmic microwave background radiation.

Applying

7 **Identify** an adjustment that was made to the steady state model of the universe to make it fit Hubble's observations.

8 The table below shows the distance to a number of galaxies and the speed at which each galaxy is moving away from us (i.e. recession velocity).

Galaxy	Distance (billions of light-years)	Recession velocity (× 1000 km/s)
A	4.50	114
B	1.80	46
C	2.40	61
D	1.10	28
E	0.85	22
F	3.30	84

  a **Use** the data in this table to draw a graph showing the relationship between distance and recession velocity.
  b **Identify** a mathematical relationship between distance and recession velocity.
  c **Use** the graph to **predict** the recession velocity of a galaxy 2.8 billion light-years away.
  d **Use** the graph to **determine** the distance of a galaxy if the red-shift of its light indicates it has a recession velocity of 13 000 km/s.

Analysing

9 **Contrast** red-shift with blue-shift.

10 **Contrast** the Big Bang theory with the steady state model of the universe.

11 Scientists define the *observable universe* as anything within 13.7 billion light-years of Earth. **Analyse** why it is impossible for us to observe anything further away than this.

Evaluating

12 Some scientists believe that in the distant future the universe may start to contract. **Propose** an observation that scientists could make that would indicate that this has started to occur.

13 The Magellanic Clouds are not widely visible in the northern hemisphere. **Assess** whether or not you think European astronomers would have developed the idea of galaxies outside the Milky Way if they had been able to see the Magellanic Clouds.

Creating

14 **Construct** a diagram to show how the motion of a star produces red-shift.

15 **Use** information provided in this chapter to **construct** a timeline showing the history of the universe up until today. Carefully consider what scale should be used to meaningfully show each important event.

Inquiring

1 Research the work done at Australia's only particle accelerator, the Australian Synchrotron.

2 Research the following cosmological concepts.
  a the multiverse
  b the anthropic principle
  c string theory
  d dark matter
  e heat death
  f big crunch

7.2 Practical activities

1 Classifying galaxies

Purpose
To develop a system for classifying galaxies on the basis of their shape.

Materials
- astronomy reference book or internet
- paper
- pencil
- cardboard
- tape

Procedure
1. Search for pictures of at least eight different galaxies including the Milky Way, Andromeda, Large Magellanic Cloud and Small Magellanic Cloud.
2. Sketch or print out the image of each galaxy on a small sheet of paper. Write the name of the galaxy on the back of the piece of paper.
3. Arrange the images into three or four groups according to their shape. Think of a name that describes the shape of each group.
4. Stick all the images from one group of galaxies onto a piece of cardboard to create a poster. Write the name of the group on the poster.
5. Repeat step 4 for each group of galaxies.
6. Copy a table like that shown in the results section to summarise your results.

Results
Copy and complete the following table or construct a similar one.

Shape	Distinctive features	Examples

Discussion
1. Scientists classify galaxies into the following groups: spiral, barred spiral, elliptical and irregular. **Discuss** how your groups compare with these, and then **classify** the galaxies in this investigation into the scientific groups.
2. **Identify** the advantages and disadvantages of each system of classification.

2 An expanding universe

Purpose
To model the expanding universe.

Materials
- balloon
- felt-tip pen
- ruler or measuring tape

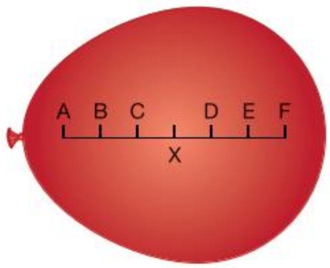


Figure 7.2.10 A balloon can be used to model the expansion of the universe.

Procedure
1. Copy the table from the results section into your workbook.
2. Partially inflate a round balloon. Mark seven points in a line, each 1 cm apart. Each point represents a galaxy. Label the points as shown in Figure 7.2.10.
3. Inflate the balloon to its maximum size. Measure the distance between the central galaxy X and each of the other galaxies.

Results
Copy and complete the following table.

Galaxy	Initial distance from galaxy X (cm)	Final distance from galaxy X (cm)	Change in distance (cm)
A	3		
B	2		
C	1		
D	1		
E	2		
F	3		

Discussion
1. **Construct** a graph of change in distance against initial distance.
2. **Compare** this with Hubble's data on stellar red-shift.

7.3 Earth and life

While cosmology deals primarily with the structure of the universe as a whole, science also has much to tell us about things much closer to home—the formation of our own solar system, the planet we live on and the origin of life itself.

Formation of the solar system

About 4.5 billion years ago, the region of space now occupied by the solar system was filled with a featureless cloud of gas. Most of this gas was hydrogen, with small amounts of helium and heavier elements such as carbon and iron. The existence of these heavy elements mean that at least one supernova must have exploded in this region of space sometime in the previous 9 billion years.

No one knows for certain what started the formation of the solar system. Some scientists believe it may have simply been due to the slow pull of gravitational forces acting over enormous periods of time. Others suggest that the shock wave from a nearby supernova triggered the cloud of gas to start to gather into a large clump known as a **protostar**. This protostar would eventually become our Sun. Material that was too far away from the Sun to be drawn into it clumped together to form the **planets**. Figure 7.3.1 on page 238 shows four stages of the formation of the solar system.

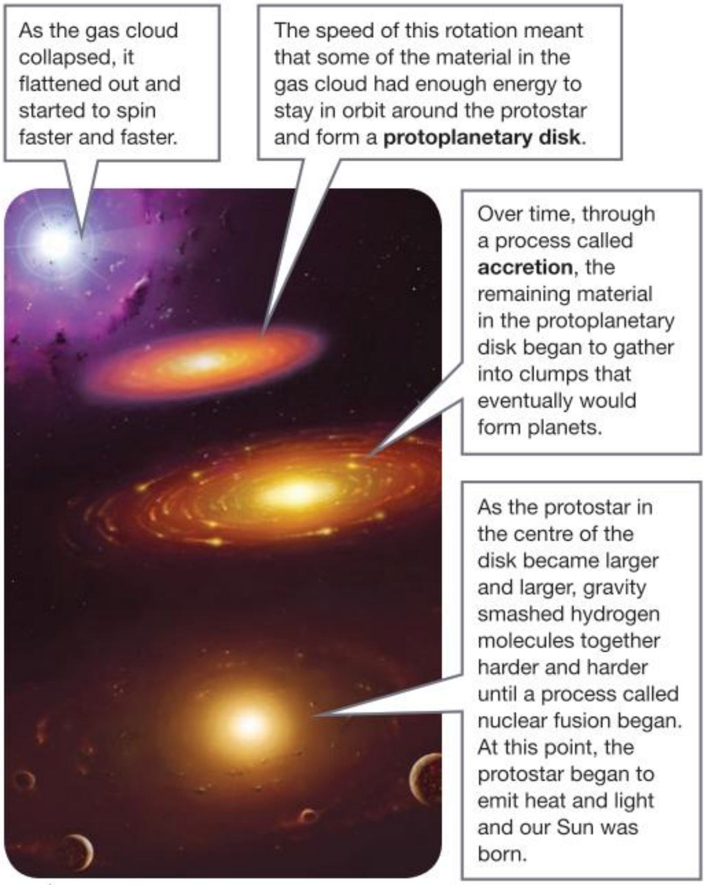


Figure 7.3.1 How the solar system is thought to have formed

Structure of the planets

The planets of the solar system formed as gravity pulled material together into clumps. The planets can be roughly split into two categories:

- **terrestrial (rocky) planets**: Mercury, Venus, Earth and Mars. These are made from the heavier elements that gathered close to the Sun
- **gas giants**: Jupiter, Saturn, Uranus and Neptune. These are made from the elements that were light enough to stay well clear of the Sun.

Since each planet formed through a similar process, their basic structures are the same, even if their composite materials differ greatly.

The work of gravity did not finish once material had been gathered together to form a planet. Over time, gravity continued to pull heavier elements towards the centre of each planet, forming a dense core. This core is surrounded by a number of layers consisting of less dense material. Earth and Jupiter are typical of the rest of the planets in their categories.

Figure 7.3.2 shows that the core of planet Earth is made of a ball of solid iron surrounded by a layer of liquid iron. Around this lies the mantle of lighter silicon-based rocks. The crust is made of rocks containing even lighter elements such as sodium, aluminium and magnesium.

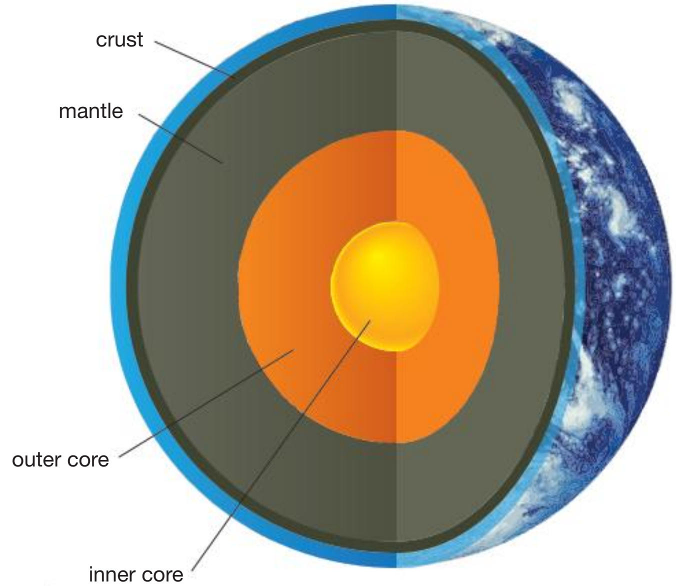


Figure 7.3.2 Internal structure of Earth

While scientists have gained some information about the structure of the Earth directly from volcanoes and deep mineshafts, most of it has been gathered indirectly from studies of earthquakes and the Earth's magnetic and gravitational fields.

When an earthquake occurs, the energy from it radiates outwards in all directions as a series of **seismic waves**. This means that the same earthquake can be felt at various points around the Earth at different times. Seismologists (scientists who study earthquakes) have discovered that seismic waves do not travel directly through the Earth but are reflected and refracted as they go from one internal layer to the next. Careful study of seismic waves has allowed the thickness and composition of layers deep within the Earth to be deduced.

The shape and nature of the Earth's magnetic field also provides clues to its internal structure. Although the way in which the Earth's magnetic field is generated is not yet fully understood, its existence suggests that there must be large quantities of iron-rich material moving around in the mantle and inner core.

On a smaller scale, gravitational field studies can point to variations in the density of the Earth's crust at various points.

When studying the structure of other planets in the solar system, astronomers can observe magnetic and gravitational fields when spacecraft fly past them. Photographs of surface structures can provide evidence of past (or in some cases ongoing) geological activity.

Jupiter is mainly composed of gas but has a rocky core surrounded by a layer of hydrogen in a metallic form. As shown in Figure 7.3.3, this is surrounded by a layer of liquid hydrogen and helium and then an atmosphere of gaseous hydrogen and helium.

1 p243 7.6

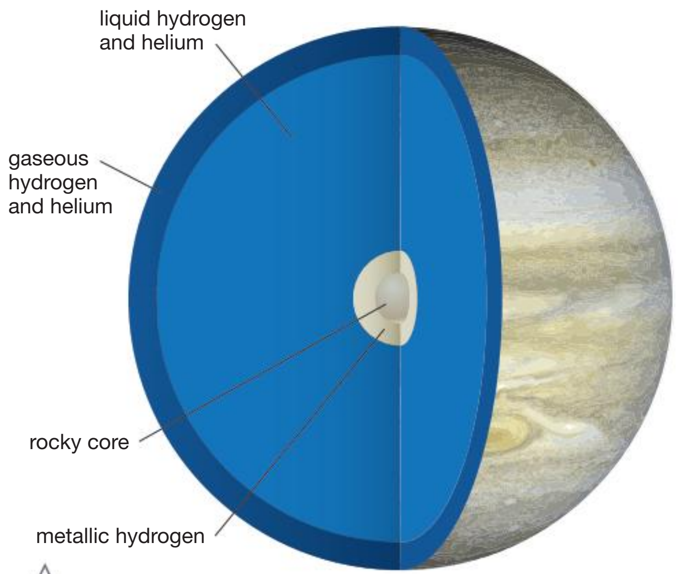


Figure 7.3.3 Internal structure of Jupiter

The Moon

Moons are natural satellites that revolve (travel in an orbit) around planets. In our solar system, all planets except Mercury and Venus have at least one moon. For example, Jupiter has 28 moons, Neptune has eight and Mars has two. Earth's single moon (the Moon) is unusual for three reasons:

- It is relatively large compared to the size of the planet it orbits. The Moon is almost one-quarter the diameter of Earth and is the fifth largest moon in the solar system. The only moons that are bigger are Io, Ganymede and Callisto (moons of Jupiter) and Titan (Saturn's largest moon). Each of these moons is tiny in comparison with the planet it orbits.
- The Moon is a lot less dense than most other rocky moons or planets in the solar system. Scientists believe that this is because it does not have an iron core.
- Samples of rock taken from the Moon landings show that lunar rocks are very similar in chemical composition to rocks found on Earth.

All of these factors suggest that Earth's moon formed in a unique way. The most popular current theory is the giant impact hypothesis. According to this theory Earth was struck by a huge Mars-size planet called Theia around 500 million years ago (Figure 7.3.4). During the impact, large amounts of the Earth's mantle (or outer layer) were thrown into space to form the Moon. The iron core of Theia then sank into the Earth and became part of the Earth's core. This theory explains the Moon's size, why it is made of similar material to Earth and does not have an iron core.

How did life begin on Earth?

One of the great mysteries of Earth's geological and biological history is how living organisms could develop on a lifeless planet. Living organisms are predominantly made of the chemical elements carbon, hydrogen and oxygen. These elements are commonly found in rocks too but in much simpler arrangements than in living things. Some people see this as evidence of the action of a supernatural creator. However, scientists must search for answers based on physical, testable evidence.

The 'creative spark'

An important example of the search for a scientific explanation for the origin of life is the work of Harold Urey and Stanley Miller.

In the 1950s, these two American scientists tackled the problem of **abiogenesis** (the formation of life from inanimate materials) by testing to see if **organic compounds** could be formed from a mixture of gases that matched the composition of the Earth's original atmosphere.

Their apparatus consisted of two flasks. One flask contained water to simulate the oceans that covered much of the Earth. The other flask containing a mixture of hydrogen, methane and ammonia to simulate the expected composition of Earth's atmosphere at the time. You can see the set-up of this apparatus in Figure 7.3.5 on page 240.The flask containing the gases also held a pair of electrodes that could be hooked up to a high voltage source to produce sparks to simulate lightning. Over time, the experiment produced a tar-like material that, when analysed, was shown to contain a number of different

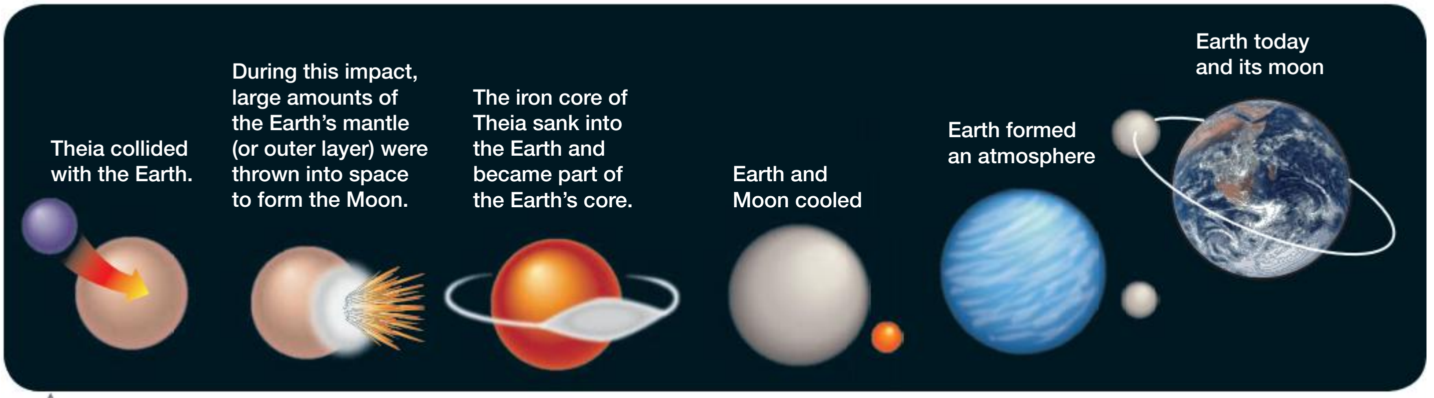


Figure 7.3.4 The Earth's Moon may have formed as a result of a collision between two planets 500 million years ago.

amino acids. These compounds are the basic building blocks of **proteins**, which, in turn, are the building blocks of DNA, the self-replicating chemical compound that is found in every living cell.

Urey and Miller's experiment demonstrated that organic compounds could be formed from inorganic material through random processes.

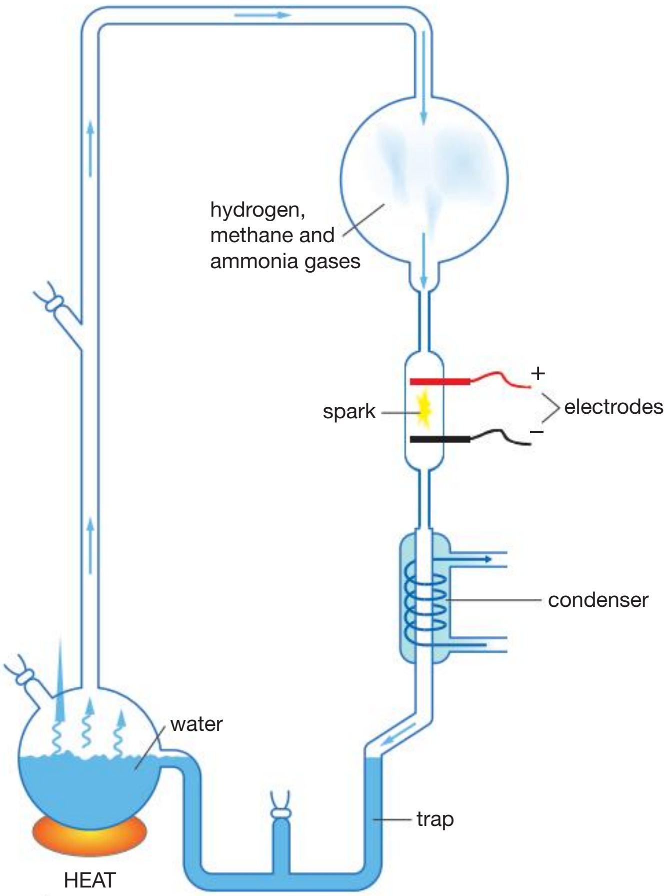


Figure 7.3.5 Apparatus for the Miller–Urey experiment

The seeds of life

Geological evidence suggests that the first living organisms developed just a few 100 million years after the Earth formed. For some scientists, this does not seem long enough for the processes suggested by the Miller–Urey experiment to produce life. They suggest that life did not begin on Earth at all, but rather came to Earth in the form of micro-organisms trapped inside a comet or meteorite. This theory, known as **panspermia**, has gained more support since the discovery of a group of organisms known as tardigrades. Tardigrades (sometimes known as water bears) are microscopic organisms that are extremely resilient and are even able to survive the vacuum of space. Tardigrades are shown in Figure 7.3.6.

Figure 7.3.6 A tardigrade, also known as a 'water bear', is a microscopic organism that can survive in space.

Panspermia has also been supported by the discovery of organic compounds in space. Scientists have detected amino acids in the tails of comets and an important group of organic compounds called polycyclic aromatic hydrocarbons (PAHs) have been discovered in the gases floating in interstellar space. Some of these interstellar gases are shown in Figure 7.3.7.

Figure 7.3.7 This spectacular image shows a region in the constellation Orion in which new stars are being formed. The different colours indicate the presence of different gases, e.g. green indicates hydrogen and sulfur. The orange and red sections indicate the presence of polycyclic aromatic hydrocarbons.

SciFile

PAHs on Earth

Two examples of substances on Earth that contain polycyclic aromatic hydrocarbons (PAHs) are caffeine and chocolate. Perhaps if life exists in other parts of the universe, it shares the human weakness for junk food!

The study of life in parts of the universe other than Earth is known as **astrobiology**. If astrobiologists are successful and living organisms are one day discovered on another planet in the solar system, then these organisms can be investigated to find how closely related they are to those living on Earth. This will allow panspermia and a number of other theories about the origin of life on our planet to be tested.

The Earth—perfectly suited to life

However life began on this planet, Earth seems to have a number of characteristics that make it ideal for living things to survive and prosper.

- Earth's orbit around the Sun places it in the 'habitable zone'—close enough to keep water as a liquid over most of the planet and make photosynthesis efficient, but far enough away from the Sun to keep temperatures within a livable range.
- The ocean tides created by the Moon and Sun created conditions that allowed early water-based life-forms to gradually adjust to living on dry land. It also helped the development of nocturnal species of animals by providing a significant amount of light at night.
- At a number of points in history, meteorite strikes and other dramatic geological events have killed most of the species living on Earth. While this would seem to be a bad thing for life, it also provided the opportunity for different species to develop. For example, the mass extinction of the dinosaurs 65 million years ago allowed warm-blooded mammals (such as humans) to thrive.

2 p244

The atmosphere

Over the last 4 billion years, living organisms have profoundly changed and shaped the face of the Earth. One of the places where this is most evident is in the Earth's atmosphere.

Early atmosphere

The Earth's early atmosphere came primarily from two sources—volcanic eruptions and comet impacts. In terms of the development of life, comet impacts were particularly important as they provided most of the water. By about 3.8 billion years ago, the Earth was covered with oceans and surrounded by an atmosphere consisting mainly of water vapour, carbon dioxide and nitrogen. Any oxygen that was present would have been bound up with hydrogen in water or mineral oxides on the surface.

Oxygen

Around 3 billion years ago, a crucial development occurred. A group of single-celled organisms known as **cyanobacteria** developed the ability to capture sunlight and use it to combine carbon dioxide with water to form **hydrocarbon** compounds and oxygen. Several cyanobacteria are shown in Figure 7.3.8. This process was an early version of photosynthesis.

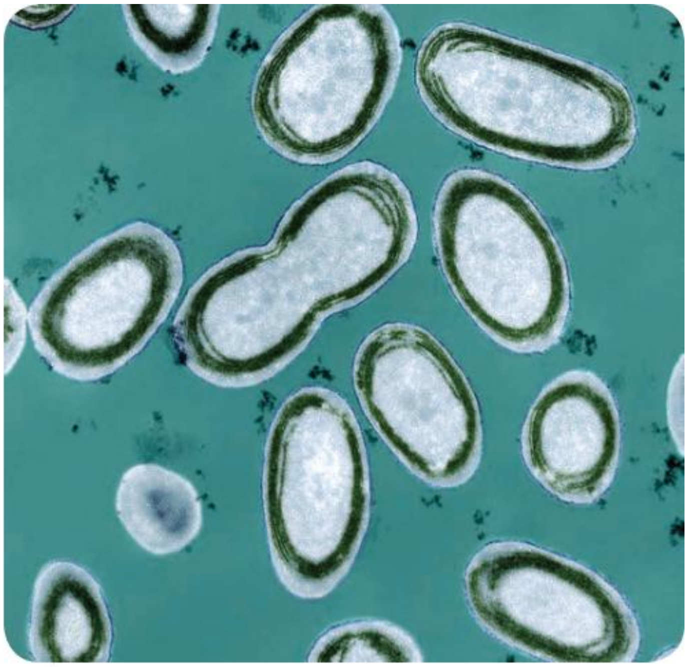


Figure 7.3.8 Tiny bacteria like these cyanobacteria transformed the Earth by producing oxygen.

Strangely, it took over half a billion years before the oxygen being produced by these bacteria started to be observed as atmospheric oxygen. Scientists argue about the reason for this lag between the start of photosynthesis and the appearance of oxygen in the atmosphere. One popular theory suggests that oxygen reacted chemically with elements in the Earth's crust to form oxides. This went on for hundreds of millions of years until, around 2.4 billion years ago, all of the reactive minerals on the Earth's surface were used up and oxygen started to collect in the atmosphere. This sudden change in the composition of the atmosphere is known as the great oxygenation event. Evidence for it can be seen in the banded iron formations that are common in rocks formed at this time like those in Figure 7.3.9.

Figure 7.3.9 Banded iron formations from the Central Pilbara in Western Australia. The red bands are oxygen-rich rocks formed between 2.5 billion and 1.8 billion years ago when oxygen became available in the atmosphere.

7.3 Unit review

Remembering

1 **List** the stages in the development of the solar system from a cloud of gas.

2 **List** ways in which the Earth's moon is different from other moons in the solar system.

Understanding

3 **Define** the following terms.
   a abiogenesis
   b panspermia

4 **Outline** the conditions that make Earth suitable for life.

5 **Explain** how scientists have developed a model of the internal structure of the Earth, even though the deepest mineshafts have only drilled a few kilometres below Earth's surface.

6 **Explain** how the different parts of the Miller–Urey experiment modelled the conditions that existed on Earth just after it formed.

Applying

7 **Demonstrate** how the giant impact hypothesis explains the unusual characteristics of the Earth's moon.

8 **Identify** ways in which comet and meteorite strikes have helped the development of life on Earth.

Analysing

9 **Discuss** the role that the Moon may have played in creating an environment suitable for the development of life on Earth.

10 **Compare** a protostar and a star.

11 **Compare** the internal structure of a rocky planet such as Earth to a gas giant such as Jupiter.

Evaluating

12 **Assess** whether or not the Miller–Urey experiment is conclusive proof that abiogenesis can occur.

13 **Propose** reasons why life is highly unlikely to be found on:
   a Venus, the second planet from the Sun with a dry, rocky surface and a crushing acidic atmosphere
   b Neptune, the furthest planet from the Sun, with a gaseous methane surface and atmosphere.

14 a **Assess** why scientists are interested in finding life on planets other than Earth.
   b Develop arguments to **justify** continuing this research.

Creating

15 **Construct** a timeline showing the major events that shaped the Earth's atmosphere over the last 4 billion years.

Inquiring

1 Tardigrades are one of a group of organisms known as extremophiles because they can survive under extreme conditions. Research different types of extremophiles. For each, identify the extreme conditions under which it can live.

2 Spirogyra is a type of green algae. It is commonly known as pond scum. Design and conduct an experiment investigating whether freezing spirogyra affects its cells.

3 The history of life on Earth has been marked by a number of mass extinction events. Research these and construct a table listing:
   - when they occurred
   - which groups of organisms became extinct
   - possible causes for the event.

4 Research SETI (the Search for Extra-Terrestrial Intelligence), discussing the methods used, such as radio telescopes (Figure 7.3.10), why these are used and the opinions on how likely it is that life will be discovered.

Figure 7.3.10

7.3 Practical activities

1 Average density of the Earth

Purpose

To measure the average density of the Earth.

Materials

- measuring cylinder
- balance
- samples of igneous rock (such as granite, basalt)
- pieces of iron and nickel
- calculator
- displacement can
- small beaker

Procedure

1. Copy the table from the results section into your workbook.
2. Measure the mass of each sample, and record this in your table.
3. Measure the volume of each sample using the displacement can.
   - a Fill the displacement can with water until water flows out of it.
   - b Place the small beaker under the spout of the displacement can.
   - c Place the sample into the displacement can and collect the water that overflows in the small beaker.
   - d Transfer the water from the beaker to the measuring cylinder. The amount of water displaced is equal to the volume of the sample.
4. Calculate the density of each of the samples. (Remember: density = $\frac{\text{mass}}{\text{volume}}$)

Results

Copy and complete the following table.

Material	Mass (g)	Volume (cm^3)	Density (g/cm^3)
Iron			
Nickel			
Granite			
Basalt			
			Average density =

Discussion

1. **Compare** the densities of nickel and iron with those of granite and basalt.
2. The Earth's core is made primarily of iron and nickel. Igneous rocks like basalt and granite are formed when material from the mantle makes its way onto the surface of the Earth. Use the results of this experiment to **predict** which will be denser—the core or the mantle.
3. Geologists have measured the Earth's density as around 5.5 g/cm^3. **Compare** the density figure with the average density you calculated in this experiment.
4. By averaging the densities as shown in your table, this experiment assumes that the core and mantle of the Earth are roughly the same size. **Critically analyse** this assumption.

2 Effect of temperature on life

Purpose

To investigate the effect of temperature on the respiration rate of yeast.

Materials

- 4 small zip-lock bags
- 20 g of yeast
- 40 g of sucrose
- 50 mL measuring cylinder
- thermometer
- water at a variety of temperatures, such as ice water, room temperature, hot tap water (around 40°C) and water from a hot water bath (around 60°C)
- wooden tongs

SAFETY

Be careful handling hot water.

Do not taste or eat yeast.

Wash your hands thoroughly with soap and water after the activity.

Procedure

1. Put 10 g of sugar and 5 g of yeast into each of the four zip-lock bags, as shown in Figure 7.3.11.
2. Pour 10 mL of ice water into one of the zip-lock bags and quickly seal it. The bag should fill with gas.
3. Repeat step 2 for each different temperature of water.
4. Look at and compare the sizes of the bags.

Discussion

1. **Identify** the bag in which the most gas was produced and the bag in which the least gas was produced.
2. **Identify** a relationship between temperature and the amount of gas produced.
3. Yeast is a microscopic fungus. The gas produced in this experiment is carbon dioxide from the respiration reaction as the yeast consumes the sugar. **Use** the results of this experiment to **predict** the effect of extremes of temperature on living organisms.
4. **Design** a way of doing the experiment using different equipment so that you can measure the volume of gas produced.

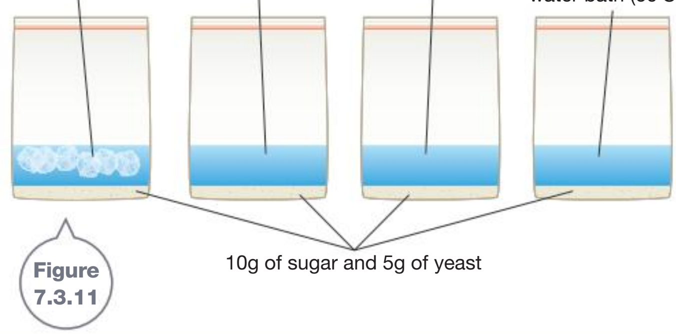


Figure 7.3.11

Chapter review 7

Remembering

1 **State** the equation for the fusion reaction that forms deuterium in stars.

2 **Recall** the size of a star (compared with the mass of the Sun) that produces a supernova.

3 **List** two methods that can be used to locate a black hole.

4 **Name** the scientist whose work on stellar red-shift provided the first evidence for the expansion of the universe.

Understanding

5 **Explain** why the ability of tardigrades to survive in space supports the theory of panspermia.

6 **Recount** the stages in the life cycle of a Sun-sized star from its beginning as a cloud of interstellar gas through to its end.

7 **Outline** how the Earth's moon was formed according to the giant impact hypothesis.

Applying

8 **Identify** evidence for the great oxygenation event.

9 Aldebaran is a star that is 65 light-years away. **Calculate** this distance in parsecs.

10 The 'twin' stars of the constellation Gemini are named Castor and Pollux.

- a Castor and Pollux have apparent magnitudes of 1.96 and 1.15 respectively. **Identify** which star appears brighter.
- b Castor and Pollux have absolute magnitudes of 1.33 and 1.09 respectively. **Identify** which star produces more light.

11 **Identify** why scientists do not use parallax to measure the distances to other galaxies.

12 The Moon has a mass of 7.3×10^{22} kg and a volume of 2.2×10^{19} m^3. **Calculate** its density.

Analysing

13 **Compare** your answer for Question 11 with the average density of Earth, 5500 kg/m^3. Explain the difference, referring to the giant impact hypothesis.

14 **Discuss** why the apparent brightness of a star is not necessarily a good indication of how much light the star produces.

15 a **Discuss** whether or not a parallax method could be used to measure the distance between the Earth and other planets in the solar system.

- b **Identify** any problems that would be associated with this.

16 **Contrast** a black dwarf with a black hole.

Evaluating

17 Science fiction writers have proposed that a black hole might act as a gateway to another galaxy. **Evaluate** whether or not this is a believable idea.

18 The famous cosmologist Carl Sagan once famously referred to the human race saying, 'We are star-stuff'. **Justify** this statement.

Creating

19 **Construct** a diagram explaining how stellar parallax can be used to measure the distance between the Sun and another star.

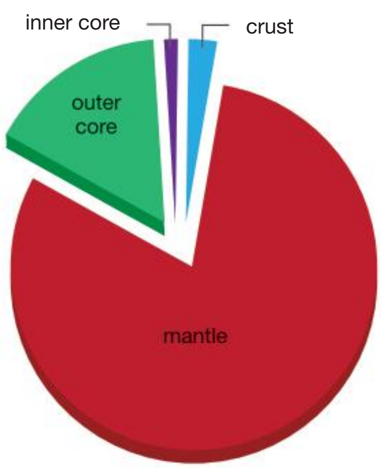
20 **Use** the following ten key terms to **construct** a visual chapter summary of the information presented in this chapter.

star
colour
magnitude
life cycle
cosmology
Big Bang
planet
structure
life
atmosphere

7.7

Thinking scientifically

Questions 1 and 2 refer to the following information. The pie graph below shows the composition of the Earth made up by each layer.



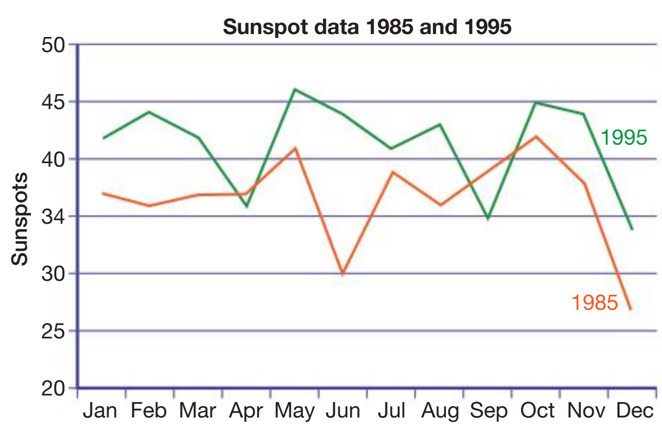
Q1 Approximately what percentage of the Earth's volume is the mantle?

A 1% **B** 2%
C 15% **D** 80%

Q2 The inner and outer cores together make approximately what percentage of the Earth's volume?

A 1% **B** 5%
C 20% **D** 95%

Questions 3 and 4 refer to the following information. Sunspots are dark regions that appear on the Sun. The line graph below shows the number of sunspots observed each month in the years 1985 and 1995.



Q3 Which of the following conclusions could reasonably be drawn from the sunspot data shown?

A The average number of sunspots in 1985 was higher than in 1995.

B December is a month in which there are always relatively low numbers of sunspots.

C There is a link between the number of sunspots and global warming.

D The number of sunspots observed in a particular month in 1995 was always higher than the number of sunspots observed in the corresponding month in 1985.

Q4 The highest numbers of sunspots in each year occurred in:

A May 1985 and May 1995

B October 1985 and October 1995

C May 1985 and October 1995

D October 1985 and May 1995.

Q5 Many galaxies contain a super-massive black hole at their centre. Astronomers currently disagree over which came first—the black hole or the galaxy. Which of the following observations would support the idea that galaxies exist first and that, over time, enough material builds up in the centre of the galaxy to collapse and form a black hole?

A The mass of a black hole is always larger than its surrounding galaxy, regardless of the age of the galaxy.

B The mass of a black hole is always smaller than its surrounding galaxy, regardless of the age of the galaxy.

C The mass of a black hole in comparison to its surrounding galaxy is relatively smaller in younger galaxies than in older galaxies.

D The mass of a black hole in comparison to its surrounding galaxy is relatively larger in younger galaxies than in older galaxies.

Q6 The Hubble constant, H_0, is a value first calculated by Edwin Hubble to measure the rate of expansion of the universe. It can be used to estimate the age of the universe, T, according to the equation:

$$T = \frac{1}{H_0}$$

The currently accepted value for the Hubble constant is approximately 2.3×10^{-18} s^{-1}. Based on this value, the age of the universe is:

A 4.4×10^{-18} s **B** 2.3×10^{17} s
C 4.4×10^{17} s **D** 4.4×10^{18} s

Glossary

Unit 7.1

Absolute magnitude: a measure of how bright a star would appear if it was 10 parsecs from Earth

Apparent magnitude: a measure of the brightness of a star as it appears to an observer on Earth

Blue supergiants: stars that are ten or more times more massive than the Sun

Binary star system: when two stars orbit a common centre of mass

Binary star system

Black dwarf: cold dark remains of a white dwarf

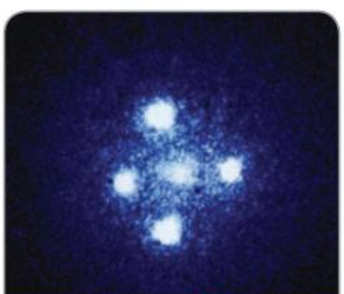
Black hole: also known as a singularity, a collapsed star so massive that not even light can escape from its gravitational field

Density: mass per unit volume of a material

Electromagnetic spectrum: different types of electromagnetic radiation ranging from radio waves to gamma rays

Gamma rays: very high-energy electromagnetic rays

Gravitational lensing: the bending of light rays due to the distortion of space caused by a massive object like a black hole



Gravitational lensing

Gravity: the force that causes all matter to collect together

Isotope: atoms with the same number of protons but different numbers of neutrons

Light-year (l.y.): the distance light travels in a year, approximately 9 500 000 000 000 km

Magnitude: a measure of the brightness of a star

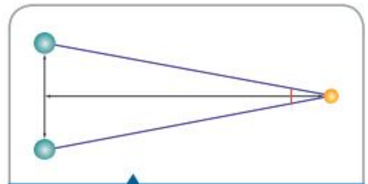
Main sequence: a group of stars lying on a line running from the top left to the bottom right of the H-R diagram

Neutrino: an almost mass-less, neutral particle released during some nuclear reactions

Neutron star: remnant of a supernova, consisting entirely of neutrons

Nuclear fusion: process in which hydrogen is converted into helium to produce light and heat

Parallax: a technique used to measure the distance to other stars



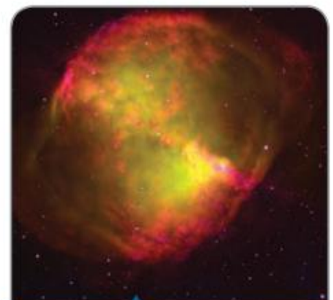
Parallax

Parsec: an astronomical unit of length equal to 3.26 light-years

Plasma: state of matter consisting of positively charged ions and free electrons

Positron: positively charged electron

Planetary nebula: a cloud of gas produced when a red giant runs out of fuel



Planetary nebula

Radiation pressure: the force produced by radiation from a hot object

Red giant: a star produced when the core of a Sun-sized star runs of hydrogen

Spectral class: a classification system for stars based on their colour

Spectrometer: a device that splits light into a spectrum to show its component wavelengths

Stellar parallax: the apparent change in the position of a star throughout the year due to the Earth's motion around the Sun

Supermassive black hole: a black hole millions or billions of times the mass of our Sun found at the centre of a galaxy

Supernova: a giant explosion that occurs when a star many times larger than our Sun runs out of nuclear fuel

Supernova

White dwarf: hot, dense star that is the remains of a red giant

Unit 7.2

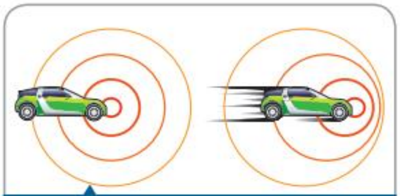
Big Bang: theory that the universe began with an enormous explosion of energy

Big Bang

Blue-shift: the compression of light waves due to the motion of stars towards the Earth; blue-shift makes light appear bluer than it should

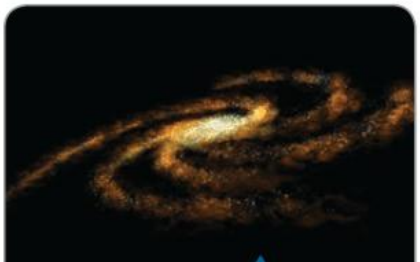
Cosmic microwave background radiation: the after-glow of the Big Bang; low energy radiation that fills the universe

Cosmology: the study of the history and structure of the entire universe


Doppler effect

Doppler effect: the expansion or compression of waves due to the motion of the the object making the waves

Milky Way: the galaxy in which the solar system is located


Milky Way

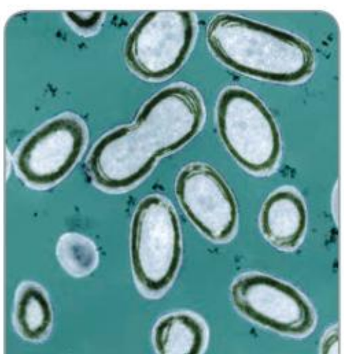
Red-shift: the stretching of light waves due to the motion of stars away from the Earth; red-shift makes light appear more red than it should

Steady state theory: now discounted theory that the universe has always existed in the form that it is in today; also known as the 'infinite universe' theory

Unit 7.3

Abiogenesis: the formation of living organisms from inanimate material

Accretion: process in which particles of dust and rock slowly come together due to gravity to form a larger object

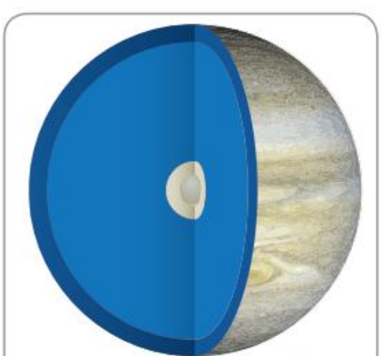

Cyanobacteria

Amino acids: organic compounds that can be combined to form proteins

Astrobiology: the study of living organisms beyond the Earth's atmosphere

Cyanobacteria: also known as blue-green bacteria, microscopic organisms that can store energy from sunlight using the process of photosynthesis

Gas giant: large planet consisting mainly of gases, e.g. Jupiter, Saturn, Uranus and Neptune


Gas giant

Hydrocarbon: a compound consisting primarily of hydrogen and carbon


Moon

Moon: any naturally occurring satellite that orbits a planet

Organic compounds: chemical compounds consisting primarily of chains of carbon and hydrogen molecules found primarily in living organisms

Panspermia: theory that life did not evolve on Earth but rather came to Earth on a comet or meteorite

Planet: a celestial body that is in orbit around the Sun, has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a nearly round shape, and has cleared the neighbourhood around its orbit

Proteins: chemical compounds that all living organisms have

Protoplanetary disk: disk of gas surrounding a protostar that will form into planets


Protoplanetary disk

Protostar: a collapsing cloud of gas that will eventually become a star

Seismic waves: waves that carry the energy from an earthquake around the Earth

Terrestrial planet: literally 'Earth-like' planet, planet made primarily of rock and solid material, e.g. Mercury, Venus, Earth and Mars


Terrestrial planet

Motion and energy

8

HAVE YOU EVER WONDERED…

- why objects speed up as they fall to the ground?
- why a boomerang comes back?
- why you sometimes feel heavier than usual when travelling in a lift?
- why it is hard for a heavy truck to stop quickly?

After completing this chapter students should be able to:

- use equipment to gather data and analyse everyday motions
- apply Newton’s laws to predict how a balanced or an unbalanced force affects the motion of an object
- use Newton’s third law to describe interactions between two objects
- explain that the law of conservation of energy means that the total energy is maintained in energy transfer and transformation
- clarify that an energy transfer or transformation is never 100% efficient
- compare energy changes in interactions such as car crashes, pendulums or lifting and dropping
- use models to describe how energy is transferred and transformed.

8.1 Describing motion

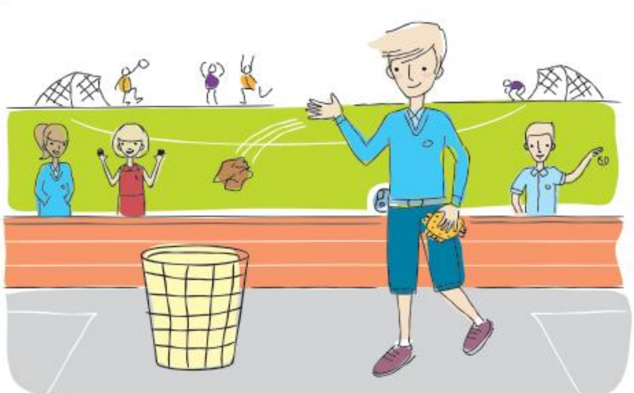
'Ready, set, go!' Many children love to race each other and see who wins. This desire also drives sports people to push their bodies to the limit. Vehicles such as aircraft, racing cars and very fast trains are designed to travel as fast as possible. It is important to be able to measure aspects of motion such as speed. It enables speed limits to be set for safe driving and allows us to estimate travel time.

INQUIRY science 4 fun

Lunchtime marathon

How far do you travel during a typical lunch break and how far do you end up from where you started?

Yes



Collect this ...

- pedometer
- ruler, trundle wheel or tape measure

Do this ...

1. Clip a pedometer onto yourself at school at lunchtime, or for an hour after school once you get home.
2. Record the number of steps you take in this time.
3. Measure the length of a typical step that you take.
4. Calculate the approximate total distance that you covered during the trial.
5. Measure the distance between where you started and where you finished the trial using measuring tape, trundle wheel or by estimating using pace length.

Record this ...

Describe any differences in your answers to steps 4 and 5.
Explain why these were different.

Distance and displacement

When planning a trip around parts of Australia, you would need to consider the **distance**, or how far away places to visit are. You would also need to consider the amount of time you have. In this case, distance would be measured in kilometres, and your time in days or weeks. If considering a trip to the end of your street, distance would be measured in metres and the time would be measured in minutes or even seconds.

You also need to consider where you will end your journey. Your **displacement** is straight-line distance between the finishing and starting points. If you travel from home to the house of a friend who lives 200 km south, then your displacement is 200 km south. Displacement specifies not only the distance from the starting point, but also the direction of the end point from your starting point.

Distance is a **scalar quantity**—it has a size but not direction. Displacement is a **vector quantity**—it has both a size *and* direction. If travelling on a return trip, you can cover a large distance, but your displacement upon returning home is zero. Figure 8.1.1 illustrates a journey that covers a certain distance, but the displacement is zero. Figure 8.1.2 compares the distance travelled with the displacement of a student who walks from their home to school.

Figure 8.1.1 Emily and Lucy take their dog, Harry for a walk and stop at a shop for an ice cream before returning home. The distance they walk is about 600 m, but their displacement is zero.

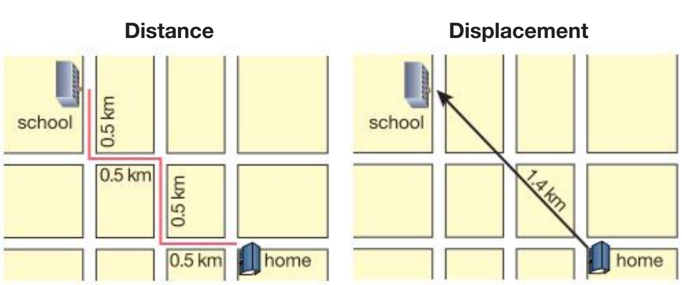


Figure 8.1.2 Greg walks to school and travels a distance of 2 km. His displacement is 1.4 km north-west.

Using SI units

It is easier to compare things such as distance, temperature and speed if people in different parts of the world agree to describe these in the same units. The International System of Units, called SI units (from the French, Le Système International d'Unités), is a standard that was introduced in 1960. This lists seven key quantities and the standard unit used to measure each. They are shown in Table 8.1.1.

Table 8.1.1 SI units

Quantity	Standard unit	Unit abbreviation
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance (used in senior chemistry)	mole	mol
Luminous intensity (brightness)	candela	cd

Combinations of these units can be used to produce SI units for all other quantities. For example, the SI unit for speed is m/s.

Speed and velocity

Average speed

Speed is a measure of how quickly something moves. Average speed can be calculated as:

$$\text{average speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

or

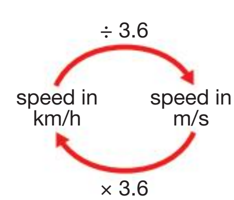
$$v = \frac{d}{t}$$

where *v* is speed, *d* is distance travelled and *t* is time taken.

An object moves faster when it travels a greater distance in a certain time, or covers a set distance in a shorter time.

Converting units

The speed of a car is usually measured in kilometres per hour (km/h). The SI unit for speed is metres per second (m/s). Speeds can be converted from m/s into km/h and km/h into m/s by multiplying or dividing by 3.6 as shown here.



WORKED EXAMPLE
Speed calculations

Problem 1

Convert the following speeds into km/h.

a 3 m/s

b 12.5 m/s

Solution

a 3 m/s = 3 × 3.6 km/h = 10.8 km/h

b 12.5 m/s = 12.5 × 3.6 km/h = 45 km/h

Problem 2

Convert the following speeds into m/s.

a 54 km/h

b 16.2 km/h

Solution

a 54 km/h = 54 ÷ 3.6 m/s = 15 m/s

b 16.2 km/h = 16.2 ÷ 3.6 m/s = 4.5 m/s

Problem 3

Theo spent 8 hours travelling 400 km from his home in Bundaberg to visit his sister in Toowoomba. Calculate Theo's average speed for the journey.

Solution

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

$$= \frac{400}{8}$$

$$= 50 \text{ km/h}$$

Theo's average speed was 50 km/h.

SciFile

Giddy-up?

Humans appear to be getting faster with every new world record set in athletics. Are animals getting faster? Research of data from horse and dog racing has shown that the top speed of a horse has not increased since the 1940s and that of a dog has not increased since the 1970s.

Calculating distance

The formula for average speed can be rearranged to calculate the distance travelled in a certain time as:

distance = average speed × time

or

$$d = v \times t$$

When driving a car, it is vital to stay alert. If a child runs onto the road, or a car breaks down in front of you, you need to react and apply the brakes as quickly as possible. During this **reaction time,** the car still moves forwards and travels a distance called the **reaction distance**. When trying to avoid a collision, this distance is critical. A driver's reaction time is slowed by distractions in the car. Distractions could be caused by:

- other people
- speaking or texting on a mobile phone
- changing the radio station.

Additional factors such as a person's age, fatigue and the influence of drugs and alcohol also slow a person's reaction time.

Once you have reacted and applied the brakes, the car will still cover some additional distance, called the braking distance, as it comes to a stop.

1 p259

8.1

WORKED EXAMPLE
Calculating distance

Problem 1

Trinh rides her bike with a constant speed of 5 m/s. It takes her 3 minutes to get to the milk bar. Calculate how far away it is.

Solution

First, convert the time she took into seconds in order to state the answer in metres.

$t = 3 \times 60 = 180$ s

Trinh has travelled:

$$d = v \times t$$

$$= 5 \times 180$$

$$= 900 \text{ m}$$

The milk bar is 900 m away.

Problem 2

While Trinh is riding, a toddler runs onto the road ahead. If Trinh took 0.5 second to react, how far does she travel before hitting the brakes?

Solution

$$d = v \times t$$

$$= 5 \times 0.5$$

$$= 2.5 \text{ m}$$

Trinh travels 2.5 m before hitting the brakes. She will then travel further as she slows to a stop.

Instantaneous speed

Average speed is the total distance travelled in a journey, divided by the total time taken. Average speed does not give any indication of how slowly or how quickly you may have travelled in a trip, or how long you were caught in a traffic jam or stopped at traffic lights. Figure 8.1.3 shows evenly spaced time intervals of a tennis serve. The racquet moves the greatest distance in the time interval at the end of the serve and so it is moving the fastest at this point. Your speed at a particular instant is called your **instantaneous speed**. The vehicle shown in Figure 8.1.4 is designed to reach an enormous instantaneous speed. In a car, this is indicated by the speedometer. If travelling above the speed limit, you can be caught by a mobile speed camera (Figure 8.1.5), which measures the instantaneous speed of a car.

Figure 8.1.3 The distance moved by this racquet in each time interval provides a measure of its instantaneous speed.

Figure 8.1.4 The Bloodhound SSC is powered by a jet engine and a rocket. Its UK designers hope it will reach an instantaneous speed of 1600 km/h!

Figure 8.1.5 Handheld speed cameras measure the instantaneous speed of a vehicle.

Velocity

You may have heard the term *velocity* used when someone is talking about speed. In science, velocity has a slightly different meaning from speed. **Velocity** is the rate at which displacement changes. In other words, velocity is how displacement changes with time. Displacement is specified with a size and a direction and so velocity must have a direction too. A person may ride a bike at a constant speed of 20 km/h. However, every time they change direction, their velocity changes too. Velocity is a vector quantity, while speed is a scalar quantity

Measuring speed

There are different ways of measuring speed. Light gates can be used to time sporting events such as downhill skiing (Figure 8.1.6). Light gates use a sensor to trigger an electronic timing mechanism when an object breaks through a light beam.

Figure 8.1.6 Light gates can be used to measure time to the millisecond and produce very accurate measurements of an object's speed.

A motion sensor (Figure 8.1.7) sends out pulses of radiation, such as ultrasonic sound waves, microwaves or infrared radiation. The reflection of this radiation from an object provides data about its position and speed.

Figure 8.1.7 Motion sensors on the bumper bar of a car provide the driver with information about how close they are to a barrier.

A ticker timer is shown in Figure 8.1.8. It consists of a small electric arm with a pin or hammer on its end. The hammer vibrates up and down 50 times per second, synchronised with the alternating current of 50 Hz supplying its power. The hammer hits a piece of carbon paper that leaves a dot on a strip of paper threaded below it. When the timer is attached to an object moving in a straight line, these dots are a record of its motion (Figure 8.1.9).

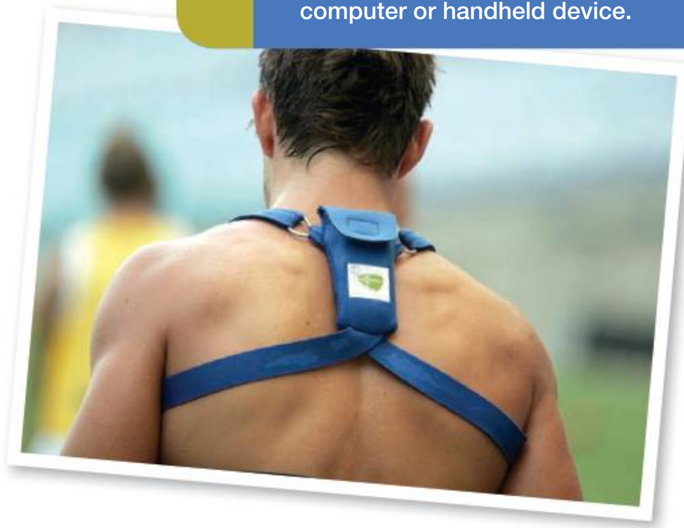
SciFile

GPS in sport

Global positioning system (GPS) equipment is used by a number of sporting teams to record real time data, such as:

- distance travelled by a player
- a player's speed (maximum, minimum, average)
- intensity of impacts
- heart rate.

The data is relayed to a laptop computer or handheld device.



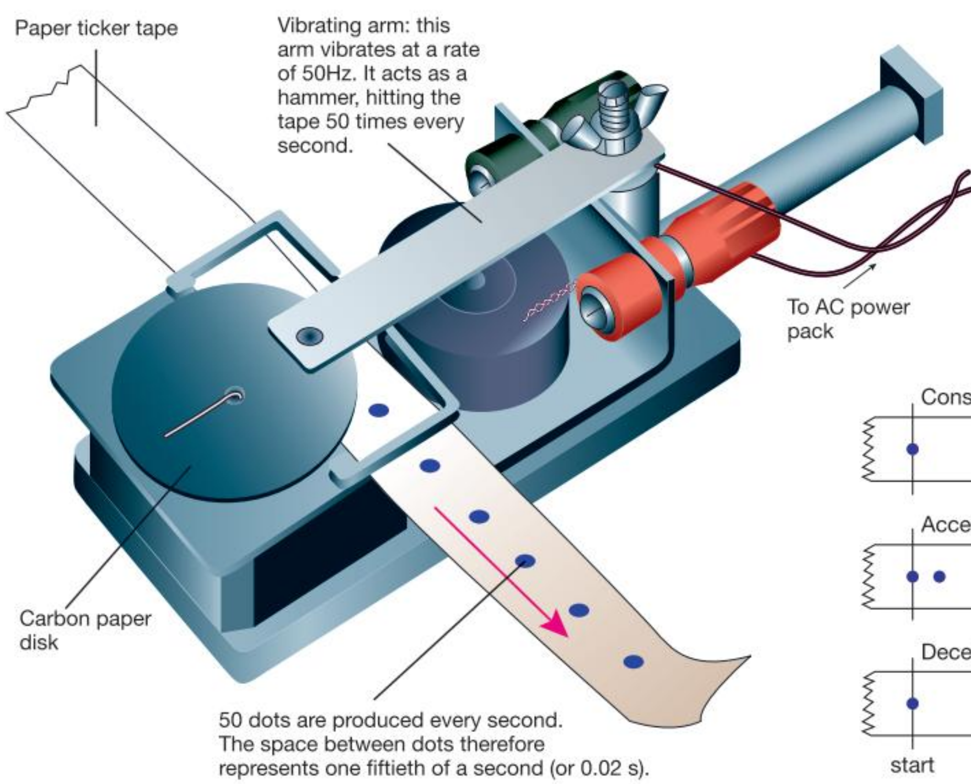


Figure 8.1.8 Analysing the distance between dots recorded on a strip of ticker tape reveals the speed of the moving object used to produce the trace.

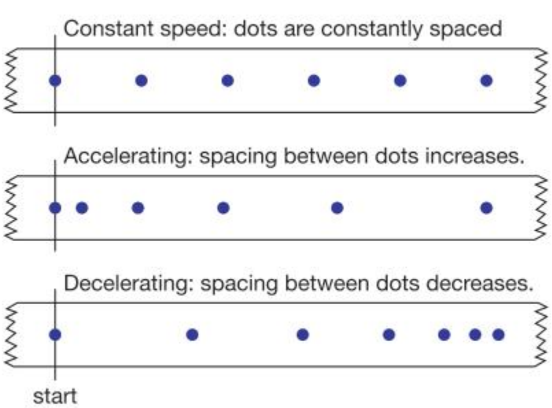


Figure 8.1.9 The spacing of the dots on a ticker tape tells you what type of motion it is. Each new dot represents 0.02 seconds has passed.

Graphing motion

A graph is a useful way of illustrating an object's motion. Time is always placed on the horizontal axis.

Distance–time graphs

A distance–time graph shows how far an object travels as time progresses. A flat line on this graph indicates that the motion has stopped. A line with a steep slope indicates that the object covers greater distance and is moving faster than a line of gentle slope does. The slope is also known as the **gradient**. The slope or gradient of a distance–time graph is equivalent to the object's average speed over a time interval. Figure 8.1.10 shows the distance–time graph of a cyclist.

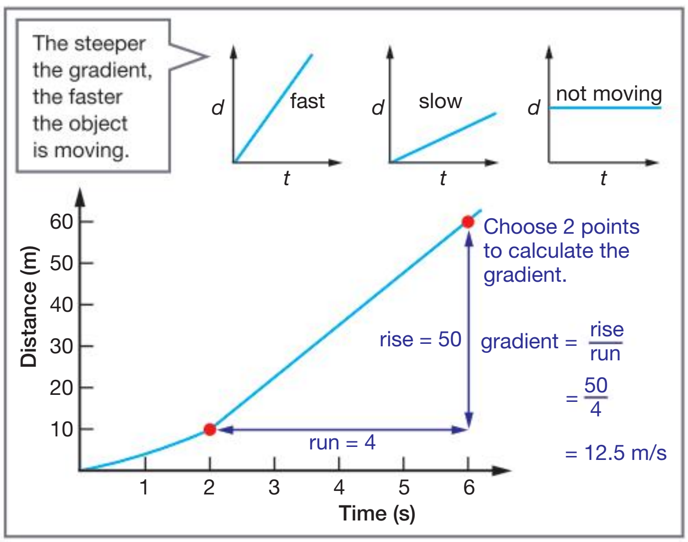


Figure 8.1.10 The cyclist gradually increases speed as they start to pedal. After 2 seconds, the cyclist is travelling at a constant speed of 12.5 m/s.

Displacement–time graphs

Alternatively, an object's displacement can be shown on the vertical axis of a graph instead of distance. In this case, the graph shows how the position of the object changes compared to where it started. Figure 8.1.11 illustrates a displacement–time graph for Mitsu walking to and returning from a friend's house.

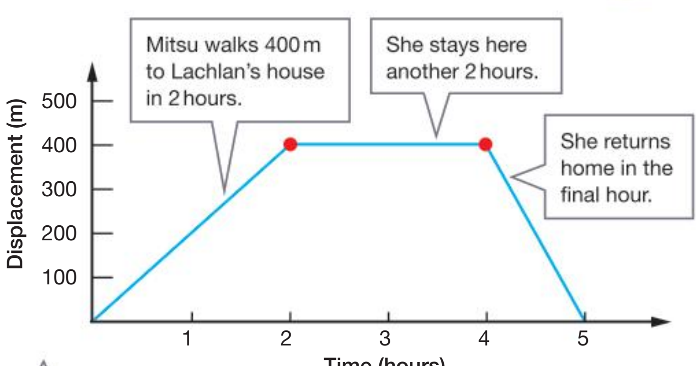


Figure 8.1.11 This graph indicates that Mitsu has travelled out and then returned to her starting point.

Speed–time graphs

A speed–time graph shows how an object's speed changes over time (Figure 8.1.12). An object's speed may:

- be constant, as shown by a flat line
- increase, as shown by the graph rising upwards
- decrease, as shown by the graph falling downwards.

The area below a speed–time graph is the distance the object has travelled up to a given point. This can be calculated as shown in Figure 8.1.13.

p260

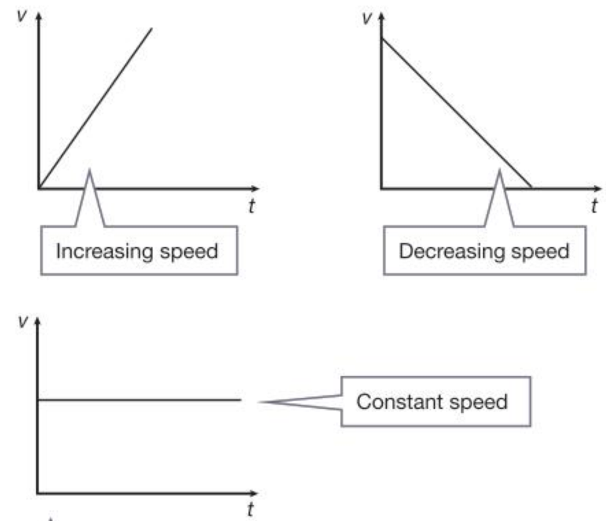


Figure 8.1.12 The slope of a speed–time graph indicates whether motion is speeding up, slowing down or constant.

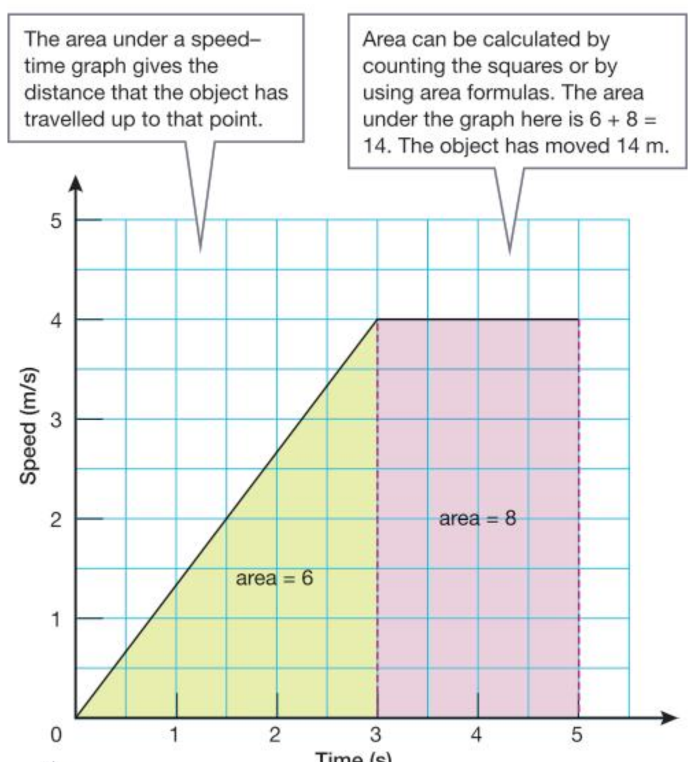


Figure 8.1.13 The area below the graph is the distance the object has travelled.

SCIENCE AS A HUMAN ENDEAVOUR

Use and influence of science

Errors in science

Figure 8.1.14 Compare the clarity of images of galaxy M100 captured by the Hubble Space Telescope before and after its mirror was corrected.

Error is the difference between the value that is measured with the actual measurement. The smaller this difference, the higher the accuracy of the measurement. **Precision** refers to how close the measured values are to each other.

In 1990, a manufacturing error the size of one-fiftieth the width of a human hair on the surface of a mirror led to months of costly repair to the Hubble Space Telescope (Figure 8.1.14). Measurements can be precise, but not accurate. This is shown in Figure 8.1.15.

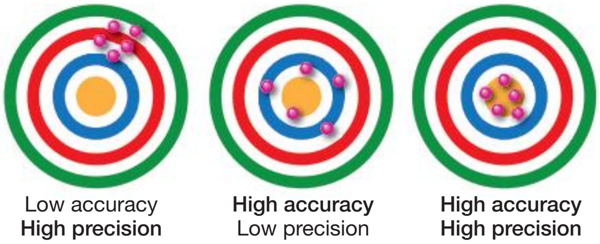


Figure 8.1.15 Measured values can be close together, but still not accurate.

When measuring a physical quantity (such as distance, time or mass) two types of errors can occur. These are systematic and random errors.

Systematic error

Sometimes a set of measurements all differ from the actual value by about the same amount. This type of error is a systematic error. It occurs in the same direction (up or down) and by the same amount each time.
A systematic error can be produced by:

- equipment not being correctly zeroed
- equipment not being correctly assembled or marked
- a change in conditions or temperature over the time a set of measurements is recorded
- an error made in the way a person records a measurement each time.

To eliminate a **systematic error**, new equipment may need to be used or the experimental technique may need to change. This type of error is not removed by completing more measurements.

Random error

A **random error** is when the measurement differs from an actual value in an unpredictable manner. Some random errors are higher than the actual value while some are lower. These errors are caused by:

- an observer's error in reading a scale, possibly caused by parallax error as shown in Figure 8.1.16
- human error in reading an incorrect value.

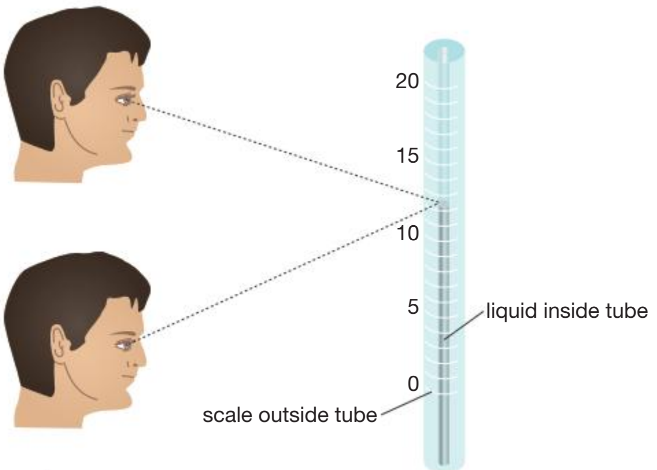


Figure 8.1.16 Parallax error occurs when an observer is above or below the level of the scale they are trying to read.

To eliminate random error, a large number of measurements should be taken. When the mean (or average) of these measurements is calculated, this should be close to the true value required.

8.1 Unit review

Remembering

1 **State** which unit(s) could be used to measure speed.
- **A** year per metre
- **B** millimetre per day
- **C** metre per kilogram
- **D** kilometre per second

2 **Recall** facts about motion by stating whether the following statements are true or false.
- **a** Distance is a vector quantity.
- **b** The SI unit for length is the kilometre.
- **c** Speed can be converted from metres per second to kilometres per hour by multiplying by 3.6.
- **d** The area below a speed–time graph is the distance travelled by an object.

Understanding

3 Jo's displacement is 100 m north. **Explain** what this means.

4 **Describe** a journey in which your displacement is zero, and another in which it is not zero.

5 Raj jogs at a constant rate of 5 km/h around the block of streets around his home. Jane thinks that Raj's speed and velocity remain constant. **Explain** whether Jane is correct.

6 **Explain** the difference between a measurement that is accurate and a measurement that is precise.

7 The company producing the mirror for the Hubble Telescope analysed it using different equipment during manufacture. New equipment indicated that there was a problem, but the manufacturers ignored these results, believing the original equipment to be more accurate. **Explain** why it is desirable to use more than one type of measuring device when taking measurements.

Applying

8 **Calculate** the:
- **i** distance travelled
- **ii** displacement of each object shown in Figure 8.1.17.

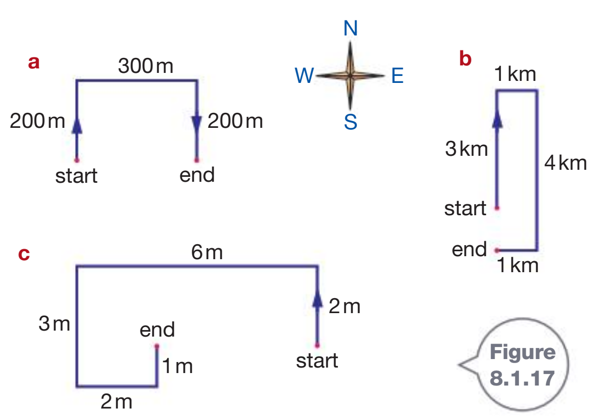


Figure 8.1.17

9 Look at the displacement–time graph of Mitsu walking from home to Lachlan's house, as shown in Figure 8.1.11 on page 255.
- **a** **Calculate** Mitsu's average speed (in km/h):
  - **i** travelling to Lachlan's house over the first 2 hours (Hint: Convert metres to kilometres.)
  - **ii** while returning from Lachlan's house over the last hour.
- **b** **Explain** why Mitsu's displacement does not change from 2–4 hours of the journey.
- **c** **Explain** how you know Mitsu has reached home at the end of the journey.

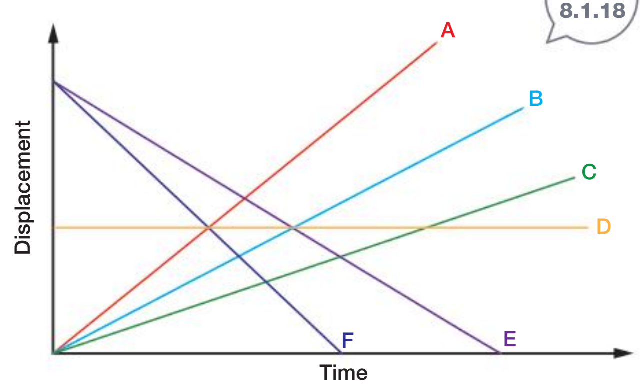
10 Copy the following table into your workbook. It shows typical top running speeds of a number of animals. **Calculate** the missing values to complete the table.

Animal	Speed (m/s)	Speed (km/h)
Cheetah		102
Red kangaroo	17.5	
Giraffe		56
Emu		50
Human	7.5	
Elephant		24
Chicken	4	
Giant tortoise	0.075	

11 **Calculate** the average speed of each of the following in the units specified in the brackets.
- **a** Tim hikes 10 km in 2 hours in the bush (km/h).
- **b** A frog leaps 16 m in 4 seconds (m/s).
- **c** A racing car travels 3 km around a circuit in 6 minutes (km/h).

12 Figure 8.1.18 shows the displacement of six objects over a time period. **Identify** which graph/s represent:
- **a** a stationary object
- **b** an object moving backwards
- **c** the fastest forward-moving object
- **d** the fastest backward-moving object.

Figure 8.1.18

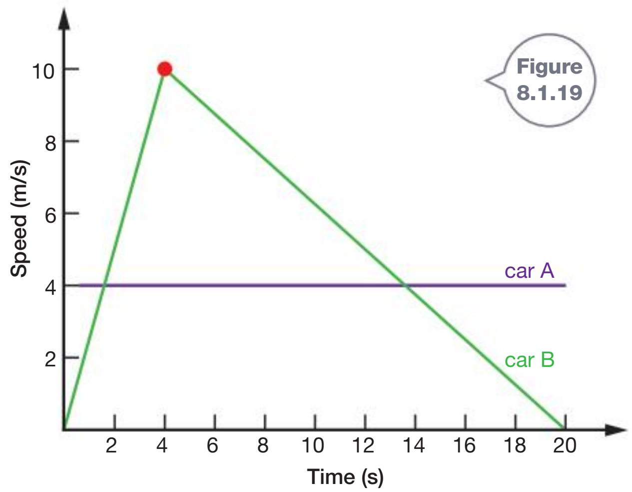


13 The driver of a car travelling at 80 km/h turned a bend and saw a broken-down car ahead. He took 0.75 second to react, and after he braked the car travelled a further 39.2 metres before stopping. **Calculate** the total distance taken for the car to stop. (Hint: Convert the speed of the car into m/s.)

Analysing

14 **Compare** distance and displacement.

15 Figure 8.1.19 shows the motion of car A and car B. **Analyse** these graphs to determine which car travels further in 20 seconds.



16 **Classify** the following measuring errors as random or systematic.

a Finn always measures his height against the wall wearing his runners.

b Asha reads a thermometer scale from above.

c Shae miscounted the number of millimetres when measuring the length of an antenna.

d Carl times Min in a running race but his stopwatch takes 0.6 second to click off.

Evaluating

17 The problems with the mirror on the Hubble Space Telescope were caused by incorrect assembly of the device used to measure the shape of this mirror. This resulted in the mirror being manufactured too flat near it edge.

a **Assess** whether the problems were caused by a systematic or random error.

b **Justify** your answer.

Creating

18 Catarina is on yard duty collecting litter at school. She walks 300 m north, then 100 m west, finally turning to walk 300 m south. The journey takes 5 minutes.

a **State** the total distance travelled.

b **Calculate** Catarina's average speed in m/s.

c **Construct** a diagram of Catarina's journey.

d **State** her displacement.

e **Calculate** Catarina's average velocity.

Inquiring

1 a Investigate current road statistics in your state and select a key area that influences the number of fatalities such as driver distractions, fatigue, speed, drug or alcohol use.

b Create an advertising campaign (billboard, radio commercial or TV commercial) to raise awareness of this issue.

2 Use a trustworthy website such as the TAC's 'How safe is your car?' to summarise information about the safety of your family car or of a car in which you sometimes travel.

3 The average human reaction time to press a button given a visual signal is 0.2–0.25 seconds. Search the internet using terms like 'reflex tester' or 'reaction time'. Test yourself and calculate your average reaction time, based on 20 tests.

4 Design an experiment that uses a video camera or motion detector to record the motion of a number of objects. Examples include:

- wind-up or battery-operated toys released from a starting point
- a cyclist riding along a street
- students in a running race.

Use your recording to assist you to construct an approximate distance–time graph for each object.

8.1 Practical activities

1 Reaction time

Purpose

To simulate a driving experience and test your reaction time.

Materials

- metre ruler
- table or bench
- calculator

SAFETY

Be careful not to fall from the chair. Ensure it is in a stable position on the table by having a partner hold it in place.

Procedure

1 Work with two partners. Select a 'driver' for this activity. This person should stop reading or writing from here and listen to their partners' instructions.

2 For the non-drivers, copy the table from the results section.

3 Position a chair on top of a bench or table, close to a wall as shown in Figure 8.1.20.

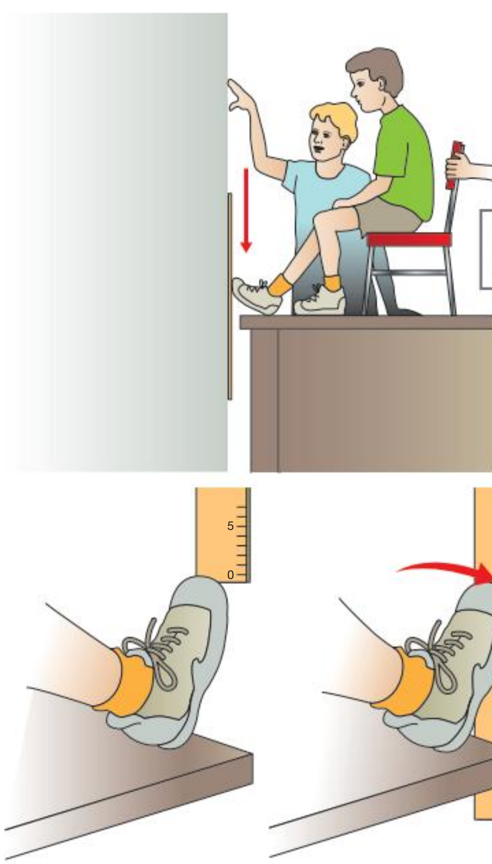


Figure 8.1.20

4 The driver sits on the chair that is held in position by another student. The remaining group member holds the ruler (or brake pedal), flat against the wall so that zero on the ruler is aligned with the driver's toes as shown.

5 Tell the driver that when the ruler starts to fall, they need to 'hit the brakes' and stop it with their foot.

6 Release the ruler and record the distance it falls before the driver stops it.

7 Complete three trials of this test.

8 Repeat the three trials, but keep talking to the driver while performing each trial.

9 Repeat the three trials again, but ask the driver to read or send a text message from a mobile phone, or to read a paragraph of printed text out loud.

Results

1 Copy and complete the following table.

Test conditions	Reaction distance (cm)			Average reaction distance (cm)	Reaction time (s)
	Trial 1	Trial 2	Trial 3		
No distractions					
Distraction (talking)					
Distraction (reading a message)					

2 Calculate the average reaction distance from each set of trials and add them to your table.

3 Calculate the reaction time for each set of results by:

- taking the square root of the reaction distance (in cm)
- multiplying your answer by 0.045.

Discussion

1 **State** the spread, or range, of results of reaction time measured in the first three trials.

2 **Describe** the effect of the distractions on the reaction time.

3 Imagine you were driving at 50 km/h (about 14 m/s) and needed to react quickly to a situation ahead. **Calculate** how far your car would travel for each average reaction time recorded in the table.

4 **Discuss** any sources of random or systematic error that could exist in this practical activity. Suggest any improvements that could be made to reduce these errors.

2 Measuring the speed of toy cars

Purpose

To analyse the motion of a toy car using ticker tape or a motion sensor.

Materials

- AC power supply and ticker timer with tape (or motion sensor)
- toy car
- sticky tape
- ruler

Procedure

1. Work with a partner. Attach about 1 metre of ticker tape to the back of a toy car.
2. Carefully thread the tape through a ticker timer.
3. Place the car on a smooth, flat surface.
4. Turn on the ticker timer.
5. Pull the car away in a straight line, varying its speed.
6. Repeat so that both you and your partner have a recorded strip of ticker tape.

Results

1. Mark the first clearly seen dot on your tape, and then mark every fifth dot recorded after this. Number each group of dots as shown in Figure 8.1.21.
2. Cut the tape into seven sections at the points you've marked. Paste these strips in order on a speed-time graph as shown in Figure 8.1.22. Each strip represents 0.1 second (as this is five times 0.02 second recorded for each dot).
3. To label the scale of the vertical axis of the graph (in mm/s), you need to calculate the average speed of each strip of five dots. To do this, copy and complete the following table.

   Note that average speed of each section = $\frac{\text{length of section}}{0.1}$

Section	Total time (s)	Length of section (mm)	Time interval of each section(s)	Average speed of section (mm/s) (length of section/0.1)
1 (dots 0–5)	0.1		0.1	
2 (dots 5–10)	0.2		0.1	
3 (dots 10–15)	0.3		0.1	
4 (dots 15–20)	0.4		0.1	
5 (dots 20–25)	0.5		0.1	
6 (dots 25–30)	0.6		0.1	
7 (dots 30–35)	0.7		0.1	

4. Complete your table and add a scale to the vertical axis of your graph.

Discussion

1. **Describe** the motion of the toy car.
2. **Explain** why a region of tape in which dots are further apart indicates a faster speed than a section in which these are bunched together.
3. **Describe** the pattern of dots made by constant speed.
4. **Identify** possible sources of error in this activity and propose how these could affect the results.

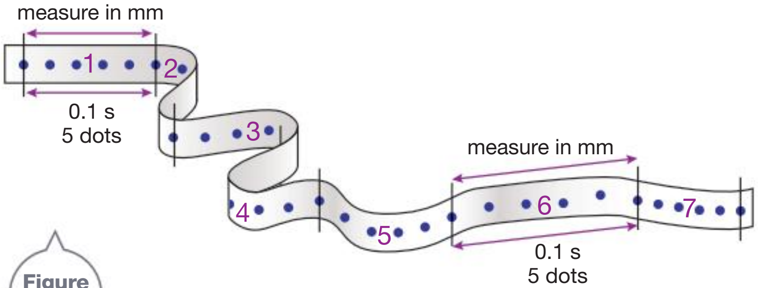


Figure 8.1.21

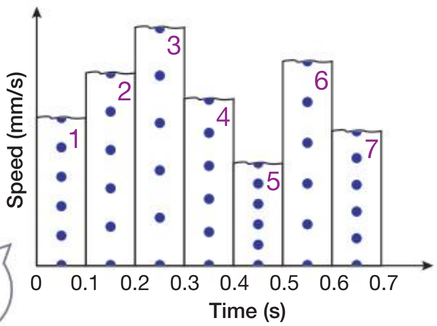
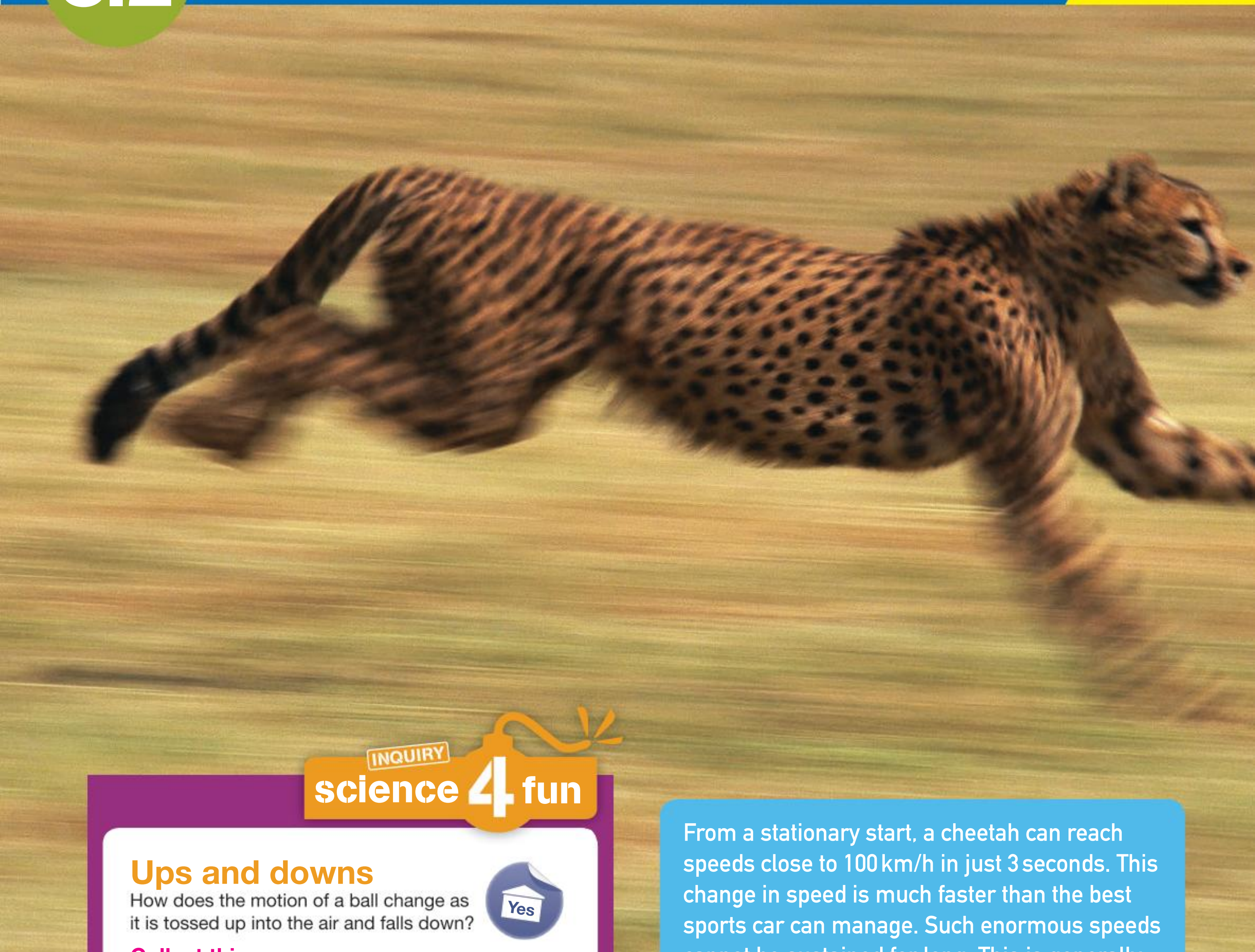


Figure 8.1.22

8.2 Changes in speed



INQUIRY science 4 fun

Ups and downs

How does the motion of a ball change as it is tossed up into the air and falls down?

Yes

Collect this ...

- video camera or mobile phone with video
- tennis ball

Do this ...

1 Work with a partner. One of you tosses a tennis ball about a metre into the air and tries to catch it while the other records the motion with the camera.

2 Replay the motion slowly and watch it carefully.

Record this ...

Describe the motion of the ball, including when it got faster and when it slowed down.

Explain why you think this happened.

From a stationary start, a cheetah can reach speeds close to 100 km/h in just 3 seconds. This change in speed is much faster than the best sports car can manage. Such enormous speeds cannot be sustained for long. This is generally not a problem because the chase of the cheetah is usually over in less than a minute. Changes in velocity are called acceleration.

Calculating acceleration

In everyday language, acceleration is a change in speed. When an object speeds up, it has accelerated. When it slows down, it has decelerated. In science, **acceleration** is the rate of change in velocity. It should be stated with a direction. Like displacement and velocity, acceleration is a vector quantity. A positive acceleration means that something is speeding up in a particular direction and a negative acceleration means it is slowing down in a particular direction.

1 p267

To simplify our ideas of acceleration, we will only consider motion in a straight line. In this case, average acceleration can be calculated using the formula:

$$\text{average acceleration} = \frac{\text{change in speed}}{\text{time}} = \frac{\text{final speed} - \text{initial speed}}{\text{time}}$$

or

$$a = \frac{v - u}{t}$$

where a is acceleration, v is final speed, u is initial speed and t is time taken.

The formula above can be rearranged to allow the final speed of an object to be calculated:

$$\text{final speed} = \text{initial speed} + (\text{average acceleration} \times \text{time taken})$$

or

$$v = u + at$$

The SI units for acceleration are m/s/s or m/s^2. However, other units can also be used. A car that increases its speed in a direction by 12 km/h every second has an acceleration of 12 km/h/s.

WORKED EXAMPLE

Average acceleration and final speed

Problem 1

A car speeds up to 60 km/h from rest in 5 seconds. Calculate its average acceleration. (Express your answer in km/h/s.)

Solution

$$a = \frac{v - u}{t}$$

$$= \frac{60 - 0}{5}$$

$$= 12 \text{ km/h/s}$$

The car increases speed by 12 km/h each second. This is shown in Figure 8.2.1.

Problem 2

A train initially travelling at 30 km/h accelerates at a constant rate of 2 km/h/s for 30 seconds. Calculate its final speed.

Solution

$$v = u + at$$

$$= 30 + (2 \times 30)$$

$$= 90 \text{ km/h}$$

The train is travelling at 90 km/h after 30 seconds.

Table 8.2.1 compares the performance of a number of cars. The shorter the time a car takes to reach 100 km/h, the greater its acceleration.

Table 8.2.1 Time taken for a range of cars to accelerate from 0 to 100 km/h

Car	Time (s)
Nissan GT-R (Figure 8.2.2)	3.5
BMW 135i	5.6
Volkswagen Golf GTI	7.3
Ford FG Falcon	7.3
Holden VE Commodore	8.1
Honda Civic	9.8
Toyota Tarago	17.7

Source: *Wheels Magazine* May 2009

Figure 8.2.2 The time taken for a car to accelerate to 100 km/h is one of many factors to consider when buying a car. Fuel consumption is another factor you might consider.

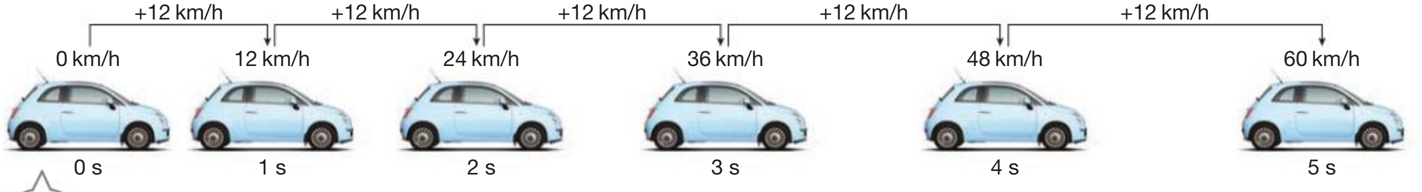


Figure 8.2.1 This car has constant acceleration. Its speed has increased by 12 km/h every second.

Acceleration due to gravity

A falling object (like the person in Figure 8.2.3) accelerates towards Earth because of the force of gravity. This means that it speeds up as it falls. Acceleration due to gravity is 9.8 m/s^2, so the speed of an object increases by almost 10 m/s (or 36 km/h) for every second that it falls. In the first second, the object's speed increases from zero to 36 km/h. One second later, it is falling at about 72 km/h. After 3 seconds, it is falling at about 108 km/h. An acceleration of 9.8 m/s^2 is called '1 g'. You may think it could reach enormous speeds, but friction between the air and a moving object will reduce this acceleration.

Figure 8.2.3 This daredevil is jumping out of a plane wearing a full body suit, complete with nylon 'wings'. This person falls at about 100 km/h, and deploys a parachute to slow their fall (decelerate) before reaching the ground. Wings and parachutes increase air resistance and so they decrease the final terminal velocity of the fall.

The friction between the air and a falling body is called **air resistance**, and the final velocity is called **terminal velocity**.

Human tolerance of g-forces depends upon how big the forces are, how long they last, the direction in which they act and the part of the body they affect. Humans can tolerate horizontal forces much better than vertical forces. Forces experienced in a vertical drop are particularly dangerous as blood flow to the brain can be disrupted and can cause loss of consciousness or death. Your body can withstand high g-forces for a moment with no damage but longer durations are deadly. Some typical g-forces are shown in Table 8.2.2.

Table 8.2.2 Some typical accelerations

Situation	Acceleration (m/s^2)	Number of g's
Free-fall	9.8	1
Space shuttle at take-off	29.4	3
Typical rollercoaster	29.4	3
A sneeze	29.4	3
Slap on the back	39.2	4
Human in a rocket sled (maximum)	455.7	46.2
Car accident at 48 km/h with airbag (force on chest)	588	60
Motorbike accident with no helmet (force on head)	1470–1960	150–200

SciFile

Gee-force!

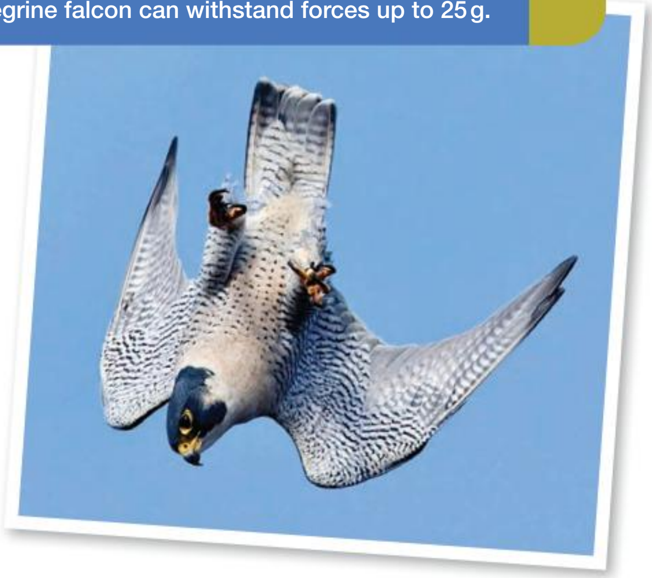
In World War I, pilots diving and looping their aircraft were observed to lose consciousness. American Air Force physician John Strapp decided to test the human g-force limits. He strapped himself into a sled, powered by nine solid fuel rockets on a railway track. Strapp accelerated to 1017 km/h in 5 seconds, before stopping in 1 second. John Strapp's body withstood a momentary force of 46.2 g! Strapp is shown in Figure 8.2.4.

Figure 8.2.4 Six images showing John Strapp accelerating then decelerating rapidly.

Super bird!

The peregrine falcon is a raptor that hunts and kills other birds. Its vision is about eight times stronger than human sight. These raptors knock their prey unconscious in a vertical dive at speeds up to 300 km/h. As it pulls out of a dive, the peregrine falcon can withstand forces up to 25 g.

SciFile



Graphing acceleration

The acceleration of an object can be calculated from the slope or gradient of a velocity–time graph. Constant acceleration is shown on a velocity–time graph as a line rising upwards. A vehicle slowing down, or decelerating, at a constant rate is shown by a line sloping downwards. The motion of an object travelling at a constant velocity (zero acceleration) is shown by a flat line. Figure 8.2.5 shows how the gradient of a velocity–time graph changes with different accelerations.

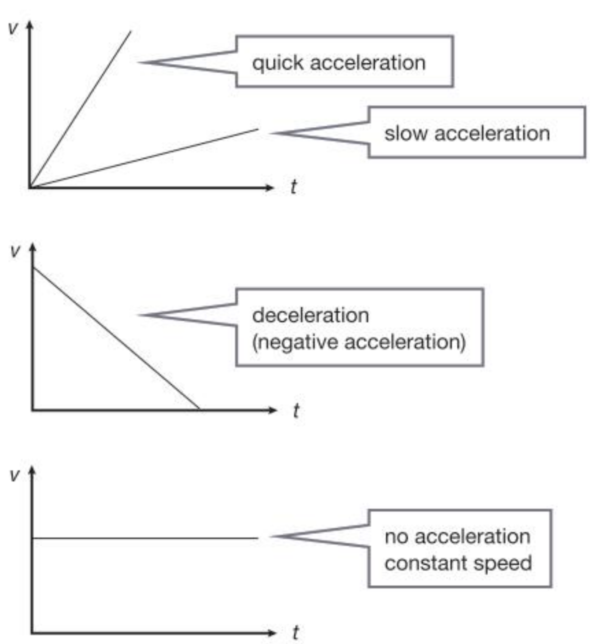


Figure 8.2.5 Acceleration is the gradient of a speed–time graph. This may be positive (speeding up), negative (slowing down) or zero (constant speed).

WORKED EXAMPLE
Interpreting speed–time graphs

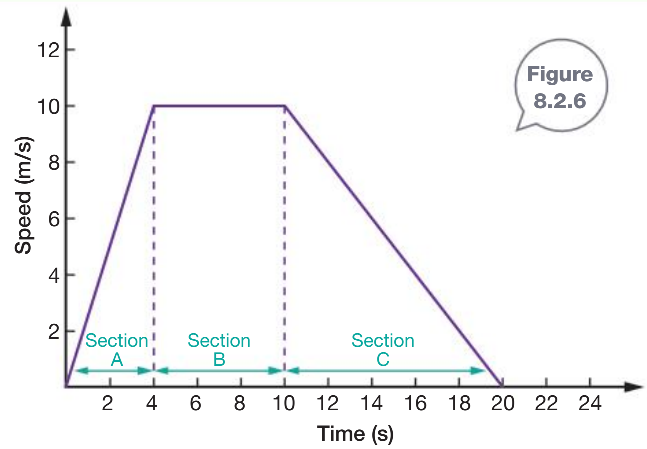


Figure 8.2.6

Problem

Sanjiv rides his scooter as described by Figure 8.2.6.

a Calculate his acceleration in sections A, B and C of his journey.

b Describe his motion in sections A, B and C.

c Calculate the distance Sanjiv covers in section A.

Solution

a Sanjiv's acceleration is the gradient of the graph in each section:

For A: acceleration $= \frac{\text{rise}}{\text{run}} = \frac{10-0}{4} = 2.5\ \text{m/s}^2$

For B: acceleration $= \frac{10-10}{10-4} = 0$

For C: acceleration $= \frac{0-10}{20-10} = -1\ \text{m/s}^2$

b In A: Sanjiv accelerates at 2.5 m/s^2 until reaching a velocity of 10 m/s.

In B: He travels at a constant velocity of 10 m/s (with zero acceleration).

In C: Sanjiv slows down, or decelerates at 1 m/s^2 until he comes to a stop.

c The distance covered is the area under this section of the graph:

distance $= \frac{1}{2} \times 4 \times 10 = 20$ m

Sanjiv travels 20 m while accelerating to 10 m/s in section A.

8.3

2 p268

8.2 Unit review

Remembering

1 **State** the formula used to calculate average acceleration.

2 **List** two different units used to describe acceleration.

3 **List** four factors that affect the response of your body to a g-force.

4 **State** what is represented by the gradient of a velocity–time graph.

Understanding

5 Although acceleration due to gravity is 9.8 m/s^2, in practice, an object dropped from a height on Earth, such as a ball dropped from a tree, will not accelerate this rapidly. **Explain** why.

6 **Explain** why your body does not tolerate vertical g-forces, particularly those downwards, as well as it tolerates horizontal g-forces.

7 **Explain** the difference in motion between a train travelling at 8 m/s^2 and another travelling at –8 m/s^2.

Applying

8 A toy truck was stationary then rolls down a long ramp with a constant acceleration of 0.2 m/s^2. **Calculate** its speed after:

- **a** 1 second
- **b** 2 seconds
- **c** 3 seconds
- **d** 10 seconds.

9 **Use** Table 8.2.1 on page 262 to **calculate** the average acceleration of each car as it accelerates to 100 km/h in the time stated. Express your answer in km/h/s and round off to one decimal place.

10 John Strapp accelerated to a speed of 1017 km/h in 5 seconds and then came to a stop in 1 second. Convert this speed into m/s and **calculate** his:

- **a** average acceleration in reaching 1017 km/h (in m/s^2)
- **b** deceleration in coming to a stop (in m/s^2).

11 Figure 8.2.7 illustrates the motion of a leaf floating in a running stream of water.

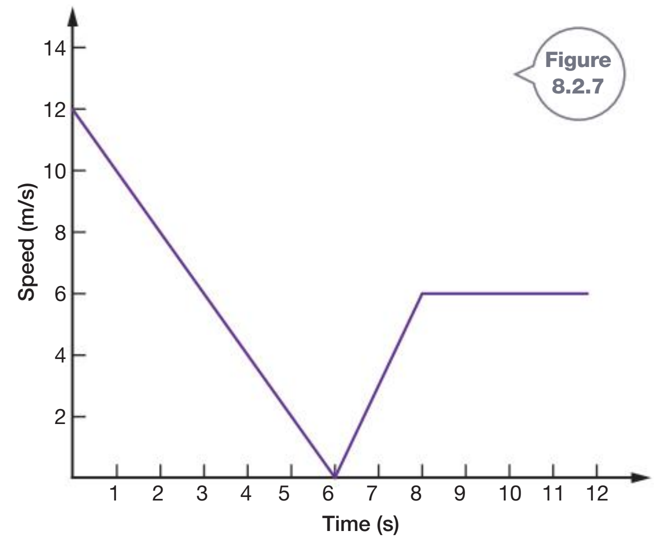


Figure 8.2.7

- **a** **Describe** its motion over the 12 seconds shown on the graph.
- **b** **Calculate** the acceleration of the leaf in the first 6 seconds.
- **c** **Calculate** the distance it travelled in this time.
- **d** **Calculate** its acceleration between 6 and 8 seconds of its journey.

Analysing

12 **Analyse** the three distance–time graphs shown in Figure 8.2.8 to determine which shows an object:

- **a** speeding up
- **b** slowing down
- **c** travelling at constant speed.

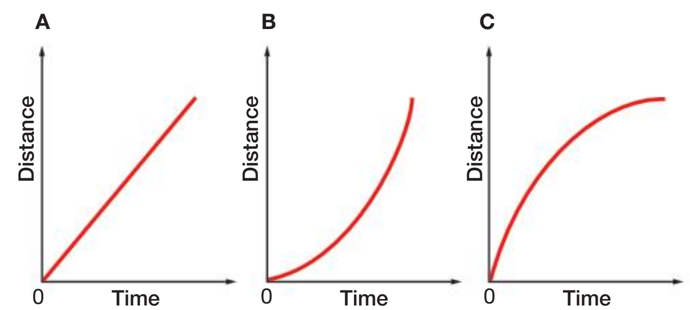


Figure 8.2.8

13 Table 8.2.1 on page 262 shows that different cars take different times to accelerate to 100 km/h. There is also a large difference between the average grams of carbon dioxide emitted per kilometre by them. **Discuss** some of the factors you would consider when purchasing a car.

Creating

14 Table 8.2.3 shows the speed of one cheetah at 5-second intervals as it chased its prey.

Table 8.2.3 Speed of cheetah chasing its prey

Time (s)	0	1	2	3	4	5	6	7	8	9	10
Speed (m/s)	0	6	14	27	27	27	27	20	12	3	0

- a **Construct** a speed–time graph from this data.
- b **Identify** the time intervals in which the acceleration of the cheetah is:
  - i zero
  - ii positive
  - iii negative.

15 **Construct** a short story that could describe the motion described by Figure 8.2.9.

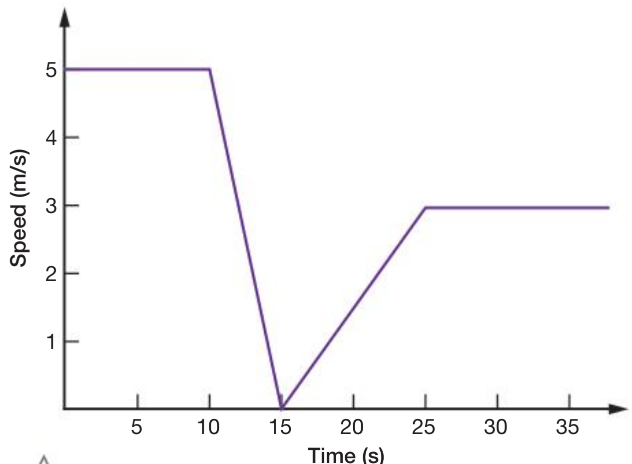


Figure 8.2.9

Inquiring

Figure 8.2.10 Modern mobile phones contain accelerometers.

1 Some handheld devices, such as the phone shown in Figure 8.2.10, contain an accelerometer. This can detect a change in motion when you rotate the device and it automatically rotates the visual display to compensate. List other devices that use accelerometers and describe their function in each.

2 Investigate the g-forces that are experienced on various rides at theme parks. Compile a table that ranks those you have researched from highest to lowest g-force rides.

3 Aristotle was an ancient Greek philosopher. He believed that objects fell towards the Earth because of a homing instinct, and that heavier objects fell faster than lighter objects. These ideas were popular for some 2000 years, but were challenged by the Italian physicist Galileo Galilei (1564–1642).
- a Explain how Galileo's approach to science differed from that of Aristotle.
- b Describe experiments Galileo conducted with falling bodies.
- c State Galileo's conclusion about falling objects.

4 Research the experiments that Galileo performed using ball bearings or marbles rolling down ramps of different inclinations. Repeat some of the experiments and summarise your findings.

8.2 Practical activities

1 Building and testing an accelerometer

An accelerometer is a device that detects acceleration. One is shown in Figure 8.2.11.

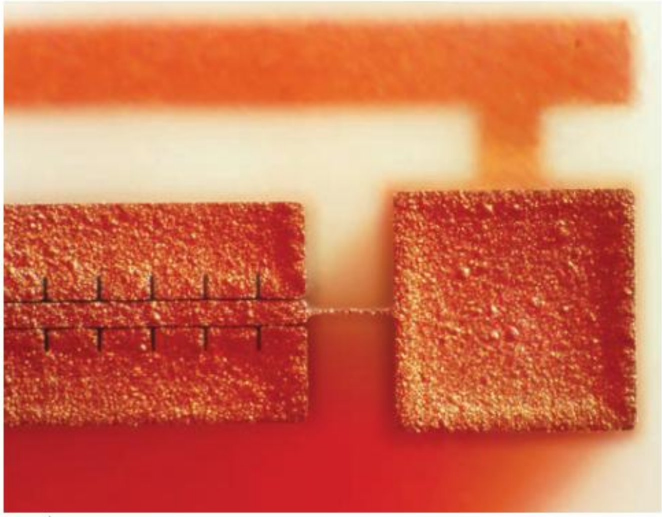


Figure 8.2.11 A micromechanic accelerometer, enlarged 30 times. Tiny movements of the mass on the right are detected by sensors found on the other side of the thin support beam. These devices are used to trigger the release of an airbag in a car.

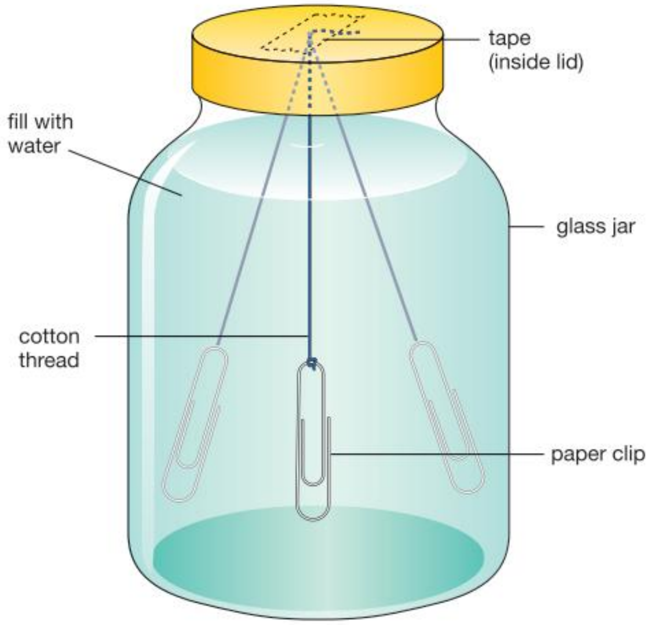


Figure 8.2.12 The suspended paper clip in this accelerometer reacts to acceleration.

Purpose

To design and construct a device that can be used to detect acceleration.

Materials

- materials of your choice

Procedure

1. Design your own accelerometer. Figure 8.2.12 shows an example that may give you some ideas.
2. Construct your device and test its response for positive and negative acceleration.

Discussion

1. **Describe** the design of your accelerometer.
2. **Explain** how it detects acceleration.
3. **Describe** how it responded to positive and negative accelerations.
4. **Identify** any random or systematic errors that could occur when using your accelerometer.
5. **Discuss** any improvements that could be made to your design.

2 Measuring acceleration

Purpose

To determine the acceleration of a trolley rolling down a ramp.

Materials

- ticker timer with power supply and tape (or motion sensor)
- pile of books or bricks to prop up ramp
- protractor
- slotted masses
- masking tape
- ramp
- trolley
- metre ruler

Procedure

1. Set up the ramp at an angle of 30° to the horizontal.
2. If your trolley is very light, add a number of slotted masses to its surface using masking tape.
3. Set up the ticker timer at the top of the ramp. Thread ticker tape through the ticker timer and attach it to the back of the trolley (Figure 8.2.13). (Alternatively, set up motion-sensing equipment.)

Figure 8.2.13

4. Turn on the ticker timer and let the trolley roll down the ramp.
5. Repeat the trial so that everyone in your group has a strip of ticker tape to analyse.

Results

1. Mark sequences of five dot intervals on your tape and analyse these using the procedure outlined in Practical activity 1 on page 267. Record your findings in a table as shown below.
2. Construct a speed–time graph by pasting the numbered sections of ticker tape on a set of axes. Label these axes with a suitable scale.
3. Construct a line of best fit through the dots of each strip as shown in Figure 8.2.14.

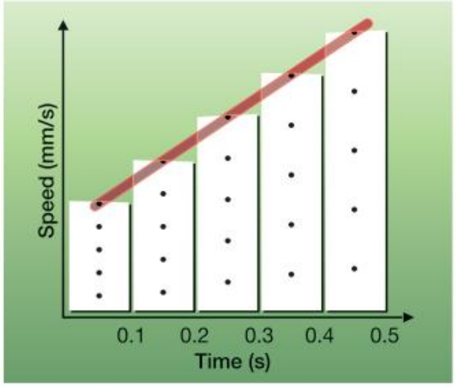


Figure 8.2.14

4. Calculate the average acceleration of the trolley by finding the gradient of the speed–time graph.

Discussion

1. **Describe** the motion of the trolley as it rolled down the ramp.
2. **Propose** one way that the speed of the trolley down the ramp could have been increased.
3. **Discuss** any sources of error that could affect the accuracy of the acceleration you calculated.

Section	Total time (s)	Length of section (mm)	Time interval of each section(s)	Average speed of strip (mm/s) (length of section/0.1)
1 (dots 0–5)	0.1		0.1	
2 (dots 5–10)	0.2		0.1	
3 (dots 10–15)	0.3		0.1	
4 (dots 15–20)	0.4		0.1	
5 (dots 20–25)	0.5		0.1	
6 (dots 25–30)	0.6		0.1	
7 (dots 30–35)	0.7		0.1	

8.3 Newton's laws of motion

Forces are pushes, pulls or twists. A force can make an object start moving, speed up, slow down, stop moving, change direction or even change its shape. Sometimes it is hard to tell that forces are acting because they are balanced and an object does not change its motion. Other times, such as in a car accident, the effect of forces is obvious. The great English scientist Isaac Newton formulated three laws of motion in 1687. These three laws explain why everything around you moves the way it does.

INQUIRY science 4 fun

Loose change

What can you do to a pile of coins without them falling over?

Collect this …

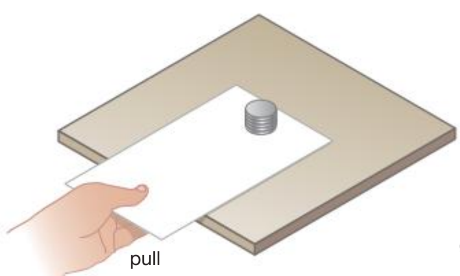
- 5 × 20-cent pieces
- ruler
- piece of paper

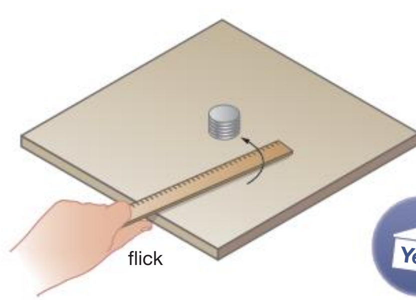
SAFETY

Do not flick objects at or near people.

Do this …

1. Rest the piece of paper on a bench so that a little of it overhangs the edge.
2. Put the pile of 20-cent pieces on the other end of the paper
3. Quickly pull the sheet of paper out and note what happens to the coins.
4. Put a pile of coins on a bench, and flick a ruler towards them to try to knock out the bottom coin. (Place a rolled-up towel near the pile to stop the coins from hitting anything.)





Record this …

Describe what happened.

Explain why you think this happened.

Yes

Newton's first law

If you give a pencil case a light push, it moves a small distance across the desk and stops. For thousands of years, people believed that such an object stopped because the force you gave the pencil case stops working. Galileo (1564–1642) realised that these objects stop because friction acts in the opposite direction to their motion. He reasoned that if there was no friction, then a single push would be enough to keep it moving. The object would only be stopped by some other force. Galileo was right. Once launched, an unmanned spacecraft such as *Voyager 1* (Figure 8.3.1) continues to travel through space, long after its fuel has gone.

Figure 8.3.1 *Voyager 1* was launched in 1977 and is still travelling at high speeds through deep space. It is currently reaching the limits of the solar system.

Isaac Newton developed Galileo's ideas further and developed three laws of motion. **Newton's first law of motion** states that:

- An object at rest will remain this way unless it is acted upon by a force.
- An object that is moving will continue to move at the same speed and in the same direction unless an unbalanced force acts upon it.

In other words, this law states that a force is needed to get something moving. A force is also required to change the speed or direction of something that is already moving. This tendency to resist any change in motion is called an object's **inertia**. The larger the mass of an object, the greater its inertia, and the harder it is to change its motion. This explains why it is easier to stop an empty runaway shopping trolley than one that is full. It also explains why it takes much more fuel for a heavy truck to start moving than for a small car.

SciFile

Isaac Newton

Born in England, Isaac Newton (1642–1727) made enormous contributions to scientific knowledge. He discovered that white light consists of many colours and that gravity is a force that affects all objects on Earth. In using mathematics to explain motion, Newton changed the way that people understood the world.

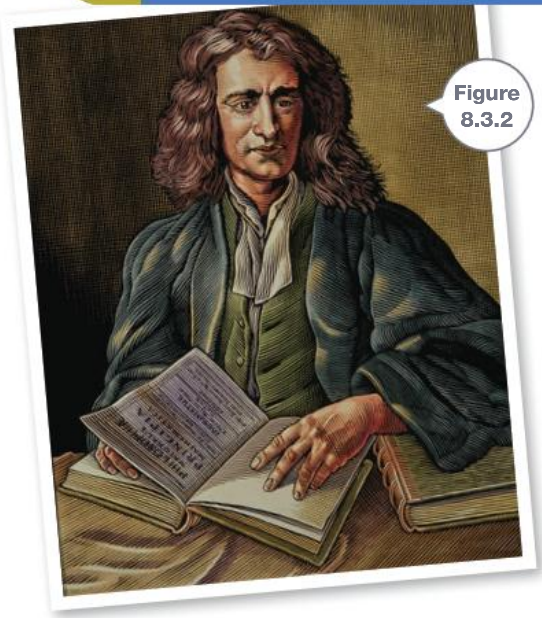


Figure 8.3.2 Sir Isaac Newton

Examples of Newton's first law

You feel the effects of inertia whenever you are in a train (Figure 8.3.3) that suddenly accelerates, stops or turns.

When a train begins to move, your feet move forwards but your body tends to remain stationary—it appears to 'fall backwards' as you try to stay stationary. Once you are moving in the train, the brakes that slow the train act on the train, but not on you. As the train slows, your feet slow down but your body continues its motion, and you can fall forwards.

Figure 8.3.3 Your inertia is obvious when travelling in a train. It causes you to lurch about as the train accelerates and decelerates.

Figure 8.3.4 This high-speed photograph shows crash-test dummies in a car hitting a wall at 56 km/h. The dummies continue to travel at this speed, colliding with objects in the car, other passengers and the car itself.

Consider what happens in a car accident. If you are travelling in a car at 60 km/h that is suddenly brought to a stop, then your body continues to travel forwards at 60 km/h. Figure 8.3.4 shows this situation using crash-test dummies. Seatbelts restrain your body so that you come to a stop with the car. An airbag in a car will inflate when the car collides with a solid object at speeds above 18 km/h. The airbag reduces the force on a passenger in a collision and prevents their head hitting the steering wheel or side of the car.

8.4

Newton's second law

Newton's second law of motion states that:

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

This can be expressed as:

$$F_{net} = m \times a$$

where F_{net} is the total force acting on an object measured in newtons (N), m is the mass of the object (kg) and a is the acceleration of the object (m/s^2).

This formula can be rearranged to express acceleration as:

$$a = \frac{F_{net}}{m}$$

According to Newton's second law, a larger force is needed to accelerate a heavy load (such as the one shown in Figure 8.3.5) than a lighter load.

Figure 8.3.6 shows a way of working out which formula you need to use.

Figure 8.3.5 The more massive an object, the more force is required for it to accelerate.

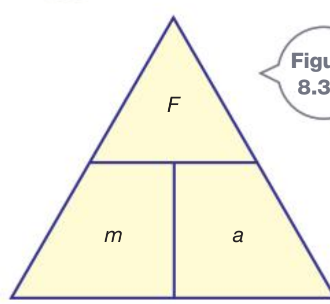


Figure 8.3.6 To calculate force, place your finger over 'F'. This gives the formula $m \times a$.

To calculate acceleration, place your finger over 'a'. The formula is $\frac{F}{m}$.

To calculate mass, place your finger over 'm'. The formula is $\frac{F}{a}$.

SciFile

No pain, more gain!

Catching a cricket ball with a rigid grip will hurt more than if you increase the time of your catch by following through the motion of the ball with your hand. Similarly, a car airbag increases the time interval of a collision and reduces the force of impact.

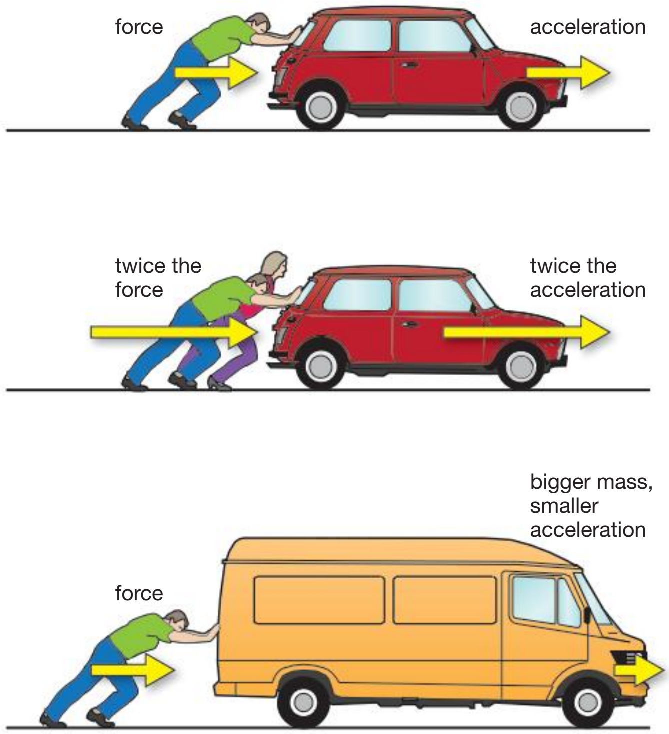


Figure 8.3.7 Acceleration depends upon the size of the force acting and the mass of the object.

Figure 8.3.7 shows what Newton's second law means in practice. Figure 8.3.8 shows what happens if all forces on an object are balanced. In this case, the overall, or net, force acting on the car is zero. If the car was stationary (at rest), then it would stay at rest. Since the car is moving, it will travel at constant speed.

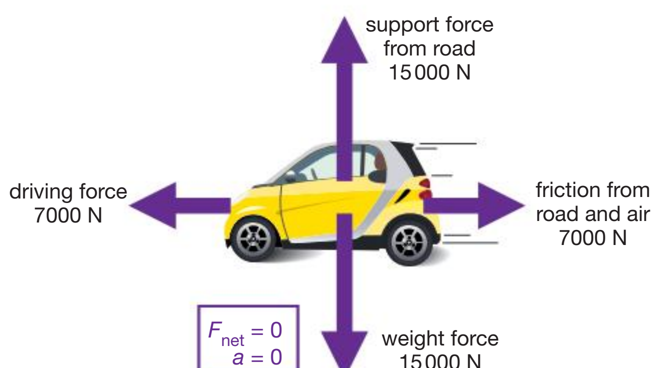
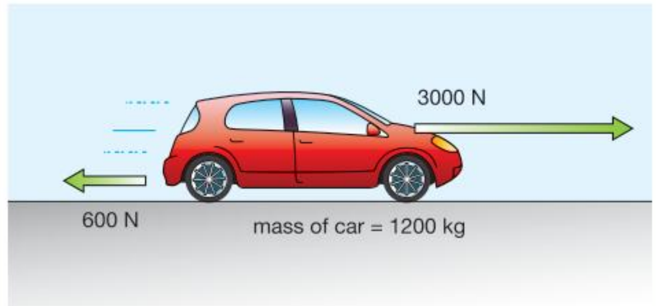


Figure 8.3.8 The vertical and horizontal forces acting on this car are balanced, so the net force acting on the car is zero.

WORKED EXAMPLE
Force and acceleration

Calculate the acceleration of each object shown.

Problem 1



Solution

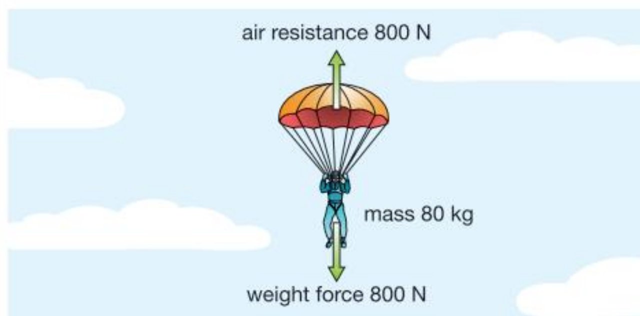
The net horizontal force acting on the car is:

3000 – 600 = 2400 N to the right

So, the car will travel with acceleration:

$a = \frac{F_{net}}{m} = \frac{2400}{1200} = 2\ m/s^2$ to the right

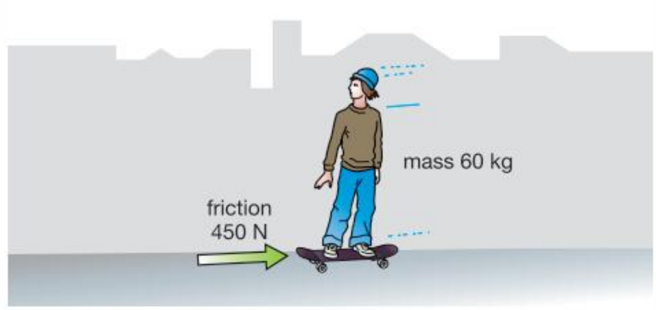
Problem 2



Solution

The net force acting on the parachute is zero. Its acceleration is zero and it falls with a constant velocity.

Problem 3



Solution

The net horizontal force acting on the boy is the force of friction, 450 N to the right. His acceleration is:

$a = \frac{F_{net}}{m} = \frac{450}{60} = 7.5\ m/s^2$ to the right

He is slowing down with a deceleration of 7.5 m/s^2.

INQUIRY science 4 fun

Heavy reading

A book rests on a table. Does the book exert a force on the table? Does the table exert a force on the book?

Yes

Collect this …

- some heavy books
- stopwatch

Do this …

1. Ask a volunteer to extend an arm at right angles to their body with palm facing up.
2. Place three books on their palm and ask the volunteer to keep their arm straight.
3. Time them for a minute, then ask how they are feeling and remove the books.

Record this …

Describe what happened.

Explain why you think this happened.

Newton's third law

Isaac Newton realised that forces always occur in pairs. If a tennis ball is hit by a racquet, the racquet applies a force on the ball, and the ball accelerates forwards. This is called an action force. However, the ball also exerts a force back onto the racquet. You can feel this force as you hit the ball. It is called a reaction force.

Newton's third law of motion states that:

For every action force there is an equal and opposite reaction force.

A few pairs of action and reaction forces are shown in Table 8.3.1.

Table 8.3.1 Some pairs of action and reaction forces

Action force	Reaction force
A nail is hit by a hammer.	The nail exerts an equal force back on the hammer.
A sprinter pushes back on the starting blocks as a race begins.	The starting blocks push forward on the sprinter.
A book resting on a table exerts its weight force onto the table.	The table exerts an equal support force upwards on the book.
An octopus squirts water out as jets through a tube just below its head.	These water jets push back on the octopus, propelling it in the opposite direction.
You stand on a skateboard and push against a wall.	The wall pushes back on you with equal force, and you move away.

Recalling Newton's second law, the acceleration that an object experiences due to a force depends upon its mass. Although the size of action and reaction forces is the same, an object of low mass will travel with much greater acceleration than a more massive object. Figure 8.3.9 shows the different effects of the action–reaction forces from a cannon.

2 p278

Figure 8.3.10 shows how a rocket relies upon action–reaction forces.

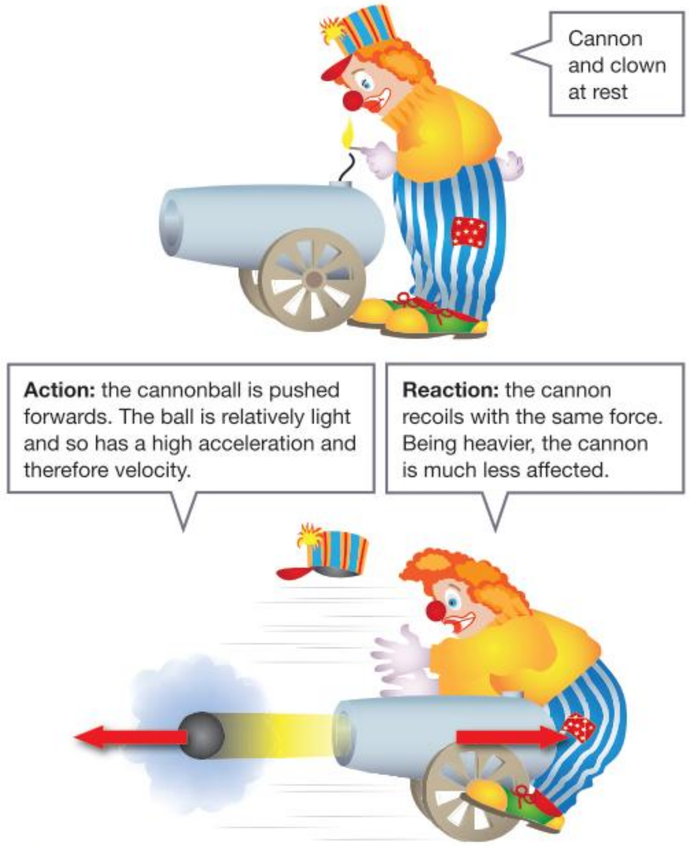


Figure 8.3.9 The action and reaction forces on the cannon and cannonball are the same, but the cannonball has greater acceleration because it has a lower mass.

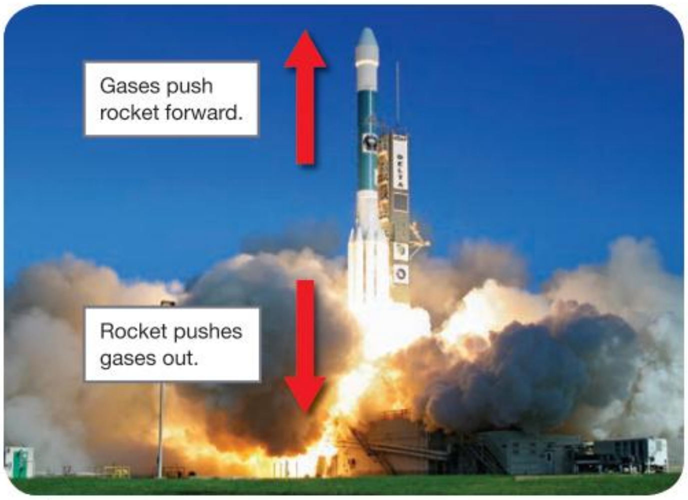


Figure 8.3.10 Explosive exhaust gases expelled from the base of a rocket exert an opposite reaction force to launch the rocket into space.

SCIENCE AS A HUMAN ENDEAVOUR

Nature and development of science

The forces of boomerang flight

Figure 8.3.11 Returning boomerangs are common in Australia, but rare elsewhere, so perhaps they were invented here. Tribes from inland regions of Australia use long and heavy boomerangs, while tribes in coastal areas use shorter and lighter versions.

Boomerangs have been used by Indigenous Australians for thousands of years. The original inventors probably tried changing the shape of the wood and throwing it to see what it would do. When the wooden shapes began returning from a throw, they had successfully invented the first boomerang.

Scientists now use the concept of force to understand how a returning boomerang works. To explain the flight path of a boomerang, you need to consider its shape (Figure 8.3.12) and its spin.

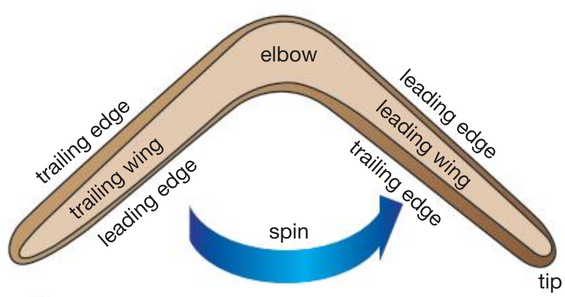


Figure 8.3.12 A boomerang consists of two wings joined at the centre. This diagram shows the design for a right-handed thrower.

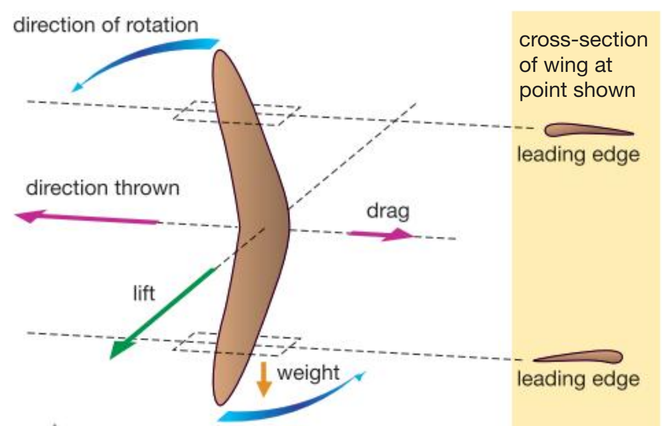


Figure 8.3.14 The boomerang is thrown and its two wings cut through the air with their leading edges. The shape of the wings creates the lift force shown.

Shape

The base of a boomerang is flat, while the top surface is curved. The shape is known as an airfoil and is like an aircraft wing. Air flows more rapidly over this curved upper surface, creating a lift force which pushes it upwards. The airfoil on the wings of a helicopter or aircraft faces upwards and the lift force acts upwards. A boomerang is thrown at a slight angle (15–20°) to the vertical, as shown in Figure 8.3.13, so the lift force created points to the centre of the boomerang's flight path, as shown in Figure 8.3.14.

Figure 8.3.13 A boomerang is thrown at an angle of around 15–20° to the vertical. If it is windy, the boomerang is thrown closer to the vertical.

Spin

The spin of a boomerang depends upon its wing length, the materials from which it is constructed and the angle that separates the wings. Air rushes more quickly over the wing rotating in the direction of the boomerang's flight than the wing rotating in the opposite direction. This uneven lift sets up complex forces that allow the boomerang to return to its thrower, as shown in Figure 8.3.15.

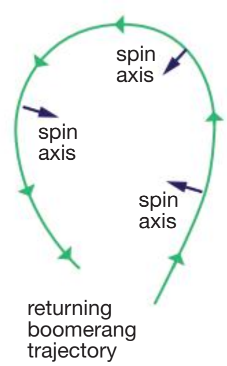


Figure 8.3.15 The boomerang returns due to forces acting at right angles to the plane of its motion.

8.3 Unit review

Remembering

1 **State** Newton's first law of motion.

2 a **State** the formula for Newton's second law that is used to calculate force.
b **State** this law expressed in terms of acceleration.

Understanding

3 **Explain** why Voyager 1 (Figure 8.3.1 on page 270) is still in motion, even though its fuel ran out a long time ago.

4 In terms of Newton's first law, **explain** why having sharp objects on the dashboard of a car, or loose objects in the back, could cause injury or death in an accident.

5 **Explain** how it is possible for the car shown in Figure 8.3.8 on page 272 to be in motion, even though the net force acting on it is zero.

6 **Explain** what an airfoil is and **describe** how this produces a lift force on an aircraft wing and on a boomerang.

Applying

7 **Use** Figure 8.3.16 to **explain** how hitting the ball with a tennis racquet involves action and reaction forces.

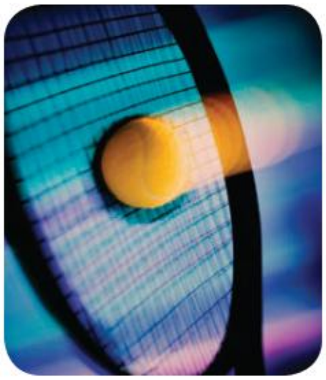


Figure 8.3.16

8 **Identify** which has greater inertia—a suitcase packed for a holiday or the same suitcase after its contents have been packed away.

9 Copy the following table and then **use** Newton's second law to **calculate** the missing values.

Net force (N)	Mass (kg)	Acceleration (m/s^2)
24.0	6.0	
13.5	3.0	
	58.0	1.5
	25.0	3.5
1160.0	80.0	
5.5		1.1

10 The mass of a Nissan GT-R is 1740 kg.
a **Calculate** the net force required for the car to travel with an acceleration of 3 m/s^2.
b If there was a 2000 N force of friction opposing the car's motion, **calculate** the size of the driving force that must be provided by the engine to maintain this acceleration.

11 **Calculate** the net force and the acceleration of each object shown in Figure 8.3.16.

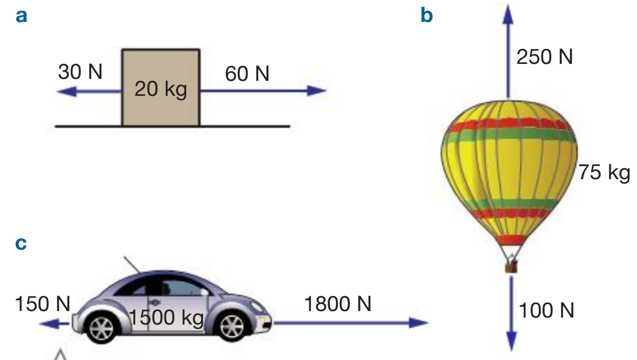


Figure 8.3.17

12 **Identify** the direction of the lift force acting on a boomerang in flight.

13 **Use** your understanding of Newton's third law to **identify** the reaction force that acts with each action force listed.
a Mylinh's foot pushes back on the footpath as she walks down the street.
b Ted applies a force to a cricket ball as he catches it.
c Sally pushes on the handle of a lawnmower.
d Alf pushes a punching bag.
e Jade pushes on pizza dough as she kneads it.

Questions 14–17 are all based on the same information.

14 Phil, a motorcyclist, takes off from rest and reaches 17 m/s in 4 seconds.
a **Calculate** what 17 m/s is in km/h.
b **Calculate** Phil's acceleration in m/s^2.
c If the mass of Phil's bike plus Phil is 190 kg, **calculate** the force required to produce this acceleration.

15 Phil's sister Yen also rides motorbikes. The mass of Yen's bike plus Yen is 150 kg. Yen can also reach 17 m/s from rest in 4 seconds. **Calculate** the force required to produce this acceleration.

8.3 Unit review

16 Yen's bike weighs the same as Phil's, but is less powerful. Yen takes Phil's bike and rides away on it.
  a **State** the combined mass of Yen and Phil's bike.
  b Given that the driving force acting on Phil's bike is the same as the force calculated in question 14, **calculate** the size of Yen's acceleration.
  c **Calculate** Yen's speed after 4 seconds.

17 As Yen has taken off with his bike, Phil is forced to use Yen's bike to try to catch up to her.
  a **State** the combined mass of Phil and Yen's bike.
  b Given that the driving force acting on Yen's motorbike is the same as that in question 15, **calculate** the size of Phil's acceleration.
  c **Calculate** Phil's speed after 4 seconds.

Analysing

18 According to Newton's second law, the acceleration of a cart of mass m being pushed with force F is $a = \frac{F}{m}$.
Ignoring any friction, **compare** the acceleration of the same cart when:
  a pushed with a force $2F$
  b pushed with a force $\frac{1}{2}F$
  c pushed with force F but loaded up so that its mass is now $2m$
  d pushed with force $2F$ and with a mass of $2m$.

Inquiring

1 Design and construct a safety capsule to protect an egg from cracking when dropped from a metre above the ground. Investigate the maximum height that your safety capsule will still protect the egg.

2 Use plastic containers filled with sand and a video camera or mobile phone to re-enact the famous trick of pulling the tablecloth (shown in Figure 8.3.18). Test the effect of using different types of tablecloths. Do not try this with glass, crockery or anything breakable.

Figure 8.3.18

3 Select a car on the market in Australia. Search the ANCAP website and other related sources of information to construct a report that summarises:
- what ANCAP stands for and what its role is
- the safety features and crash-test rating of the model of the car you chose to investigate.

4 a Compile a list of instructions that describe how to throw a boomerang correctly.
  b Investigate how the angle to the vertical that the boomerang is launched affects its flight. Write a report on your discoveries.

5 Describe the different directions that your body is pushed or pulled when playing on playground equipment such as roundabouts, see-saws, swings and slides. Explain each of these sensations in terms of inertia.

8.3 Practical activities

1 Newton's second law

Purpose

To test whether an object moves with greater acceleration when the size of a pulling force is increased.

Materials

- trolley
- piece of wood
- G-clamp
- string or fishing line
- electronic balance
- pulley and clamp
- 50 g slotted masses
- calculator
- stopwatch and ruler (to measure acceleration) (Alternatively, use light gates for data-logging or ticker timer and ticker tape and carbon disks.)

SAFETY

Keep your feet away from the falling masses. Put padding (such as books) on the floor under the falling masses.

Procedure

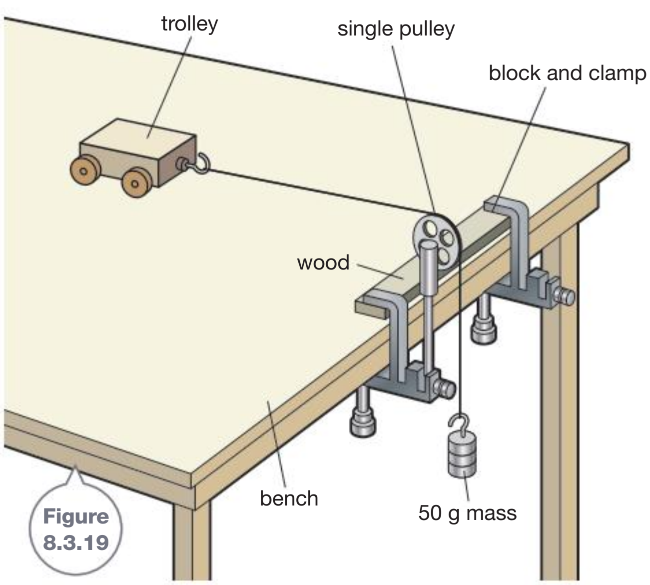


Figure 8.3.19

When setting up, make sure the masses do not reach the ground when the trolley reaches the pulley.

1 Copy the table from the results section on page 278 into your workbook or use a spreadsheet.
2 Measure the mass of a trolley and record this value.
3 Clamp a piece of wood and a single pulley to a bench top.
4 Set up the trolley and hanging masses as shown in Figure 8.3.19.
5 Pull the trolley back so that when released, it accelerates towards the edge of the bench.
6 Measure the distance from the starting point of the trolley to the pulley.
7 Release the trolley from its starting position and use a stopwatch or light gates to measure the time taken to reach the pulley.

   Alternatively, calculate acceleration using the ticker tape method shown in Unit 8.2 Practical activity 2 (page 268), but divide mm/s^2 by 1000 to obtain acceleration in m/s^2.
8 Record three trial measurements of time.
9 Repeat this task for increasing hanging masses as shown in the results table.

Results

1 Calculate the average time taken by the trolley for each hanging mass tested.
2 As the trolley starts from a stationary position, its acceleration can be calculated:

   $a = \frac{2d}{t^2}$

   where d is distance travelled (m) and t is time taken (s).

   Calculate acceleration, $a = \frac{2d}{t^2}$, using the distance you measured (in metres) and the average time taken (in seconds).

Newton's second law continued on next page

Newton's second law continued

Hanging mass (g)	Force applied (N) (hanging mass × gravity)	Time for trolley to reach pulley			Average time (s)	Acceleration (m/s²)
		Trial 1 (s)	Trial 2 (s)	Trial 3 (s)		
100	1					
200	2					
300	3					
400	4					
500	5					

3 Using a set of axes, plot a graph of force applied (N) on the vertical axis against acceleration (m/s^2) on the horizontal axis.

4 Draw a line through the points on your graph and calculate its gradient ($\frac{rise}{run}$)

Discussion

1 **Describe** the effect of increasing force on the acceleration of the trolley.

2 According to Newton's second law, the gradient of your graph should be the mass of the trolley. **Compare** your result to this value.

3 **Propose** any sources of error that would affect the results you obtained in this experiment.

2 Balloon challenge

Purpose

To design and conduct an experiment using a balloon to investigate Newton's third law of motion.

Materials

Choose from a range of materials, such as:

- string or fishing line
- straw
- balloon
- masking tape
- piece of dowel
- pivot pin

Procedure

1 Design a way of using a balloon releasing air to investigate Newton's third law.

2 Investigate how the reaction force is affected by more air being released by the balloon.

3 Balloons could move horizontally along a string or piece of fishing wire, or spin on an axis such as that shown in Figure 8.3.20.

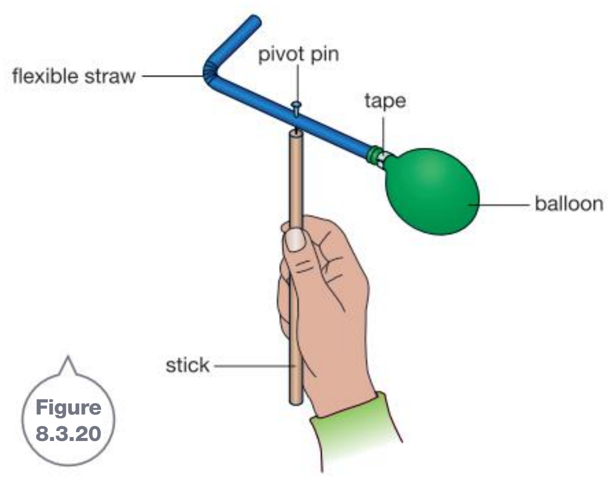


Figure 8.3.20

Results

1 **Describe** your practical design, including a diagram in your response.

2 **Describe** what happened.

3 **Explain** your results in terms of Newton's third law.

4 **Propose** how you could make improvements to your practical activity.

8.4 Energy changes

This bullet hit the egg at a speed of about 100 m/s. The bullet has energy because of its movement. The force of the impact shatters the egg. The bullet exits the egg with slightly less energy than it had when it hit it, because some energy has been transferred to the egg. Whenever something happens around you, energy has been transferred or transformed.

Energy and work

Whenever a force moves something, **work** is done. Work is a measure of the amount of energy used in moving the object. It is measured in joules (J):

Work can be calculated using the following equation:

$$\text{work done} = \text{force applied} \times \text{distance moved (in the direction of the force)}$$

or

$$W = F \times d$$

where W is the work done (J), F is the force applied (N) and d is the distance moved (m).

In each situation shown in Figure 8.4.1, work is done as objects or people are moved a distance by a force. If a force acts but nothing moves, such as that shown in Figure 8.4.2 on page 280, then no work has been done. **Power** is the rate that work is done, or how fast energy is used. Power is measured in watts (W):

$$\text{power} = \frac{\text{work done}}{\text{time}}$$

Figure 8.4.1 Work is done as a force lifts a teabag, pulls you up a cliff or pulls along a sled.

Figure 8.4.2 If an object doesn't move, then no work has been done.

Kinetic energy

An object that is moving has the ability to do work. A speeding bullet does work because it pushes things around in the collision. A car travelling at high speed will crumple on impact and break apart, or crush what is in its path. The energy of a moving object is called **kinetic energy**, E_k. It is calculated using the following equation:

$$E_k = \frac{1}{2}mv^2$$

where m is the mass of the object (kg) and v is its speed (m/s).

Compare the size of kinetic energy at different speeds for the small and large car calculated in the Worked Example on the next page. Doubling the mass of a moving object doubles its kinetic energy. However, doubling its speed increases its kinetic energy by a factor of four. The greater a vehicle's kinetic energy, the more work it can do. This is why even a small increase in speed rapidly increases the risk of death or injury when travelling in a car. This is shown in Table 8.4.1.

Table 8.4.1 Speed and injury risk

Speed (km/h)	Risk of death or injury compared with travelling at 60 km/h
65	Double
70	4 times
75	11 times
80	32 times

Source: *Road Traffic Authority of NSW*

WORKED EXAMPLE
Calculating work and power

Problem

Tom pulls Su on a sled for 10 seconds with a force of 120 N over a distance of 3 metres. Calculate:

a the work Tom has done on the sled

b Tom's power in pulling the sled.

Solution

a $F = 120\text{ N}, d = 3\text{ m}$

$W = F \times d$

$= 120 \times 3$

$= 360\text{ J}$

b $\text{Power} = \frac{\text{work done}}{\text{time}}$

$= \frac{360}{10}$

$= 36\text{ W}$

INQUIRY science 4 fun

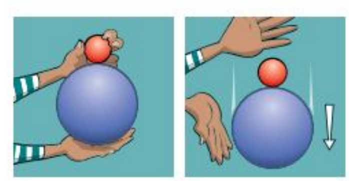
Energy transfer

What happens when the kinetic energy of one ball is transferred to another ball?

Yes

Collect this …

- basketball
- tennis ball
- video camera (optional)



Do this …

1. Hold a basketball about a metre above a hard floor.
2. Hold a tennis ball just above the basketball.
3. Drop both balls at exactly the same time and record what happens.

Record this …

Describe what happened.

Explain why you think this happened.

Another reason why increased speed is more dangerous is that cars travelling at higher speed require longer distances to stop. This is shown in Figure 8.4.3.

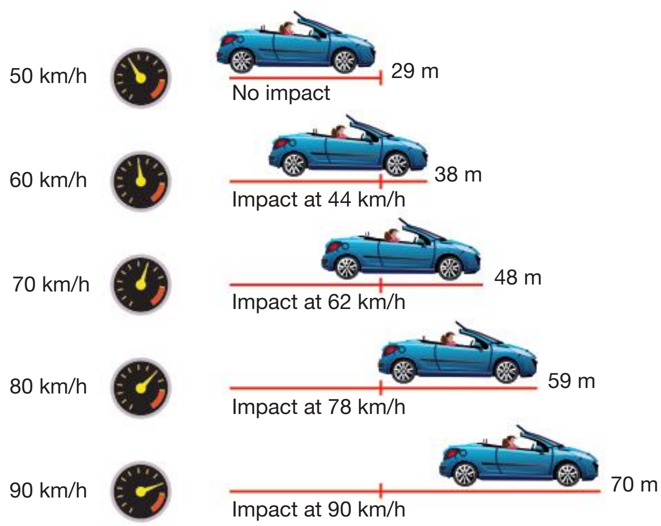
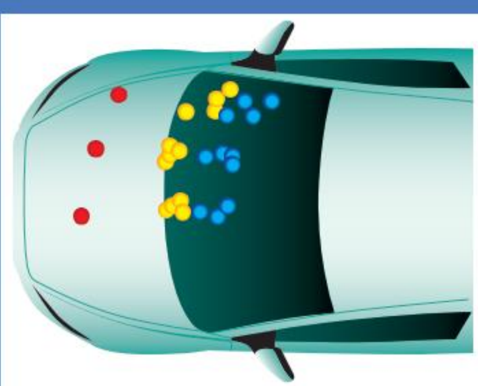


Figure 8.4.3 This shows how the distance required for a car to stop increases for cars travelling at 50, 60, 70, 80 and 90 km/h.

SciFile

Bonnet bags?

Pedestrians hit by a car can suffer injuries or death due to contact of their head with a bonnet or windscreen. Where they hit is shown in Figure 8.4.4. Researchers in the UK have developed a system that releases a giant airbag from the bonnet and covers the windscreen when it detects that a pedestrian is about to be hit.



- 6-year-old child
- Small adult (<150 cm)
- Large adult

Figure 8.4.4 This illustration shows where three different pedestrians will hit their head on a car.

WORKED EXAMPLE
Calculating kinetic energy

Problem 1

Calculate the kinetic energy of this Ford Focus travelling at:

a 5 m/s (18 km/h)

b 16 m/s (57.6 km/h)

Solution

a Ford Focus at 5 m/s

$$E_k = \frac{1}{2}mv^2$$
$$= \frac{1}{2} \times 1300 \times 5^2$$
$$= 16\,250 \text{ J or } 16.25 \text{ kJ.}$$

b Ford Focus at 16 m/s

$$E_k = \frac{1}{2}mv^2$$
$$= \frac{1}{2} \times 1300 \times 16^2$$
$$= 166\,400 \text{ J or } 166.4 \text{ kJ}$$

Problem 2

Calculate the kinetic energy of a Ford Territory, travelling at:

a 5 m/s (18 km/h)

b 16 m/s (57.6 km/h)

Solution

a Ford Territory at 5 m/s

$$E_k = \frac{1}{2}mv^2$$
$$= \frac{1}{2} \times 2025 \times 5^2$$
$$= 25\,312.5 \text{ J or about } 25.3 \text{ kJ}$$

b Ford Territory at 16 m/s

$$E_k = \frac{1}{2}mv^2$$
$$= \frac{1}{2} \times 2025 \times 16^2$$
$$= 259\,200 \text{ J or } 259.2 \text{ kJ}$$

Potential energy

Potential energy is energy that an object has because of its position or structure. For example, chemicals in foods and explosives contain energy in their chemical bonds. Potential energy is often called stored energy. Potential energy gives objects the capacity to makes things happen, or to do work.

Elastic potential energy

A stretched or compressed spring or elastic material has **elastic potential energy**. This energy is converted into kinetic energy when the spring is released and returns to its original shape. Springs on a trampoline, car bumpers, bungee cords, sling shots, mouse traps (Figure 8.4.5) and even tennis balls store elastic potential energy and release it in different ways.

1 p285

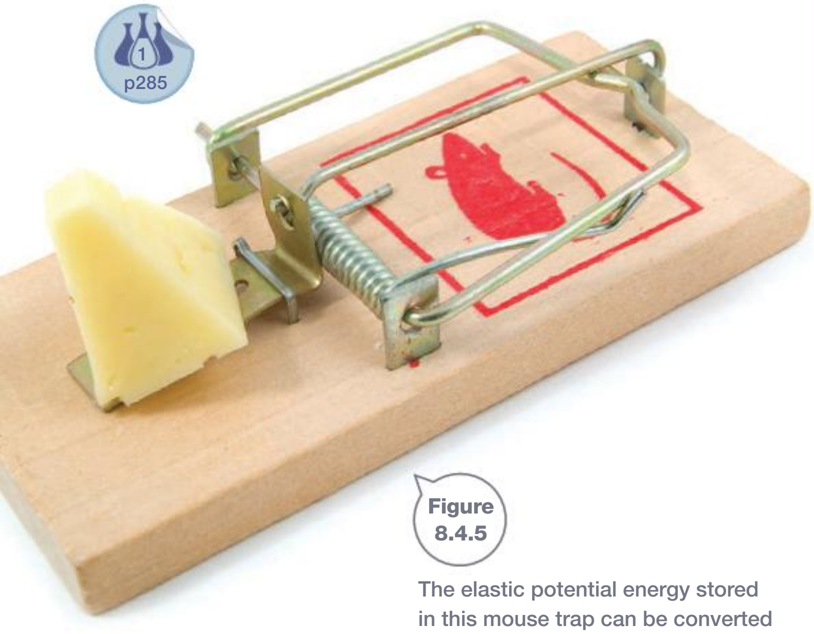


Figure 8.4.5 The elastic potential energy stored in this mouse trap can be converted in an instant into kinetic energy, sound energy and heat energy.

Gravitational potential energy

An object positioned above the ground has **gravitational potential energy**. For example, a tree branch has gravitational energy. If it falls, it will do work on any car it hits. The branch does work on the car because it moves it, or parts of it, into a different shape.

Gravitational potential energy, E_p, can be calculated using the equation:

$$E_p = mgh$$

where m is the mass (kg), g is the acceleration due to gravity (9.8 m/s^2 for objects near Earth) and h is the height (m).

WORKED EXAMPLE

Calculating potential energy

Sara is 6 years old and has a mass of 30 kg.
Calculate Sara's gravitational potential energy:

a when she climbs 2 m up a vertical ladder to the top of a slide

b at the bottom of the slide.

Solution

a $E_p = mgh$

$= 30 \times 9.8 \times 2$

$= 588$ J

Sara's gravitational potential energy at the top of the slide is 588 J.

b At the base of the slide, Sara's height above ground is zero, and so her gravitational potential energy is zero.

Conservation of energy

The **law of conservation of energy** states that energy may be transferred from one object to another, but is never created or destroyed. For any situation in which energy is transferred between objects, there is always the same amount of energy at the end as there was at the start. In other words, the total energy (E_t) involved in the system remains the same. This can be expressed by stating:

$$E_t = E_p + E_k$$

An example of this is shown in Figure 8.4.6. A tennis ball dropped from a height initially has only gravitational potential energy. As it falls, its gravitational potential energy decreases and its kinetic energy increases and the ball speeds up. Just before the ball hits the ground, all of the energy it started with has been converted into kinetic energy.

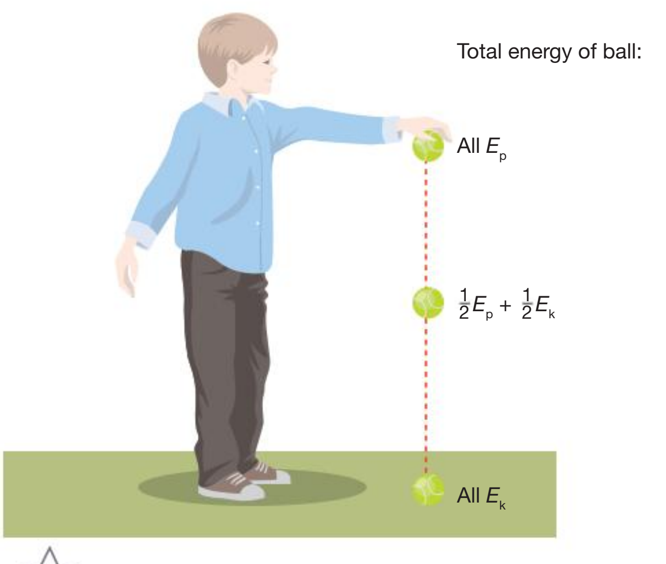


Figure 8.4.6 The total energy possessed by the tennis ball remains constant at each stage of its motion.

WORKED EXAMPLE
Converting potential to kinetic

Problem

A 0.5 kg ball is dropped from a height of 3 metres. Calculate its:

- **a** gravitational potential energy when it is released
- **b** total energy when it is released
- **c** kinetic energy when it has fallen half way
- **d** kinetic energy when it hits the ground.

Solution

a $m = 0.5$ kg, $g = 9.8$ m/s^2, $h = 3$ m

$E_p = mgh$

$= 0.5 \times 9.8 \times 3$

$= 14.7$ J

b When released, the ball has no kinetic energy, so the total energy is 14.7 J.

c Half way, the ball is at a height of 1.5 m and has gravitational potential energy:

$E_p = mgh$

$= 0.5 \times 9.8 \times 1.5$

$= 7.35$ J

The total energy is still 14.7 J, so the kinetic energy must be $14.7 - 7.35 = 7.35$ J.

The ball has the same amount of kinetic energy as potential energy at this point.

d When it reaches the ground, there is no gravitational potential energy, so kinetic energy is 14.7 J.

SciFile

Efficient travel

Cycling at speeds around 16–24 km/h is the most efficient form of transport for humans. 500 kJ can power a cyclist a distance of around 5 km, but the same energy will only power a car about 100 m!

Efficiency

Some energy is 'lost' as heat and sound energy each time a ball bounces. If this was not the case, a ball would keep bouncing forever. Similarly, in the previous Worked Example, although most of the gravitational potential energy Maddie had at the top of the slide was converted into useful kinetic energy, some of this gravitational potential energy was converted into sound energy and heat energy. These are not useful energy transformations.

The **efficiency** of an energy conversion is a measure of how much useful energy is produced. It can be expressed as:

$$\text{Efficency} = \frac{\text{useful energy}}{\text{total energy}} \times 100\%$$

2 p286

8.6

SciFile

Inductive charging

When using wires and cables to charge up electronic devices such as phones, cameras and MP3 players, some energy is lost as wasted heat energy. A number of companies developed a more efficient way to transfer energy. Through a process called inductive charging, the receiver in a device needing power is able to wirelessly accept energy from a transmitter in a charging pad.

SciFile

Efficiency of pets

Dogs are more efficient than cats when it comes to eating food! Dogs convert about 70% of their energy used to walk into forward motion. In contrast a cat typically only converts between 20–38% of the energy used to walk into actually moving forward.

8.4 Unit review

Remembering

1 **State** the units used to measure:
 a energy
 b work done.

2 **Recall** the equation used to calculate kinetic energy.

3 **State** whether a car has more kinetic energy when travelling at 10 km/h or when travelling at 60 km/h.

4 **Recall** the three factors that change the amount of gravitational potential energy possessed by an object.

5 **List** three objects that use elastic potential energy to do work.

Understanding

6 **Describe** what happens to the:
 a gravitational potential energy of an object when its height above the ground is doubled
 b kinetic energy of an object when its speed is doubled.

7 Energy is sometimes defined as 'the ability to do work'. **Explain** how an object with potential energy or kinetic energy can do work.

Applying

8 A child of weight 250 N climbs 1.5 metres up a rope ladder in 5 seconds. **Calculate** the:
 a work done
 b power of the climb.

9 **Identify** in which of the following situations work is being done.
 a A softball is thrown into the air.
 b A person rests against a chair.
 c Water runs from a tap into a sink.
 d A car is held on a hill by its brakes.

10 **Calculate** the kinetic energy of:
 a an 80 kg jogger running at 4 m/s
 b a 10 000 kg bus travelling at 54 km/h
 c a 100 g tennis ball hit at 30 m/s.

11 **Calculate** the gravitational potential energy of a:
 a 0.5 kg bird flying 20 m above the ground
 b 20 000 kg helicopter hovering 300 m above the ground
 c 2 kg money box sitting on a bookshelf at a height of 2 m.

Analysing

12 A 1 kg ball is dropped onto concrete from a height of 2 m. **Analyse** this situation and **calculate**:
 a its gravitational potential energy before it is dropped
 b its kinetic energy as it hits the ground
 c the speed with which it hits the ground (round off to one decimal place).

Evaluating

13 Researchers estimate that the risk of serious injury or death approximately doubles for every 5 km/h that a car travels above 60 km/h. **Justify** how this could be possible.

14 Figure 8.4.7 shows a section of a rollercoaster used at a theme park.

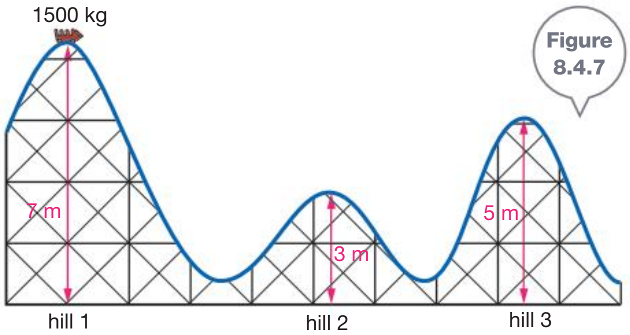


Figure 8.4.7

The rollercoaster, fully loaded with passengers, has a total mass of 1500 kg. Assume that it starts from rest and ignore the effects of friction.
 a **Calculate** its gravitational potential energy at the start of its journey.
 b **Calculate** its kinetic energy at the top of hill 2.
 c **Calculate** its kinetic energy at the top of hill 3.
 d **Calculate** its speed (to one decimal place) over hill 3.
 e If friction was taken into account, **propose** how your answers to these questions would differ.

15 **Justify** why the first hill on a rollercoaster track is usually the largest.

Inquiring

1 View footage from Pearson Reader of a collision at 60 km/h and another at 100 km/h. Compare the damage caused in these two collisions and suggest why around 40% of road deaths are due to excessive speed.

2 Investigate regenerative braking and explain how this makes a vehicle more energy efficient.

3 Investigate and explain how a plug-in hybrid electric vehicle (PHEV) operates. Outline the advantages and disadvantages of this form of transport.

4 Investigate the rebound height of different types of bouncing balls dropped from the same height and compare the energy losses of each.

8.4 Practical activities

1 Extension of an elastic band

Purpose

To investigate the effect of weight on the stretching of an elastic band.

Materials

- 2 similar elastic bands
- retort stand and clamp
- 5 × 50 g hanging masses
- ruler

Procedure

1. Copy the table in the results section. Use it or a spreadsheet to record your findings.
2. Hang an elastic band from a retort stand as shown in Figure 8.4.8 and measure its natural, unstretched length.
3. Hang a 50 g mass from the elastic band and measure its new length.
4. Calculate the extension caused by the 50 g mass.
5. Repeat for 100, 150, 200 and 250 g.
6. Repeat this process using two elastic bands looped together end to end and then positioned in parallel. (Make sure you first record the unstretched length of each combination.)

Results

1. Copy and compete the following table.

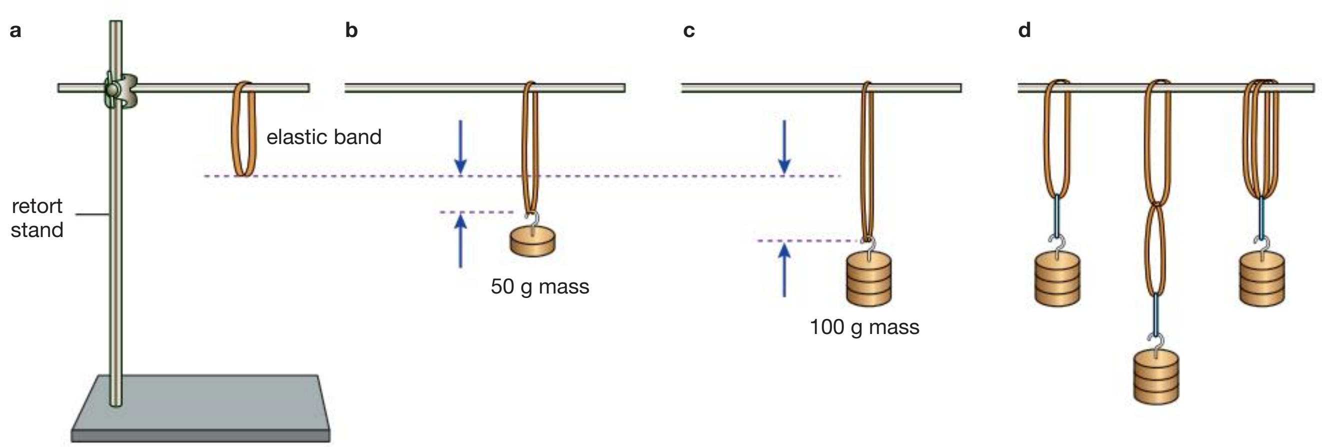
Mass attached (g)	Elastic band length (mm)			Extension of single band (mm)	Extension of two bands end to end (mm)	Extension of two parallel bands (mm)
	Single	Two bands end to end	Two bands parallel			
0				0	0	0
50						
100						
150						
200						
250						

2. Plot a graph of the extension (mm) on the vertical axis against mass (g) on the horizontal axis. Draw a line of best fit through the points.
3. On the same set of axes, plot the graphs for the double elastic band combinations.

Discussion

1. **State** which type of energy is stored in the elastic bands.
2. **Explain** how, when stretched, these rubber bands have the ability to do work.
3. **Describe** which arrangement produced the stiffest combination of elastic bands.
4. **Discuss** any sources of error from your experiment.

Figure 8.4.8



2 Energy changes in a rollercoaster

The efficiency of a rollercoaster can be found by calculating:

$$\text{efficiency} = \frac{\text{height ball reaches}}{\text{height ball was released}} \times 100\%$$

Purpose

To investigate the efficiency of three rollercoaster tracks of different designs.

Materials

You can use your own selection of materials, which may include:

- clear plastic tubing or computer cable channel
- retort stands and clamps
- marbles or ball bearings.

Procedure

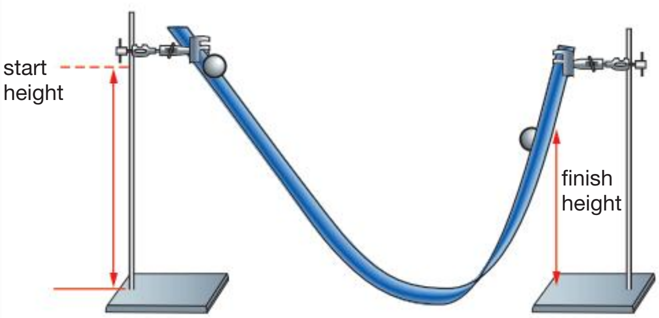
1. Design and construct three arrangements of track to investigate, such as those shown in Figure 8.4.9.
2. Record the height of the release of the marble and the height it reaches in each case.

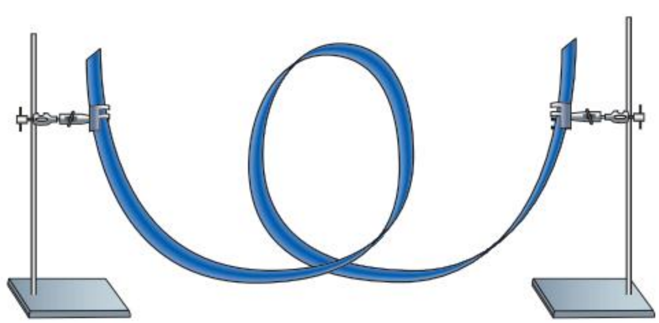
Results

Construct diagrams to show the design of each track, marked with the heights of release and finish heights.

Discussion

1. **Calculate** the efficiency of each design and explain why the efficiency was less than 100%.
2. **Discuss** any areas of difficulty you encountered in your investigation.
3. **Propose** an additional experiment you could conduct about energy conversions using this equipment.





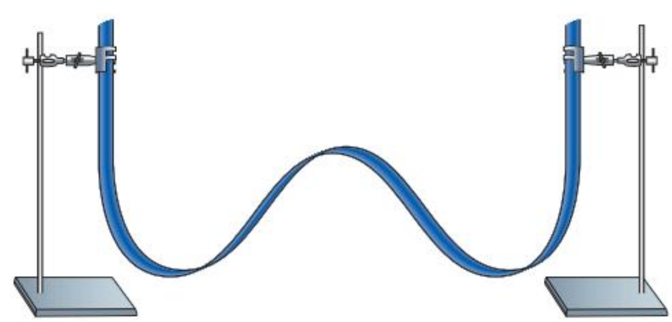


Figure 8.4.9

Chapter review 8

Remembering

1 **Recall** the SI units from the following list: kilogram, centimetre, second, gram, milligram, year, hour, tonne, minute, kilometre.

2 **State** how to convert a speed from km/h into m/s.

3 **State** what is represented by the gradient of a:
- a distance–time graph
- b velocity–time graph.

Understanding

4 **Explain** why if a horse stops running when it comes to a fence, its rider can be thrown over the top of it.

5 **Explain** why wearing a helmet when riding a bike reduces the force of an impact if the rider is involved in a collision.

Applying

6 Figure 8.5.1 shows the displacement of Steve as he rides his bike.

Use this to find:
- a the total distance travelled
- b his displacement
- c his speed in the first 2 hours
- d at which time he was stationary
- e his speed in the last 3 hours of her journey
- f his average speed over the entire trip (in km/h).

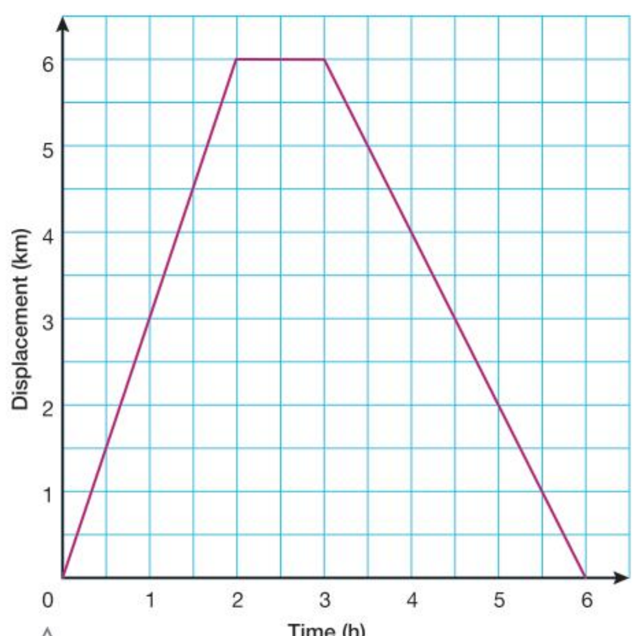


Figure 8.5.1

7 Carlo rides a tricycle down a hill, with constant acceleration of 0.1 m/s^2. This means that his speed increased by 0.1 m/s each second. If he has an initial speed of 0.2 m/s, **calculate**:
- a his speed after 3 seconds
- b this speed in km/h.

8 Two astronauts, William and Sage, are making in-flight repairs to their space shuttle. Sage asks William to pass her a toolbox, which has a mass of 5 kg. William gives the toolbox a push of 7 N. **Calculate** the acceleration of the toolbox.

9 **Calculate** the kinetic energy of a:
- a 0.1 kg apple thrown across a room at 2 m/s
- b 75 kg athlete running at 5 m/s
- c 2500 kg delivery van travelling at 80 km/h. (Hint: Convert this speed to m/s.)

10 **Calculate** the potential energy of:
- a a 9 kg rock suspended on a ledge 7 m above the ground
- b an 80 kg man who has climbed 40 m up a vertical rock face
- c a 15 kg chimpanzee sitting on a tree branch 20 m high.

11 Figure 8.5.2 represents a constant force applied to push a couch 6 m across a floor. **Calculate** the work done when it has shifted:
- a 2 m
- b 6 m.

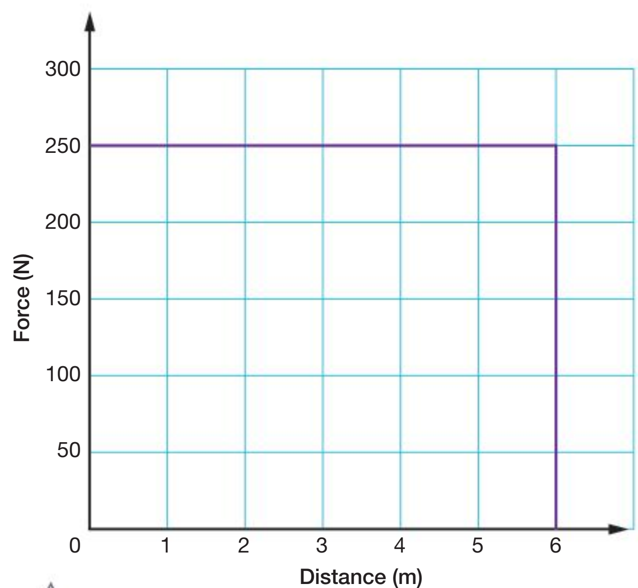


Figure 8.5.2

8 Chapter review

12 Tahlia is caught in a burning building and needs to jump from a window near the top of the building to be saved by the rescue team below. The total energy in a system is conserved. **Use** this fact to **calculate** the missing values in the diagram.

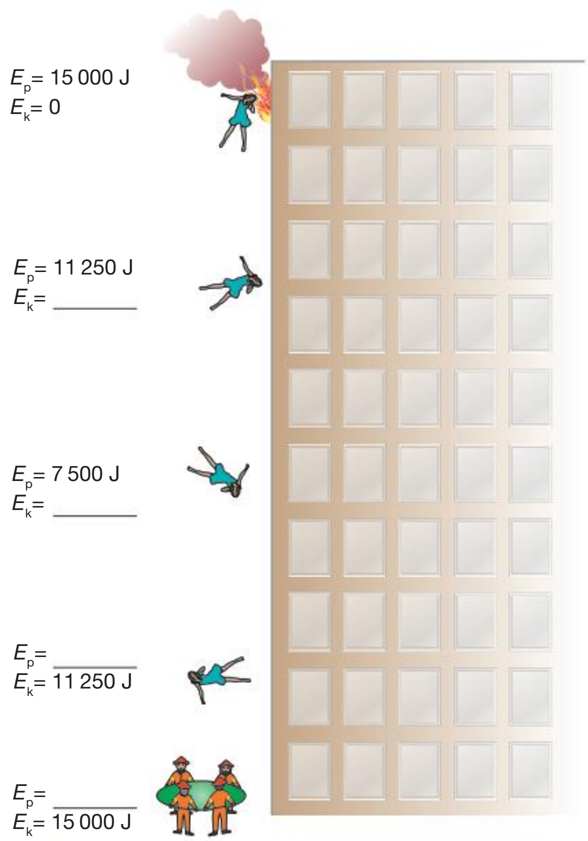


Figure 8.5.3

Analysing

13 **Analyse** the three speed–time graphs shown in Figure 8.5.4 and **describe** the motion represented by each.

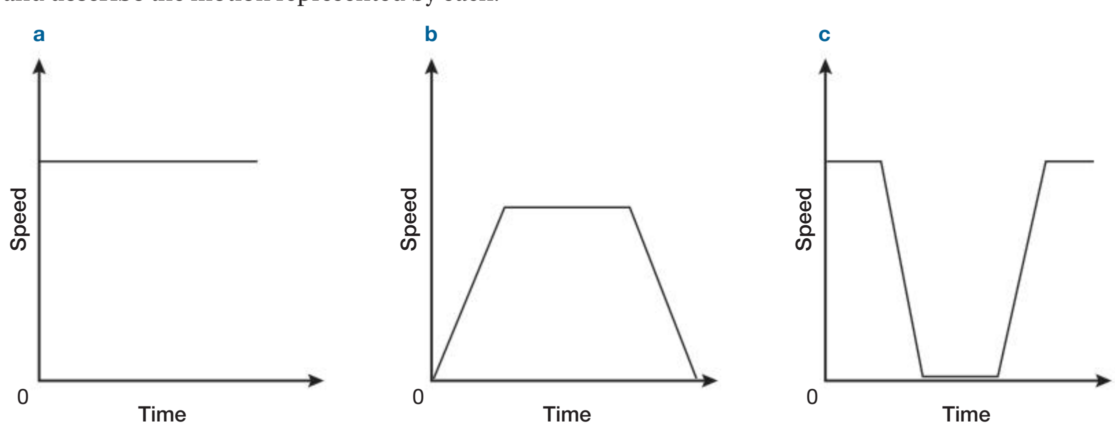


Figure 8.5.4

Evaluating

14 **Justify** why your body is thrown to the right when turning a sharp left corner on a rollercoaster.

16 You travel from the ground to the 20th floor in a city lift. **Propose** why you feel very heavy through most of the journey

Creating

15 The table below contains data about the speed of the racehorse *Newton's wings* in a race.

Time (s)	0	20	40	60	80	100	120	140	160	180
Speed (m/s)	0	3	5	7	9	9	9	9	9	9

a **Construct** a speed–time graph of this data

b **Calculate** Newton's wings' top speed in km/h.

c **Use** your graph to calculate the distance run by the horse in the race.

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

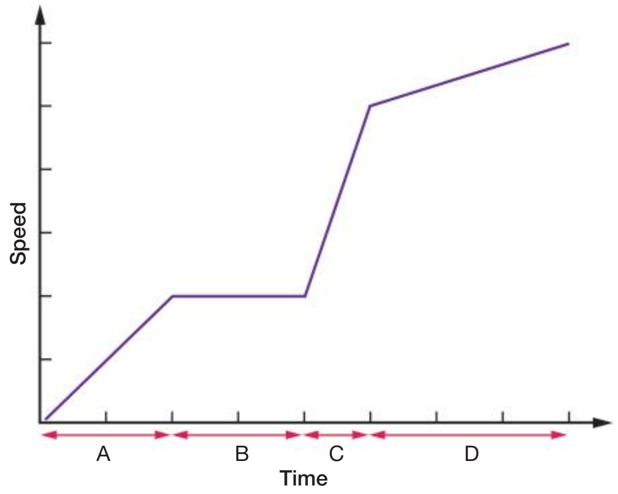
distance
displacement
speed
velocity
acceleration
force
Newton's laws
work
kinetic energy
gravitational potential energy

8.7

Thinking scientifically

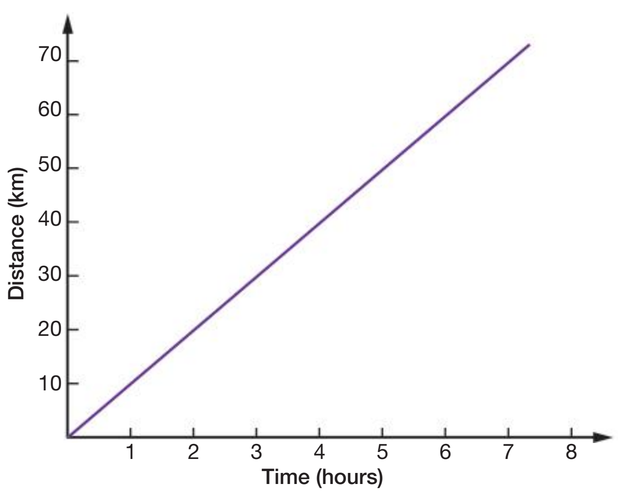
Q1 The graph below shows the motion of Tina, riding a bike home from school. Given that the gradient of a speed–time graph is Tina's acceleration, the time interval over which Tina has the greatest acceleration is:

A section A
B section B
C section C
D section D.

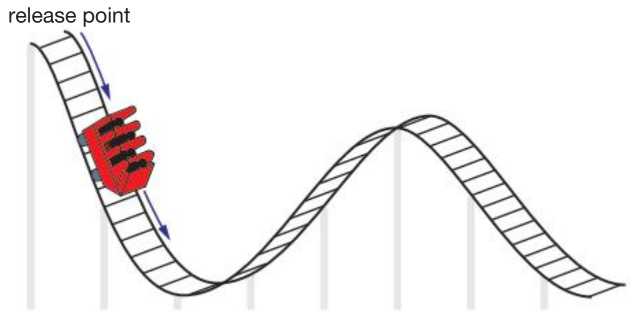


Q2 The distance–time graph of Ben's motion as he rides in a long-distance cycling event is shown below. Given that Ben's average speed is the distance travelled divided by time taken, his average speed across this time interval is:

A 10 km/h
B 10 m/s
C 1 km/h
D 1 m/s.



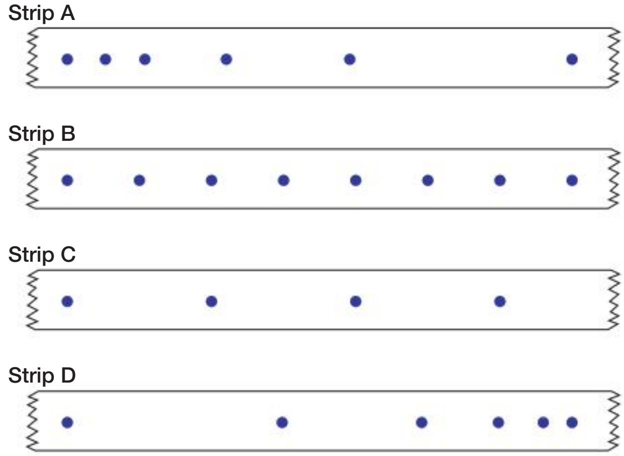
Q3 The diagram shows the position of a rollercoaster cart soon after it is released on a track. Select the alternative that describes how its energy is changing at this moment in time.



A increasing kinetic energy, constant gravitational potential energy
B increasing kinetic energy, decreasing gravitational potential energy
C decreasing kinetic energy, increasing gravitational potential energy
D decreasing kinetic energy, constant gravitational potential energy

Q4 The hammer on a ticker timer vibrates up and down 50 times per second. The following four strips of ticker tape were attached to a moving object. These dots display a record of its motion. The strip that indicates the fastest constant speed is:

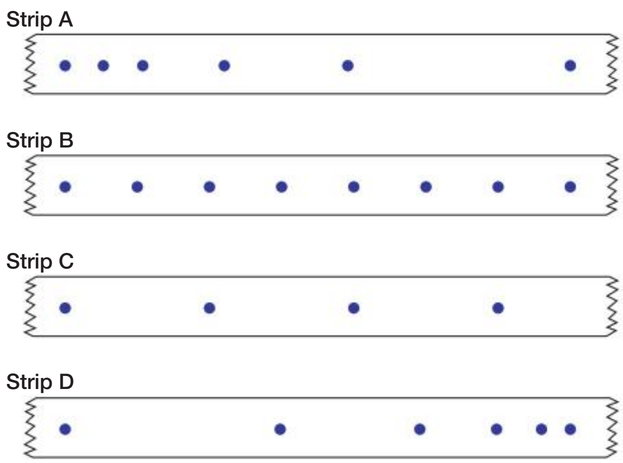
A strip A
B strip B
C strip C
D strip D.



Thinking scientifically

Q5 The hammer on a ticker timer vibrates up and down 50 times per second. The following four strips of ticker tape were attached to a moving object. These dots display a record of its motion. The strip that indicates an object that is slowing down is:

A strip A
B strip B
C strip C
D strip D.

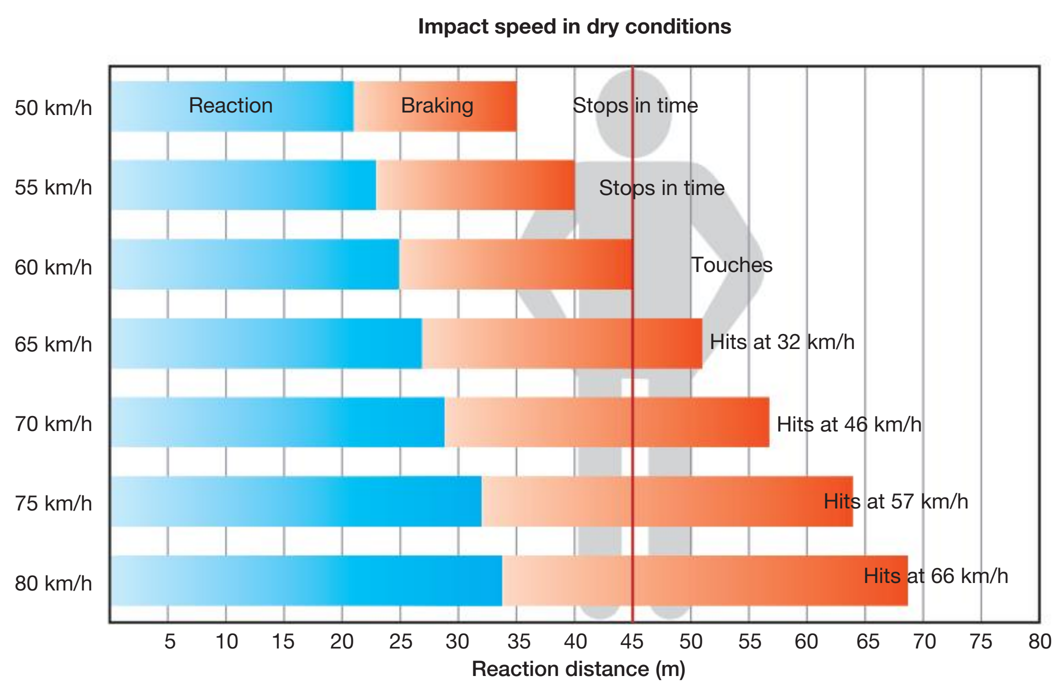


Q6 Cathy pushes a shopping cart of mass *m* with force *F*. By Newton's second law of motion (and ignoring friction), the cart has acceleration $a = F/m$. Cathy now uses the same-sized force to push a cart that has three times the mass. Its acceleration is:

A double the acceleration of the first cart
B three times the original acceleration
C one-third of the original acceleration
D half of the original acceleration.

Q7 Study the graph below, which estimates the typical reaction time and reaction distance for drivers travelling at various speeds. Imagine that two cars are travelling along a multilane highway, car A at 55 km/h and car B at 75 km/h. A wombat staggers onto the road 50 m ahead of the cars the instant they are both the same distance away from it. Assuming the drivers react as shown in the graph, determine the correct alternative.

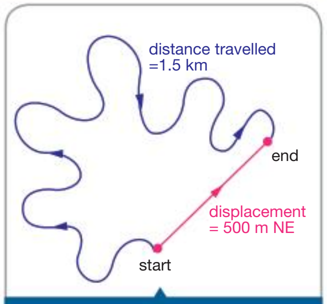
A Both cars stop in time.
B Only car A stops in time.
C Only car B can stop in time.
D Neither car is able to stop in time.



Glossary

Unit 8.1

Displacement: a measurement of the change in position of a moving body; a straight line connecting the start and end points is specified in terms of length and direction



Displacement
Distance

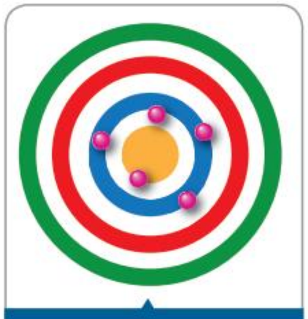
Distance: a measurement of how far apart objects are

Error: the difference between the value that is measured and the actual measurement

Gradient: slope of a hill of a graph: gradient = $\frac{\text{rise}}{\text{run}}$

Instantaneous speed: the speed of an object at a particular moment

Precision: how close measured values are to each other


Precision

Random error: error that changes

Reaction distance: distance moved while reacting to an emergency

Reaction time: the length of time it takes a driver to respond to a hazard

Scalar quantity: a quantity, such as distance or time that has size but not direction

Speed: the rate of change of distance

Systematic error: error that always differs by the same amount

Vector quantity: a quantity, such as displacement or velocity, that has size and direction

Velocity: the rate of change of displacement

Unit 8.2


Acceleration

Acceleration: rate of change of velocity

Air resistance: friction between the air and a moving object

Terminal velocity: the final velocity that an object falls with no further acceleration possible due to air resistance

Unit 8.3

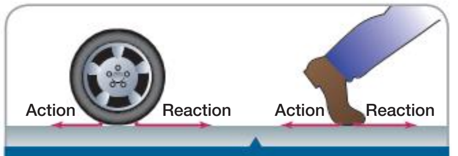
Inertia: the tendency of an object to resist changes in its motion


Inertia

Newton's first law of motion: an object at rest will remain this way unless it is acted upon by an unbalanced force; an object that is moving will continue to move in the same manner unless acted upon by an unbalanced force

Newton's second law of motion: an object will accelerate in the direction of an unbalanced force acting upon it such that: $F_{net} = m \times a$

Newton's third law of motion: for every action, there is an equal and opposite reaction

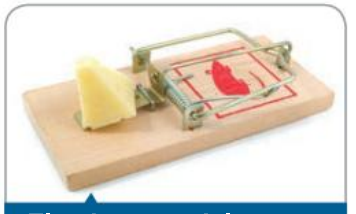


Newton's third law of motion

Unit 8.4

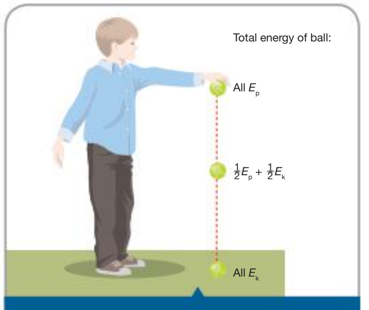
Efficiency: a measure of the useful energy output of an energy transfer

Elastic potential energy: energy stored in a stretched or compressed material, such as a spring or elastic band


Elastic potential energy

Gravitational potential energy: the potential energy possessed by an object due to its position above the ground

Kinetic energy: the energy of a moving body



Gravitational potential energy

Law of conservation of energy: energy may be transferred but is never created or destroyed

Potential energy: energy possessed by an object because of its position or structure, also called stored energy

Power: the rate at which work is done; measured in watts (W)

Work: the energy transferred by a force that acts over a certain distance; measured in joules (J)

9 Structures

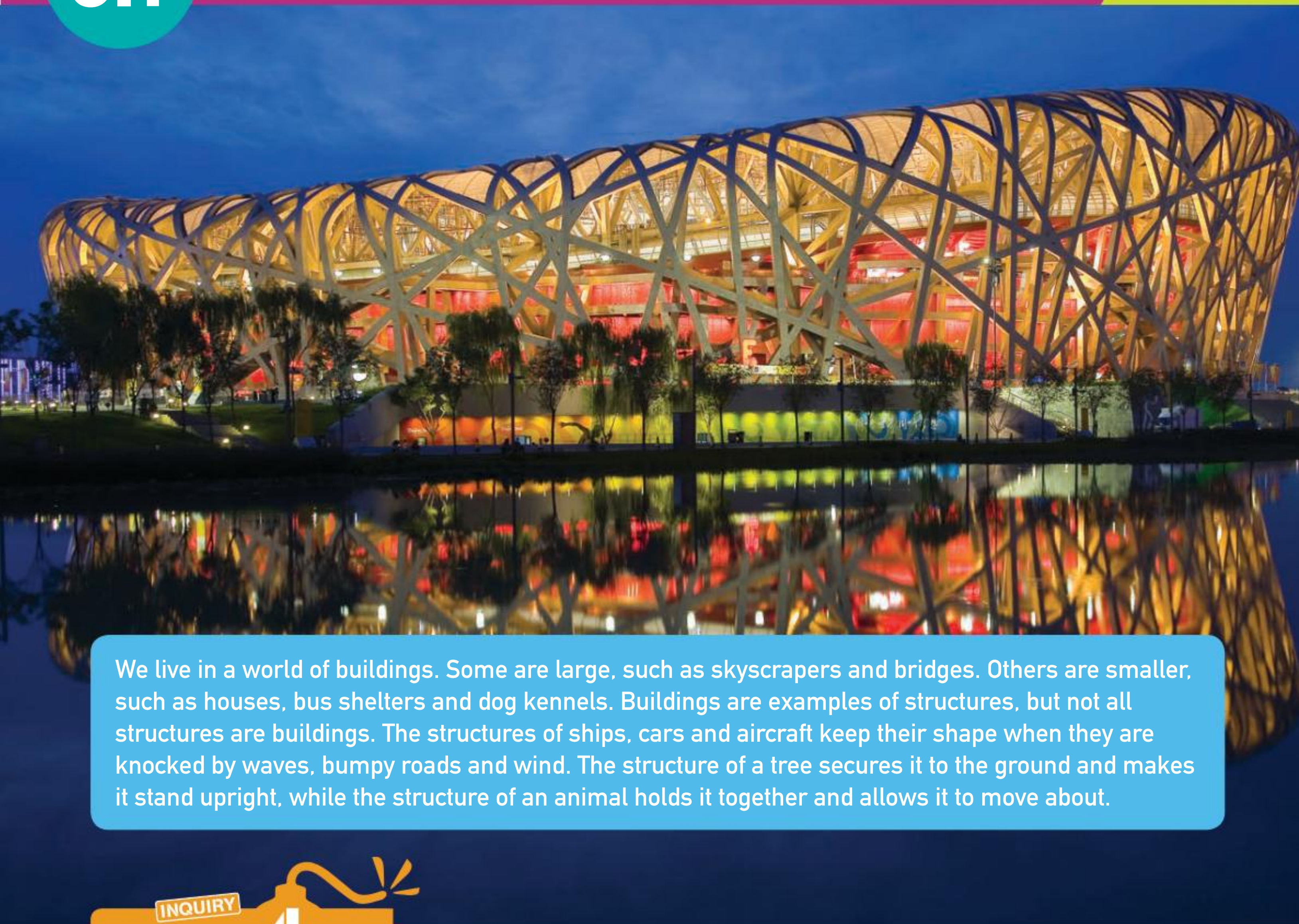
HAVE YOU EVER WONDERED…

- what holds a building up?
- what tension and stress are?
- why house frames are made of wood or steel?
- how skyscrapers can be built so high without falling down?
- how bridges can span huge distances without breaking in the middle?

After completing this chapter students should be able to:

- recall that a stationary object, or a moving object with constant motion, has balanced forces acting on it
- use Newton's second law to predict how a force affects the movement of an object
- apply Newton's third law to describe the effect of interactions between two objects
- use modelling and simulations to investigate situations and events.

9.1 Forces in a structure



We live in a world of buildings. Some are large, such as skyscrapers and bridges. Others are smaller, such as houses, bus shelters and dog kennels. Buildings are examples of structures, but not all structures are buildings. The structures of ships, cars and aircraft keep their shape when they are knocked by waves, bumpy roads and wind. The structure of a tree secures it to the ground and makes it stand upright, while the structure of an animal holds it together and allows it to move about.

INQUIRY science 4 fun

Tense standoff

Can you stand a ruler on its end?

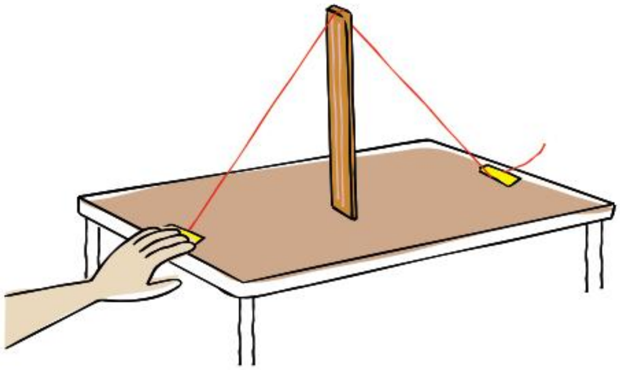
Yes

Collect this ...

- 30 cm ruler
- at least 60 cm of string
- 2 drawing pins or sticky tape

Do this ...

1. Try to stand a ruler on its end. Can you do it?
2. Secure one end of the string to the table by pinning or taping it down.
3. Stand the ruler up and pass the string over it as shown below.
4. Secure the other end so that the string is tight.



Record this ...

Describe what happened.
Explain why you think this happened.

Force

If something falls down, changes shape, changes direction, speeds up, slows down or stops, then a force caused the change. A **force** is a push, pull or twist. Examples are the push to open the front door when you get home from school, the pull of gravity as you step off a diving board at the local pool, or the twist on a towel as you try to wring the water out of it.

Most objects have more than one force acting on them at the same time. For example, the bike shown in Figure 9.1.1 has four forces acting on it. Your pedalling produces a force that pushes you forwards. The wind and roughness of the road produce another force that pushes backwards, slowing you down. (These forces are known as air resistance and friction.) Weight is a force that pulls the bike downwards while the ground produces another force called a reaction force that stops you from sinking into it. What the bike does depends on whether all those forces are balanced or unbalanced.

Newton's first and **second laws** of motion summarise what happens:

- If forces are balanced, then no change will happen—the object will stay at rest or will keep moving at a constant speed.
- If forces are unbalanced, then the object will accelerate and its motion will change.

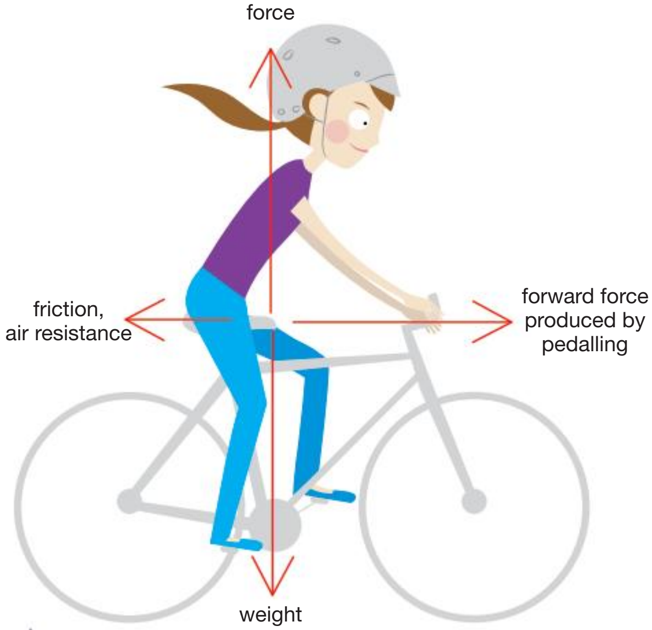


Figure 9.1.1 There are four main forces acting on a bike. The longer the arrow, the bigger the force.

Balanced and unbalanced forces

A bike resting on its stand is not moving, and so the forces on it are **balanced**. There are gravity and reaction forces acting on the bike but they balance each other, adding up to zero.

Unbalanced forces cause the movement of the bike to change. For example, the bike **accelerates** (speeds up) when there is an overall, unbalanced force pushing it forwards. This happens when you pedal harder than what is needed to overcome air resistance and friction. A bike **decelerates** (slows down) because there is an overall, unbalanced force pushing back on it that is slowing (perhaps stopping) its forward movement. This will happen when the force from the brakes, air resistance or friction is greater than the force from your pedalling, or if you stop pedalling. The bike will change direction if there is an overall, unbalanced force pushing it sideways. This happens when you turn the handlebars or are knocked sideways when you hit the kerb.

SciFile

Moving and shaking

Engineers who design buildings and bridges for earthquake-prone regions sometimes test a model of their structure on a shake table. This special platform shakes the model in several different directions at once to test how the structure could withstand a real earthquake.

Buildings normally don't move about and so are very different from bikes. Buildings are designed so that *all* the forces on them (and in every part of them) are *always* balanced. This way the structure won't move but will stay upright and retain its shape. If any of the forces on the building become unbalanced, then the building (or part of it) will change. The building might break, crack, crumple or twist. This is known as **failure**.

If the failure is minor, then it can cause parts of the structure to move a little or change shape slightly. Doors might jam or windows stick, or tiles, plaster and brickwork might crack. This has happened in Figure 9.1.2.

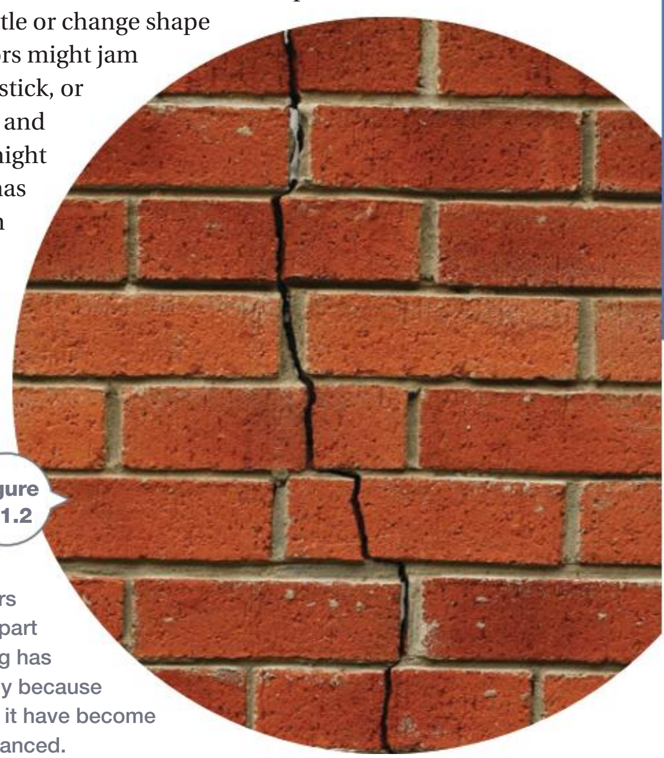


Figure 9.1.2 Cracks and jamming doors indicate that part of the building has shifted slightly because the forces on it have become slightly unbalanced.

If an important part of its structure fails, then the whole building is likely to collapse. For example, the failure of a wall might cause one part of the building to fall down, twisting the rest of the structure so badly that it can no longer stay upright. This is what happened to the hotel in Figure 9.1.3.

Figure 9.1.3 Buildings like this hotel can collapse if the forces on them (or on a part of them) become badly unbalanced.

Gravity, mass and weight

Gravity pulls everything towards the centre of Earth (or the Moon or Mars if you happen to be there instead). It is what makes things fall down, including buildings.

The **weight** of a building depends on gravity and on the mass (the amount of material) that is in it.

SciFile

Losing weight!

Your weight depends on your mass and the mass of the planet you are on. Smaller planets and moons generally have less mass than bigger ones, and so gravity and weight are less there too. For example, on the Moon you weigh only one-sixth what you do on Earth!

Weight is a force and so bigger buildings push down on the ground more than smaller buildings. Likewise, buildings made of dense materials such as brick, stone, steel and concrete push down on the ground more than buildings of a similar size made of less dense materials such as timber, plaster, bamboo or thatched grasses.

9.1

Compression and tension

Every part of a structure is pulled downwards by its weight. If the structure is to stay upright, then this weight needs to be balanced by another force that pushes it or pulls it upwards. **Newton's third law** states that for every force, there is an equal and opposite force. Hence, every part of a structure should have a reaction force that balances its weight. The overall force on each part is zero and so the part stays in place and the structure does not fail. This combination of weight and reaction forces causes different parts of a structure to be in compression or in tension.

Compression

Figure 9.1.4 shows a carport. The weight of the roof pushes downwards through the posts and would push them into the soil if the ground didn't push back upwards to balance it.

The downwards push of the roof and the upwards push from the ground compress (squash) the post. The post is said to be in **compression**. If the post cannot withstand all that compression, then the structure will fail.

In the same way, the weight of the column in Figure 9.1.5 and force from the ground compresses its bricks.

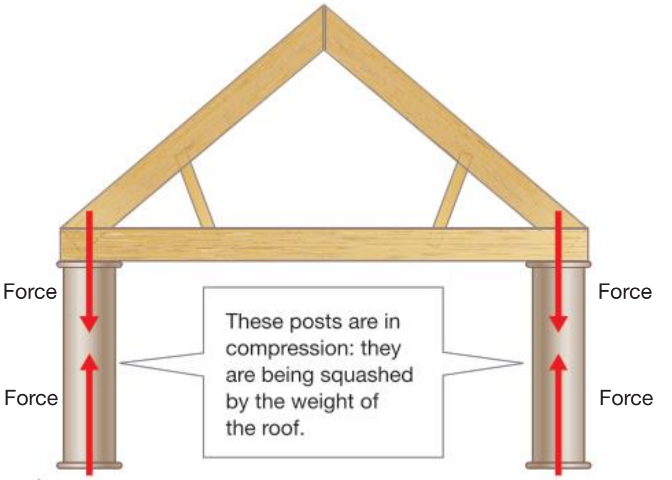


Figure 9.1.4 The forces in a post compress it, squashing it and making it a little shorter. The post is said to be in compression.

1 p300
2 p301
3 p301

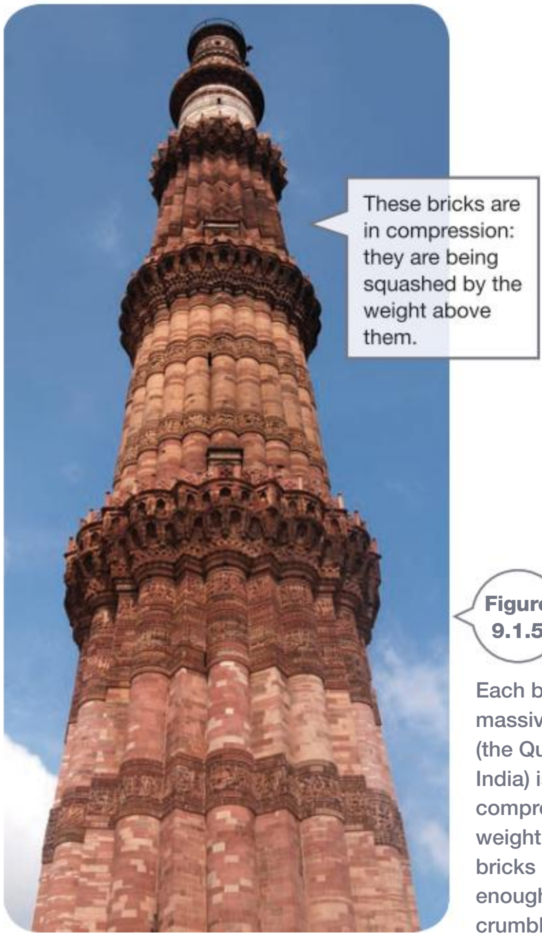


Figure 9.1.5 Each brick in this massive 73 m column (the Qutab Minar in India) is being compressed by the weight above it. If the bricks are not strong enough, they will crumble and fail.

Tension

Another way of supporting the weight of a structure is to pull it upwards by a cable, chain or rope. The Sydney Harbour Bridge (Figure 9.1.6) uses cables to support its deck of road and rail tracks. The weight of the deck pulls the cables downwards but the arch of the bridge pulls the cable upwards. These two up and down forces stretch the cable, keeping it taut (tight). The cable is said to be in **tension**. Cables in tension can also hold a roof up, like the stadium roof in Figure 9.1.7.

Figure 9.1.6 The weight of the road and rail tracks of the Sydney Harbour Bridge is suspended from cables attached to the arch overhead. Each cable is in tension and is being stretched.

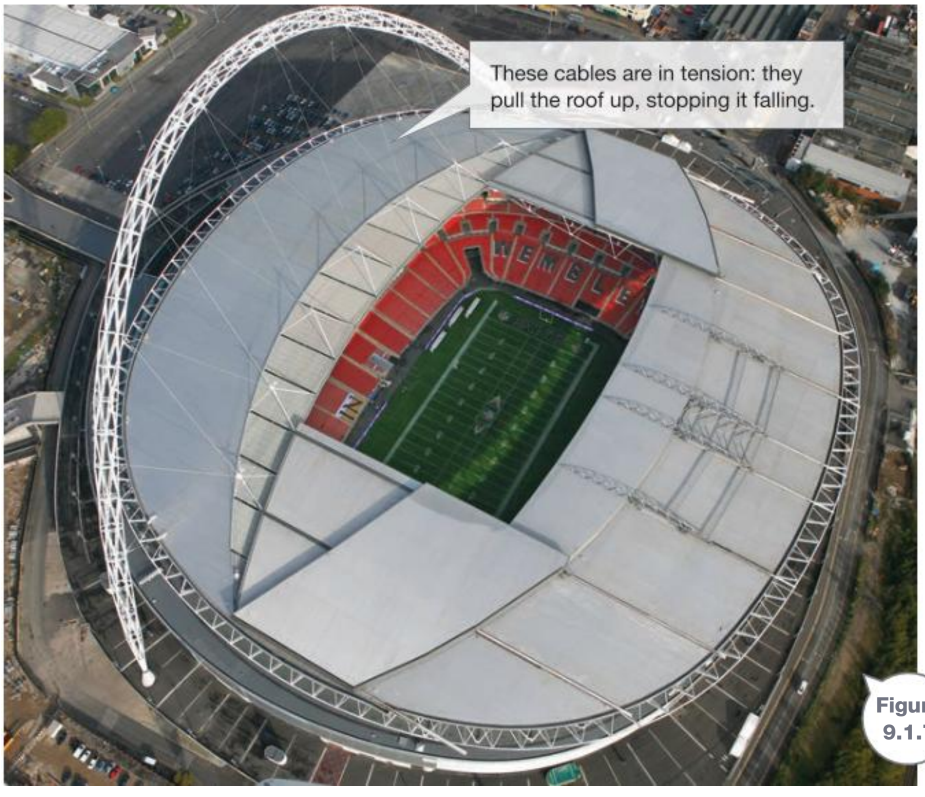


Figure 9.1.7 These cables hold up the roof of the Wembley Stadium in England. The cables are in tension and engineers design them so that they can easily withstand the tensile forces on them.

SKILL BUILDER

Identifying compression and tension

Compression squashes and tension stretches. To identify which parts of a structure are under compression and which are under tension, think about what each part would do if it were replaced by a cable, chain or rope.

- If the part is under tension, then the cable, chain or rope would remain taut (tight).
- If the part is under compression, then it would collapse if it were replaced by a cable, chain or rope.

Substances used in structures

Concrete, brick, marble and granite are incredibly strong when compressed, but they break when stretched. In contrast, substances like carbon fibre, nylon and Kevlar are strong only when stretched. Other materials like steel, aluminium, timber and bone are strong when under compression or tension. Choose the wrong substance and the part it is made from will fail, possibly causing the structure to collapse.

4 p302 9.2

Stress

Force is important when discussing the materials a building is built from, but another quantity called stress is even more important. **Stress** measures how concentrated a force is on a material. High stresses are more likely to cause a material to fail than low stresses. Like forces, stress can be compressive (placing the substance in compression, squashing it) or tensile (placing it in tension, stretching it).

Table 9.1.1 shows the stress that different materials can withstand before they break. Stress can be expressed using the units newtons per square metre (unit symbol N/m^2) but its numbers are usually so high that stress is usually measured in meganewtons per square metre (MN/m^2) instead. These are also the units used for pressure when discussing liquids and gases in chemistry. For this reason, stress can be thought of as the pressure on a solid material.

Table 9.1.1 Strength of materials when placed under compression and tension

Behaviour	Material	Maximum compressive stress (MN/m^2)	Maximum tensile stress (MN/m^2)
Strong under compression only	Concrete	20	2
	Marble	80	0
	Granite	240	0
	Brick	35	2
	Cast iron	550	170
Strong under tension only	Carbon fibre	0	5560
	Nylon fibre	0	500
	Kevlar	0	3620
Strong under compression *and* tension	Steel	500	820
	Aluminium	200	200
	Brass	250	250
	Timber (pine, cut along the grain)	35	40
	Bone	170	130

Stress and area

Stress depends on the force being applied and the area the force is being applied to (Figure 9.1.8). Mathematically, stress is given by the formula:

$$\text{Stress} = \frac{\text{force}}{\text{area}} = \frac{F}{A}$$

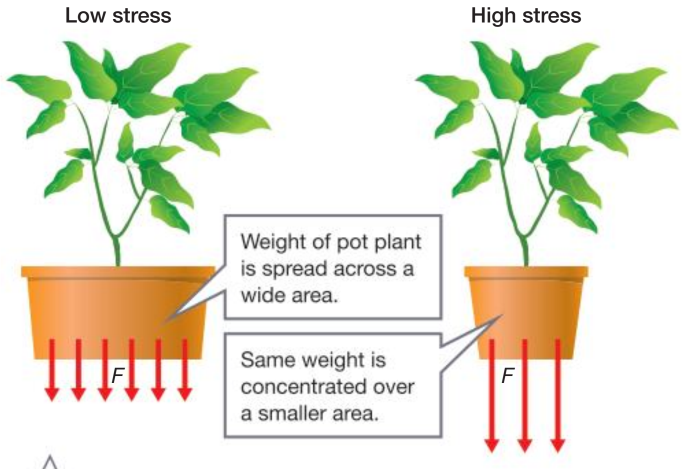


Figure 9.1.8 Stress is highest when force is high and the area to which it is applied is small.

You always exert the same weight force on the ground regardless of what shoes you wear. However, different imprints are left behind by different shoes. For example, high-heels sink deep into mud and snow while flat, wide-soled boots have far less effect. What has changed is the area over which your weight is spread. Boots spread your weight over a large area and so the stress on the mud and snow is small. Skis, snowboards and snowshoes (like those in Figure 9.1.9) spread your weight over an even larger area and have even less effect than boots. High-heels concentrate your weight into a tiny area. Stress on the mud or snow is high and down you sink.

Figure 9.1.9 Snowshoes, skis and snowboards have large surface areas and spread your weight much more than normal shoes. Stress on the snow is minimal (very small), allowing you to move easily across the snow.

Stress also explains why knives, axes and scissors all need to be sharp to be effective. Sharpening makes the cutting edge very narrow, reducing the area over which the cutting force is applied. The force is concentrated on whatever you are cutting and stress on the material is high. This makes it easier to cut.

Necking

Stress also explains why a material is most likely to break at a scratch or dent. Think of a wire with a severe scratch at one point. The cross-sectional area will be constant all along the wire except where the scratch is. There the wire is thinner and the area less. When the wire is placed under tension, stress at the scratch will be far higher than along the rest of the wire. This causes it to stretch more at the scratch than the rest of the wire, thinning it even more. As the wire gets thinner, stress increases until eventually the wire snaps at the scratch. The process is called **necking** because of the neck-shape formed just before it breaks. Figure 9.1.10 outlines how it happens.

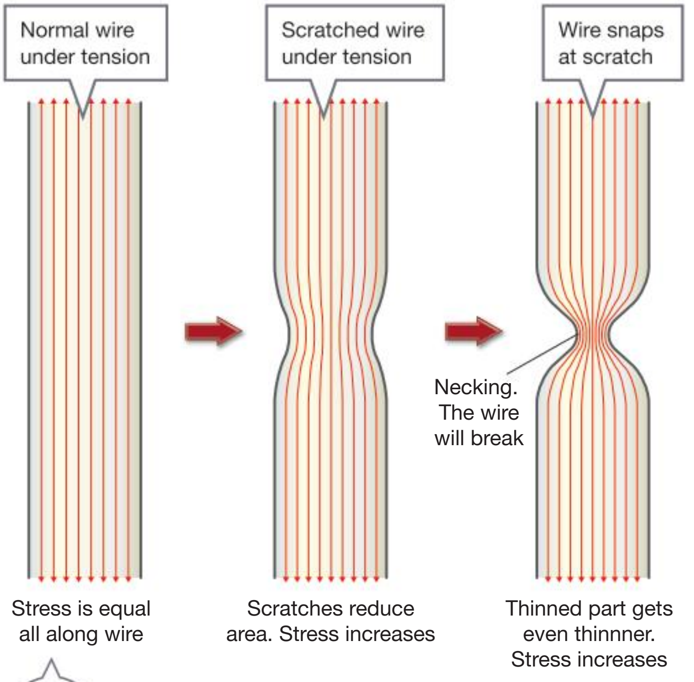


Figure 9.1.10 Scratches increase the stress on a wire. This leads to necking and eventual breakage.

9.1 Unit review

Remembering

1 **State** whether the following are under compression or tension.
- **a** columns
- **b** cables

2 **List** the following materials in order of compressive strength from strongest to weakest:

concrete, marble, granite, brick, pine, bone

3 Using Table 9.1.1 on page 297, **name** two materials that are strong under:
- **a** compression but not tension
- **b** tension but not compression
- **c** both compression and tension.

Understanding

4 **Predict** what would happen if a garden hose was placed under:
- **a** tension
- **b** compression.

5 **Outline** why wires are more likely to break at a scratch than anywhere else.

6 **Describe** the property of Kevlar that makes it the ideal material to make sails from for a yacht.

Applying

7 Figure 9.1.11 shows a bird's-eye-view of three cars driving down a road and the overall forces acting on them. **Identify** which car would be:
- **a** accelerating
- **b** decelerating
- **c** changing direction.

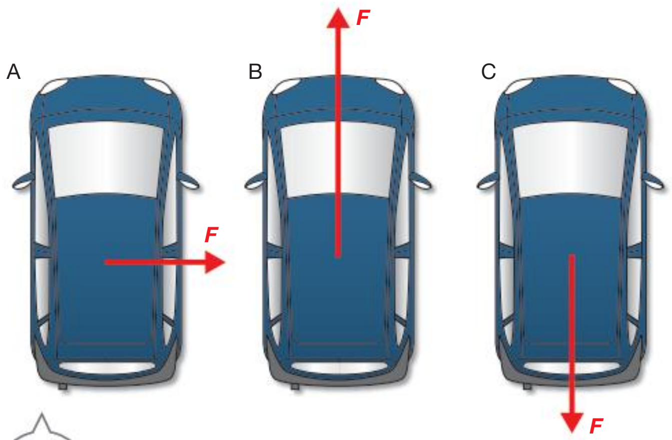


Figure 9.1.11

8 **Identify** whether the following are under compression or tension.
- **a** earlobes that have heavy earrings in them
- **b** the legs on a table
- **c** the string of a guitar
- **d** your legs when you are standing
- **e** a child's arms when hanging from the monkey bars or climbing frame

9 Being poked by someone's finger hurts more than being pushed with an open hand with the same force. **Use** the concept of stress to **explain** why.

10 **Calculate** how much stronger granite is under compression than:
- **a** concrete
- **b** marble.

11 **Calculate** how much stronger carbon fibre is under tension than:
- **a** nylon
- **b** pine.

12 Different forces were applied to different areas of a building material. **Calculate** which of the following samples is under the greatest stress.

Material A: 2 MN applied over 1 m^2

Material B: 2 MN applied over 0.5 m^2

Material C: 4 MN applied over 2 m^2

Material D: 1 MN applied over 0.5 m^2

Analysing

13 In the Science4fun activity on page 293, a ruler is held upright by a string. **Identify** whether the following are in compression or tension.
- **a** the string
- **b** the ruler

14 In force diagrams like those in Figure 9.1.12, longer arrows indicate larger forces. Forces of equal size are drawn as arrows of the same length. **Use** this information to **analyse** the force combinations shown. **State** which are balanced and which are unbalanced.

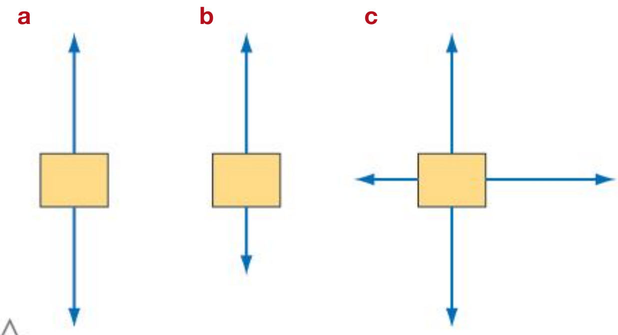


Figure 9.1.12

15 **Classify** the force combinations shown in Figure 9.1.13 as compression or tension.

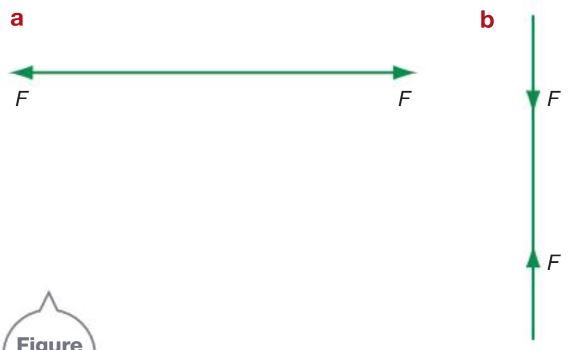


Figure 9.1.13

16 **Analyse** the components in the structures holding up the signs in Figure 9.1.14 and **classify** the forces in them (labelled I–VIII) as either tension or compression.

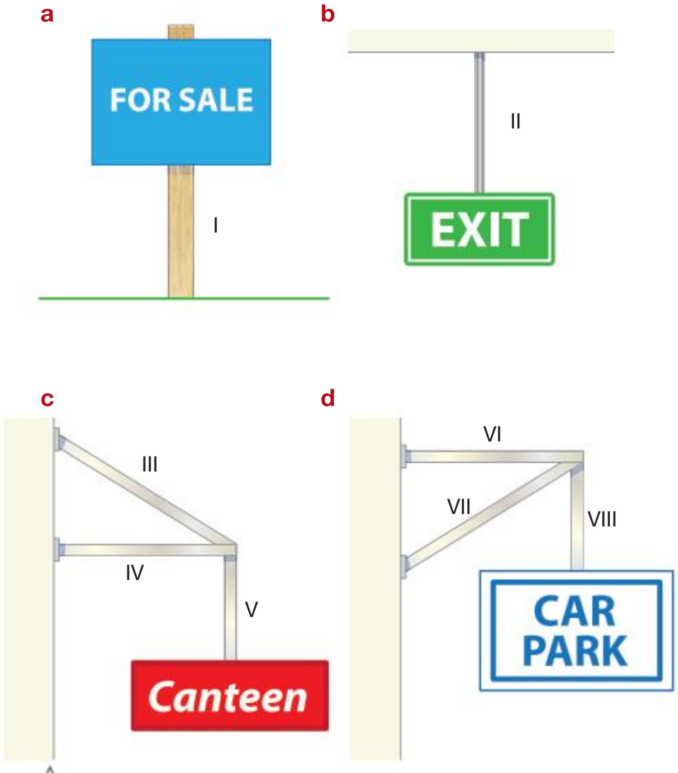


Figure 9.1.14

Evaluating

17 If something is not moving, then there are no forces involved.
- a **Analyse** the above statement and decide if you agree or disagree with it.
- b **Justify** your answer.

18 The frames that make up the structures of many houses are commonly made of timber. **Propose** three reasons why.

19 The frames and outside of many aircraft are made from aluminium. **Propose** reasons why.

20 People wearing high heel shoes are sometimes required to remove their shoes before walking across polished wood floors. **Propose** a reason why.

21 Nails have sharp tips and are not blunt. **Use** the concept of stress to **propose** a reason why.

Inquiring

1 a Find out what a pile driver is, where and why it is used and what forces are involved.
- b Find videos showing a pile driver in action.

2 Search the internet for videos showing how a house is built from the foundation up. Possible key words are *build house video*.

3 Columns often have fancy tops called capitals. Explore the internet to construct a portfolio of images showing different types of capitals. Find images of capitals known as:
- Ionic
- Corinthian
- Egyptian
- Doric
- Byzantine
- Romanesque.

4 Research one of the following substances: Kevlar, fibreglass, steel. Whichever one you look into, find:
- a what its properties are
- b how it is manufactured
- c what it is used for.

5 Use the key words *earthquake shake table* or *earthquake simulation* to find animations and video on structures being tested under earthquake conditions.

6 Mudbricks aren't made of just mud. Research what else is added to them, find a 'recipe', and use it to make a brick.

9.1 Practical activities

1 Investigating column shapes

Columns and pillars have been used since ancient times to support structures. Their strength depends on a number of factors.

Purpose

To test the strength of columns with cross-sections of different shapes.

Materials

- small tub (e.g. margarine tub)
- sheet of cardboard, large enough to support the tub
- 50 g masses
- multiple sheets of A4 paper (uncrumpled scrap A4 is fine)
- sticky tape
- access to scissors

Procedure

1 Curl an A4 sheet to construct a cylinder as shown in Figure 9.1.15.

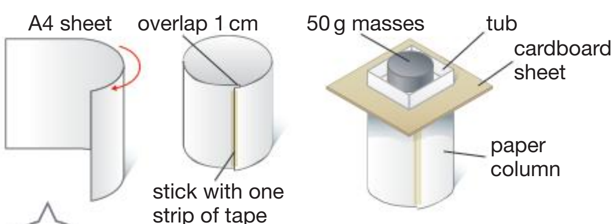


Figure 9.1.15

2 Join the edges of the cylinder by overlapping a maximum of 1 cm and using one strip of sticky tape along the outside edge.

3 Set up the column, cardboard sheet and tub as shown.

4 Add 50 g masses to the tub until the column 'fails'.

5 Now construct columns with the shapes shown in Figure 9.1.16. Make sure that:
   - the paper is folded so that the columns are all the same height
   - the creases are 'crisp' and parallel
   - the overlap is roughly the same each time (maximum 1 cm)
   - one single strip of tape is used each time along the outer edge of the join.

6 As before, test each column by adding 50 g masses to the tub until the column fails.

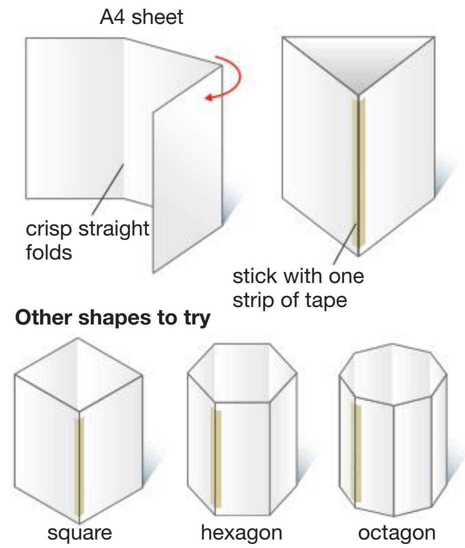


Figure 9.1.16

Results

In your workbook, construct a table like that shown below and use it to record your results.

Cross-section shape	Number of 50 g masses required to cause failure	Mass required to cause the failure (g)
Circle (forming a cylinder)		
Triangle		
Square		
Hexagon		
Octagon		

Discussion

1 **Describe** what happened to each column as it failed. Did it crumple evenly, split or bend?

2 **Compare** the results you obtained by ranking the columns in order from strongest to weakest.

3 **Describe** what happened to the column strength as the number of sides increased.

4 Cars do not have flat sheets of metal making up their bonnets, boots and doors, but have creases and folds in them. **Use** the results from this experiment to **propose** a reason why.

2 Investigating column diameter

Purpose

To test the strength of columns with different diameters.

Materials

- as per Practical activity 1

Procedure

Design an experiment that tests the strength of cylindrical columns of different diameters.

Results

Construct a table and line graph to display your results.

Discussion

1 **Rank** your columns in order from strongest to weakest.
2 **Describe** how this pattern is displayed in the line graph.

3 Loads on bridge columns

Purpose

To observe what happens to the compression in the columns of a bridge as a load passes over it.

Materials

- 1 m length of light wood (e.g. balsa, pine)
- 1 m ruler
- felt-tip pen
- 2 scales or electronic balances (representing 2 columns)
- large mass (e.g. 100 g, 200 g, 500 g)

Procedure

1 Use the 1 m ruler to place a mark on the length of wood every 20 cm.
2 Set up the apparatus as shown in Figure 9.1.17. The scales are the columns of your bridge.
3 If the scales have a 'tare' button, tare the scales so that they read zero.
4 Place the mass on the wood directly above one of the scales. (Call this Scale 1.)
5 Take the readings off both scales and record them in a table similar to that in the results section.
6 Shift the mass to the next 20 cm marking and repeat until the mass is directly above the other scale. (Call this Scale 2.)

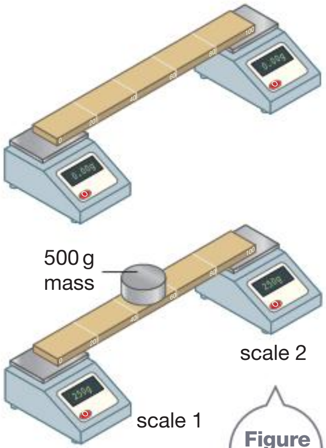


Figure 9.1.17

Results

In your workbook, construct a results table like that shown below.

Distance from Scale 1 (cm)	Distance from Scale 2 (cm)	Reading on Scale 1 (g)	Reading on Scale 2 (g)	Total mass reading (g)
0	100			
20	80			
40				
60				
80	20			
100	0			

Discussion

1 The scale readings you took are related to the compression forces in each column. The higher the mass, the higher the compression force in the column. As the mass is moved across the bridge, **describe** what happens to the compression in:
   a column 1
   b column 2.

Loads on bridge columns continued on next page

Loads on bridge columns continued

2 Imagine a heavy truck passing over a bridge like that tested in this experiment. **Identify** where the truck would be if the compression was:
   a the same in both columns of the bridge
   b zero in one of the columns.

4 Material testing

Purpose
To test the behaviour of a material.

Materials
- retort stand, bosshead and clamp
- fishing line
- 30 cm ruler
- 50 g masses and holder (with hook)
- foam rubber or something similar to act as a cushion

Procedure
1 Set up the apparatus as shown in Figure 9.1.18.
2 Lightly stretch out the fishing line as it hangs from the retort stand and accurately measure its natural length (in millimetres) before any masses are added to it.
3 Use the hook to add masses to the line. Each time a new mass is added, measure the new length of the fishing line. Record the masses (in gram) and length (in millimetres) in a table like that shown below.
4 Keep adding masses until the fishing line snaps or you have added 1 kg.

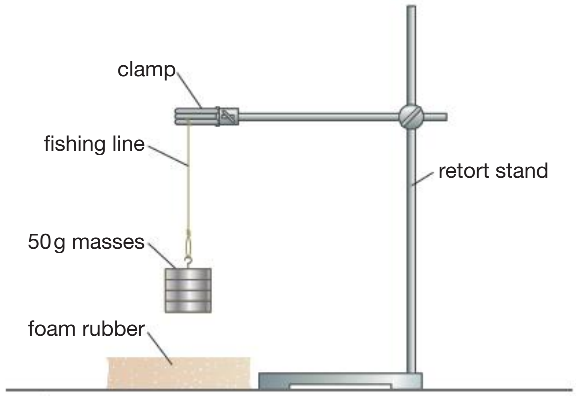


Figure 9.1.18

Results
1 In your workbook, construct a results table like the one shown below.

Mass added (g)	Length (mm)	Extension (mm)
0		
50		
100		
150		
200		
250		

2 Calculate how much the fishing line has extended each time a mass is added by subtracting the length of the line with no mass. That is:

extension = length of line with mass attached – length if line with no mass

3 Accurately plot a line graph of the line's extension against the mass added.

Discussion
1 **Assess** whether the following were under compression or tension in this experiment:
   a the fishing line
   b the upright on the retort stand
2 Imagine a fish being reeled in on this fishing line. **State** the mass of the fish that would snap the line.

9.2 Taller and taller

Towering 818 m over the desert sands of the United Arab Emirates is the Burj Khalifa, current holder of the title 'world's tallest building'. Even taller towers are planned for Dubai and other cities in the Middle East and Asia. Throughout history, humans have built tall towers to impress, intimidate and watch over their surroundings, and in worship. Towers have also helped us communicate with flags, smoke signals, radio and TV.

INQUIRY science 4 fun

Balancing forks

Can you balance two forks on a toothpick?

Yes

Collect this ...

- glass of water
- 2 forks
- toothpick
- matches (optional)

Do this ...

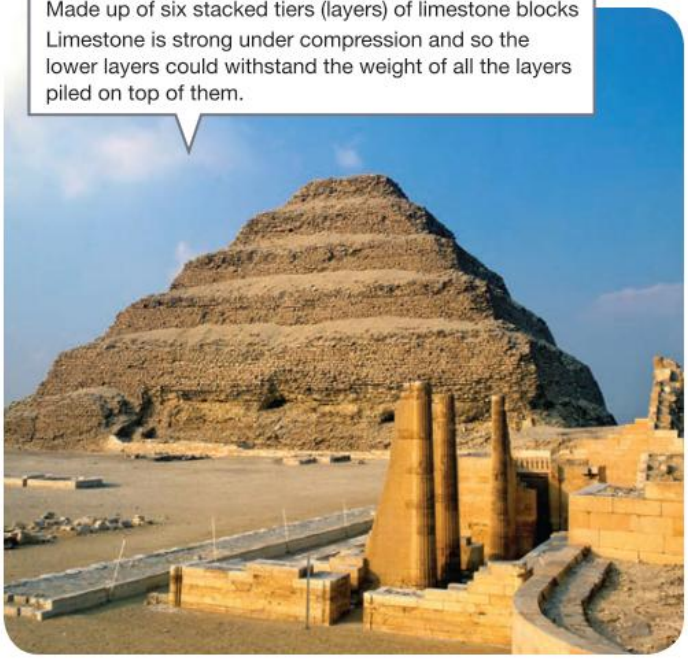
1. Join two forks by sliding and weaving their prongs together.
2. Slide a toothpick between the prongs so that it is secure and won't come out.
3. Place the other end of the toothpick on the edge of a glass containing water, as shown.
4. Let go. It should balance. If not, then try again. With enough care, it *will* balance!

Record this ...

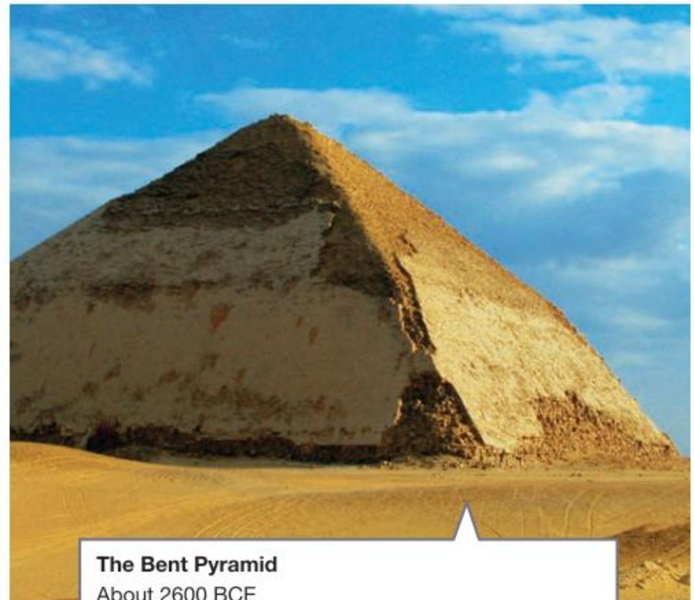
Describe what happened.
Explain why you think this happened.

The pyramids of Egypt

For over 4000 years, the pyramids of Egypt were the world's tallest buildings. Over a period of a hundred years or so, the engineers, builders and architects of ancient Egypt learnt from their past mistakes to make them taller and taller (Figure 9.2.1 on page 304). There are at least 118 ancient pyramids in Egypt. Many are small, and others are just piles of rubble that are buried in the desert sands. The Great Pyramid of Khufu (also known as Cheops) was among the world's tallest buildings until it was overtaken in 1889 by the 300-metre high Eiffel Tower in Paris, France.



The Step Pyramid
2630 to 2611 BCE
62 m high
Built for Pharaoh Djoser
Made up of six stacked tiers (layers) of limestone blocks
Limestone is strong under compression and so the lower layers could withstand the weight of all the layers piled on top of them.



The Bent Pyramid
About 2600 BCE
105 m high
Built for Pharoah Snefru
First attempt at building a smooth-sided pyramid
Made of limestone
45 m up, the angle drops from 55° to 43° to make the completed pyramid lighter so it would not collapse.

Maidum Pyramid
About 2600 BCE
92 m high
Built for Pharaoh Snefru
A step pyramid with its three lower steps filled in to form smooth sides
Upper levels were so steep that they later collapsed.

The Great Pyramid
Built around 2550 BCE
147 m high
Built for Pharaoh Khufu (Cheops)
Among the tallest buildings in the world for over 4000 years
Made of limestone.

Figure 9.2.1 The earliest pyramids were piles of rubble or mud brick and most of them collapsed. These four limestone pyramids show how the ancient Egyptians learnt from past mistakes to build taller and taller structures.

p310

SciFile

Pharaoh Snefru

Another theory is sometimes used to explain the shape of the Bent Pyramid: Pharaoh Snefru was nearing death and so the pyramid that was to be his tomb needed to be completed in a hurry! The new angle made it quicker to build.

Towers

The pyramids were not the only tall structures of the ancient world. The ancient peoples also built towers.

Towers were traditionally made from stone, brick or mud. Some are shown in Figures 9.2.2 and 9.2.3. As they got taller, they also got heavier, and so they needed thicker walls at their base to stop them collapsing. They had few openings (such as doors and windows) since openings weakened the walls. This made the rooms inside the towers small and dark, particularly on the lower floors where the walls needed to be thickest. You also needed to climb stairs or ladders to reach the upper levels.

For these reasons, the height of towers was limited to around ten storeys. They were rarely used for accommodation and work but instead were used as lookouts, lighthouses, temples, the spires of cathedrals, and the minarets of mosques.

Figure 9.2.2 San Gimignano in Italy was a wealthy town in the Middle Ages. Rival families in the town built 72 stone towers to impress one another! Fifteen of these towers remain.

Figure 9.2.3 The high-rise apartment blocks in Shibam (Yemen) were built 300 years ago from mud. The tallest has 11 storeys.

Skyscrapers

The weight of a structure (and everything inside it) doesn't need to be held up by the walls when a frame is used. While the walls of many houses in Australia are made of solid brick or stone, many others have a frame of wood or steel that holds up the weight of their roof and upper floors. You can see a typical house frame in Figure 9.2.4. An older version is shown in Figure 9.2.5. Windows and doorways can be placed in gaps in the frame, and lightweight materials such as weatherboards, cement sheeting or a single layer of brick (brick veneer) can be attached to it to disguise and protect the frame and to keep out the weather.

Figure 9.2.4 Wooden or steel frames carry all the weight of the structure.

Figure 9.2.5 In the past, wooden frames were often filled with mud, bricks, or wattle and daub (woven sticks and mud).

Skyscrapers also use a frame (known as a **superstructure**) to support them and to form their basic shape. The frame is made of steel or reinforced concrete (concrete with steel bars or mesh in it). An example is shown in Figure 9.2.6 on page 306. The walls only need to be strong enough to support their own weight. Any lightweight material can be used to fill the gaps and to make the skyscraper weatherproof. In modern skyscrapers, these gaps are most commonly filled with large plates of relatively cheap glass, providing the apartments and offices inside with abundant light and uninterrupted views.

Steel and reinforced concrete perform well when placed under compression and under tension so the frame can withstand the weight of the structure, as well as supporting its floors. The frame can also withstand any twists or stretches that might happen with changes of weather.

Figure 9.2.6 This skyscraper's frame is made of steel and surrounds a solid core occupied by the lift and stairwells.

The height of buildings was naturally limited by how many stairs people were willing to climb. Then, in 1853, American inventor Elisha Otis demonstrated the first **elevator** (lift) with a brake that stopped the elevator from falling if its cable broke. His design provided a safe and easy way of reaching the upper floors, allowing structures to be built higher than ever before.

9.3

Tall, taller, tallest

To measure the height of a building, you first need to know where its top is. The top could be considered to be the:

- very tip of the building
- top of its roof
- highest occupied floor
- highest part of the building but not including 'add-ons' such as TV antennae, radio masts, satellite dishes or flagpoles. Most buildings are measured this way.

The Burj Khalifa is currently the highest building in the world regardless of what criterion is used. In Australia, the Q1 tower (Surfer's Paradise, Queensland) and the Eureka Tower (Melbourne, Victoria) can both be considered to be Australia's tallest building, depending on how you judge where their tops are. The spire of Q1 reaches to a height of 323 m, but its roof only reaches 275 m. The roof of the Eureka Tower is at 297 m but it has no spire. Figure 9.2.7 shows the height of some of the world's tallest buildings.

2 p310

SciFile

Skyscrapers rise from the ashes

In 1871, 17 500 buildings in Chicago (USA) burnt down in a massive fire. This opened up the centre of America's second largest city for redevelopment with skyscrapers. The first steel-framed skyscraper was built there in 1885. It had ten storeys and was 55 m high.

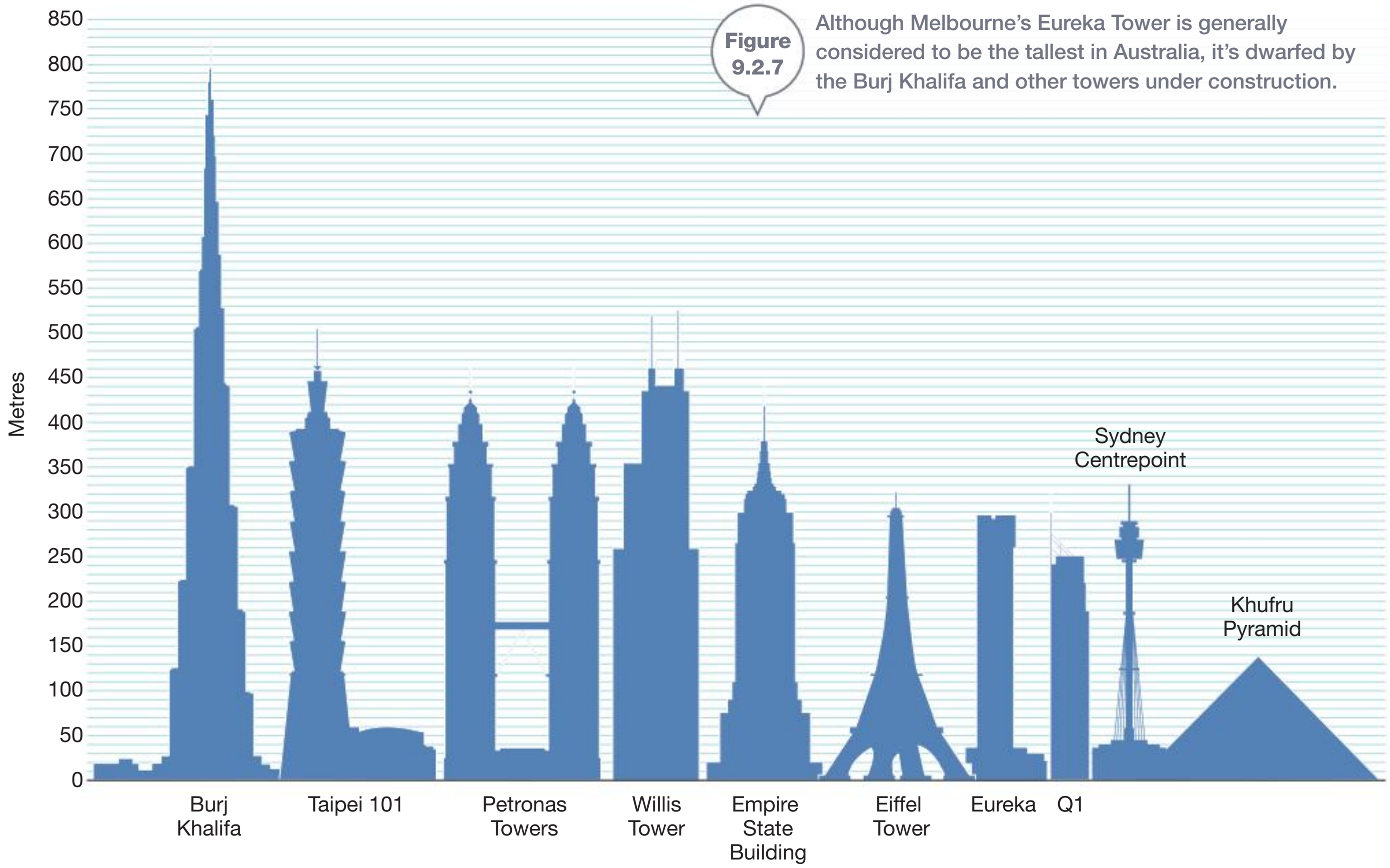


Figure 9.2.7 Although Melbourne's Eureka Tower is generally considered to be the tallest in Australia, it's dwarfed by the Burj Khalifa and other towers under construction.

Stability

Tall, thin structures tend to fall over more easily than short, wide structures because they have a relatively:

- high centre of mass
- small base.

Centre of mass

All objects have a **centre of mass** (sometimes known as their **centre of gravity**). This is the point at which all the mass of the object can be thought to be concentrated. It is also the point through which the object's weight force can be thought to act. For symmetrical objects with a uniform spread of mass, the centre of mass is at with the centre of the object. For example, the centre of a cricket ball is also its centre of mass. Likewise, the centre of mass of this textbook is roughly at its centre. You can find where it is exactly by trying to balance the closed book on the tip of your finger.

SciFile

Navel gazing

When you stand upright, your centre of mass is located a little below and behind your belly button. Lifting your arms spreads your mass over more height and so your centre of mass moves upwards too. As Figure 9.2.8 shows, twisting and bending can shift your centre of mass outside your body.

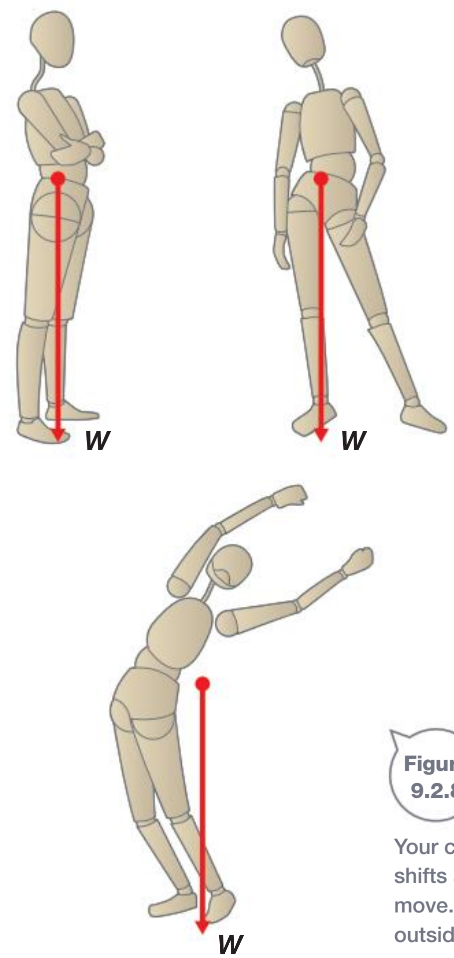


Figure 9.2.8 Your centre of mass shifts around as you move. Sometimes it lies outside of your body!

Size of base

An object is stable and won't fall over if its weight force (drawn as a vertical arrow from its centre of mass) passes through its base. In contrast, an object will topple over if its weight force passes outside its base. This explains why trucks tend to topple over more easily than cars, especially when on a slope or when cornering. You can see this in Figure 9.2.9.

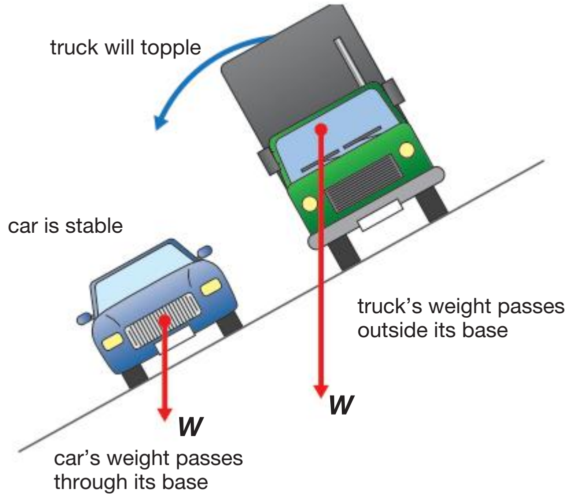


Figure 9.2.9 Tall objects have higher centres of mass than short objects.

Most structures are designed so that they are naturally stable, with their centres of mass directly over their base. Towers and skyscrapers twist and sway in the wind and during unexpected extreme events such as earthquakes and hurricanes. Whatever happens, the base must be wide enough to ensure that the centre of mass is always over it (Figure 9.2.10).

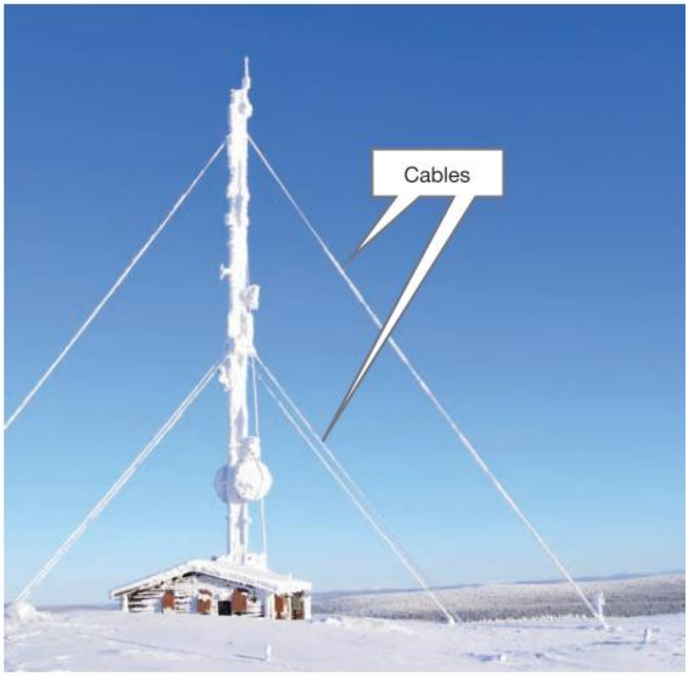


Figure 9.2.10 A high centre of mass and small base make thin radio and TV transmission towers extremely unstable. Cables minimise the twisting and sway of the tower and spread the base of the structure across a greater area, making it more stable.

SCIENCE AS A HUMAN ENDEAVOUR

Use and influence of science

The Leaning Tower of Pisa

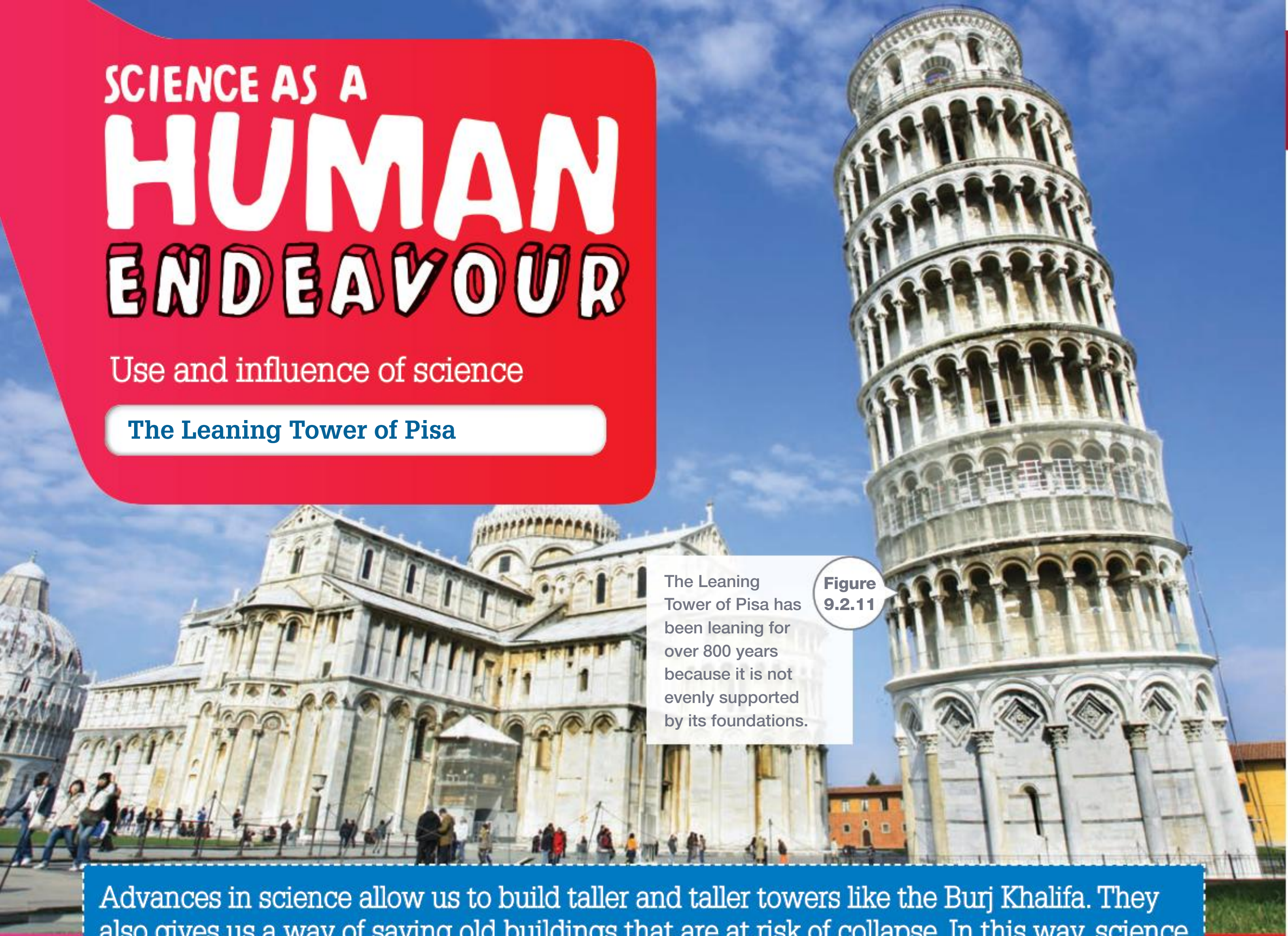


Figure 9.2.11 The Leaning Tower of Pisa has been leaning for over 800 years because it is not evenly supported by its foundations.

Advances in science allow us to build taller and taller towers like the Burj Khalifa. They also gives us a way of saving old buildings that are at risk of collapse. In this way, science allows us to preserve important monuments like the Leaning Tower of Pisa in Italy.

The Tower of Pisa (Figure 9.2.11) first began to lean in 1178, five years after construction began. It had only got to the third floor and already the weight of its marble was too much for the ground underneath it to support! Work stopped, and began again in 1272 with its new, upper floors being built with one side shorter (and lighter) than the other.

Over the centuries, the angle of the tower increased until it was feared that it would collapse. After several attempts that made the situation worse, scientists and engineers developed a program that would stop the lean and drag it a little more upright (Figure 9.2.12). All this had to be done very slowly since any abrupt movement of the tower could cause it to crumble. Between 1990 and 2001, the program:

- removed the tower's bells to make it lighter (the tower was originally a belltower)
- carefully removed soil from under its raised side
- added lead weights on its raised side to push it down.

The tower now leans about 4° from the vertical, and its top is 3.9 m out of alignment.

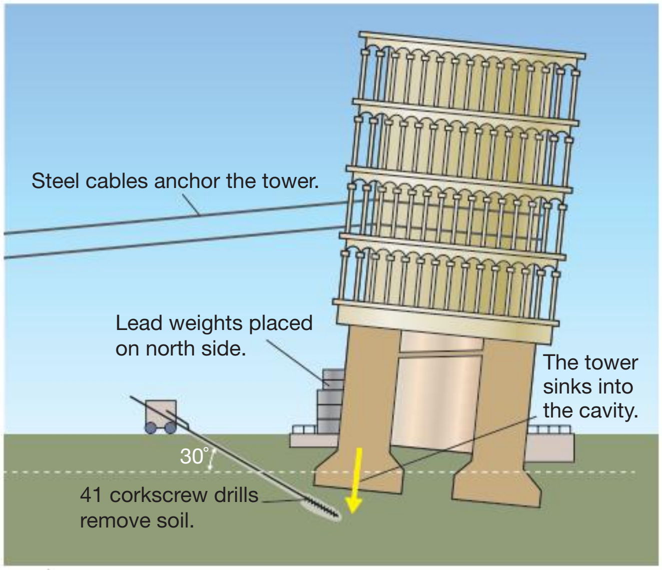


Figure 9.2.12 A restoration program has halted the increasing lean of the Leaning Tower of Pisa.

9.2 Unit review

Remembering

1 **Name** and **specify** the height of the structure that is or was the world's tallest:
  a for over 4000 years
  b in 1889
  c currently.

2 **Name** the event that caused Chicago (USA) to become the home of the skyscraper.

3 The Science4fun activity on page 303 shows how two forks can be balanced on a toothpick hanging off the edge of a glass.
  a **State** whether the forces on the forks are balanced or unbalanced.
  b **State** what the *overall* force on the forks is when they are balanced.

Understanding

4 The later, successful pyramids were made of limestone. **Explain** why this material was ideal for the job.

5 **Explain** why towers made of stone or brick were rarely used for accommodation.

6 **Outline** how the Leaning Tower of Pisa was straightened.

Applying

7 Both the Q1 (Queensland) and Eureka (Victoria) towers can claim the title of 'Australia's tallest'.
  a **Explain** how both can hold the title.
  b **Identify** which one you think should be given the title.

Analysing

8 **Compare** a house frame with a skyscraper superstructure by listing their similarities and differences.

9 **Analyse** Figure 9.2.13 and determine whether the people will topple over or not.

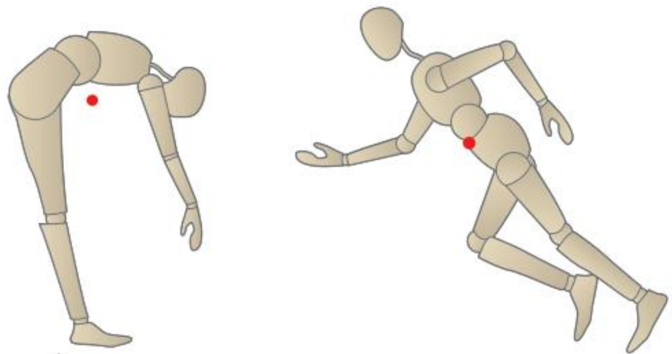


Figure 9.2.13

Evaluating

10 The Great Pyramid is now 10 m shorter than when it was built. **Propose** reasons why.

11 **Propose** what cities would be like now if the elevator (lift) had never been invented.

12 Four-wheel-drive cars are more likely to roll over than normal cars. **Propose** a reason why.

13 Skiers are always encouraged to bend their knees. **Propose** reasons why.

Creating

14 An architect wants to build a structure with the shape shown in Figure 9.2.14 but knows that it will be unstable.
  a **Analyse** the structure and **predict** where its centre of mass would be.
  b **Construct** two diagrams showing different ways the structure might be made stable.

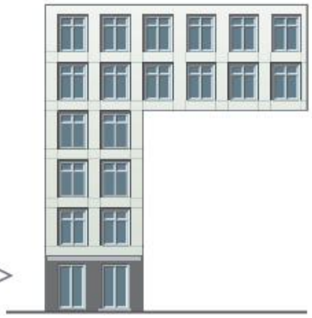


Figure 9.2.14

Inquiring

1 There are plans for a skyscraper with rotating floors in Dubai and another in Moscow. Search the internet to find video of what they will look like and how they will work.

2 Find videos on the internet showing how a skyscraper is planned using computer-assisted design (CAD).

3 Construct a portfolio that contains photos of the following skyscrapers:

- Empire State Building
- Taipei 101
- Sears or Willis Tower
- Shanghai World Financial Centre
- Guangzhou TV Tower
- Abraj Al Bait Towers
- Petronas Towers
- Freedom Tower
- CN Tower
- Burj Khalifa
- Russia Tower
- Pentonium.

Label each photo with its year of construction, height, location and function (such as apartments, offices).

9.2 Practical activities

1 Natural pyramids

A cone is a pyramid with a circular base. When materials pile up into a cone, the angle the side makes with the horizontal is called the angle of repose.

Purpose

To determine the angle of repose of different substances.

Materials

- funnel
- retort stand, bosshead and clamp
- 1 sheet of graph paper
- ruler with millimetre markings
- various substances such as fine sand, coarse sand, flour, fine blue metal screenings

Procedure

1. Set up the funnel as shown in Figure 9.2.15.
2. Place your finger over the end of the funnel and fill it with fine dry sand. Remove your finger quickly and let the sand run out onto the graph paper.
3. Use the ruler to measure the height of the mound and the graph paper to estimate its diameter.
4. Make cones using the other materials, ensuring that the cones are all about 15 cm in diameter.

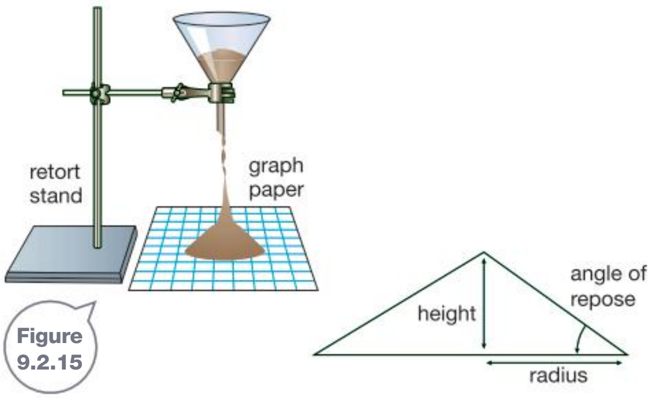


Figure 9.2.15

Results

1. In your workbook, construct a table like the one shown below.
2. To calculate the angle of repose of each material:
   - divide the height by the radius. Your answer should be less than 1.
   - push the $\tan^{-1}$ button (you may need to push the inverse/shift button first).

Discussion

1. **Propose** a reason why different substances had different angles of repose and made different height cones.
2. The first pyramids were made of rubble and mud bricks loosely piled on top of one another. **Use** the results from this experiment to **propose** why most of them collapsed.

Material	Diameter (mm)	Radius (mm)	Height (mm)	Angle of repose (°)

2 Wonky tower

Purpose

To construct the tallest self-supporting tower possible using straws and pins.

Materials

- 20 plastic or paper drinking straws
- scissors
- pins
- 50 g mass

Procedure

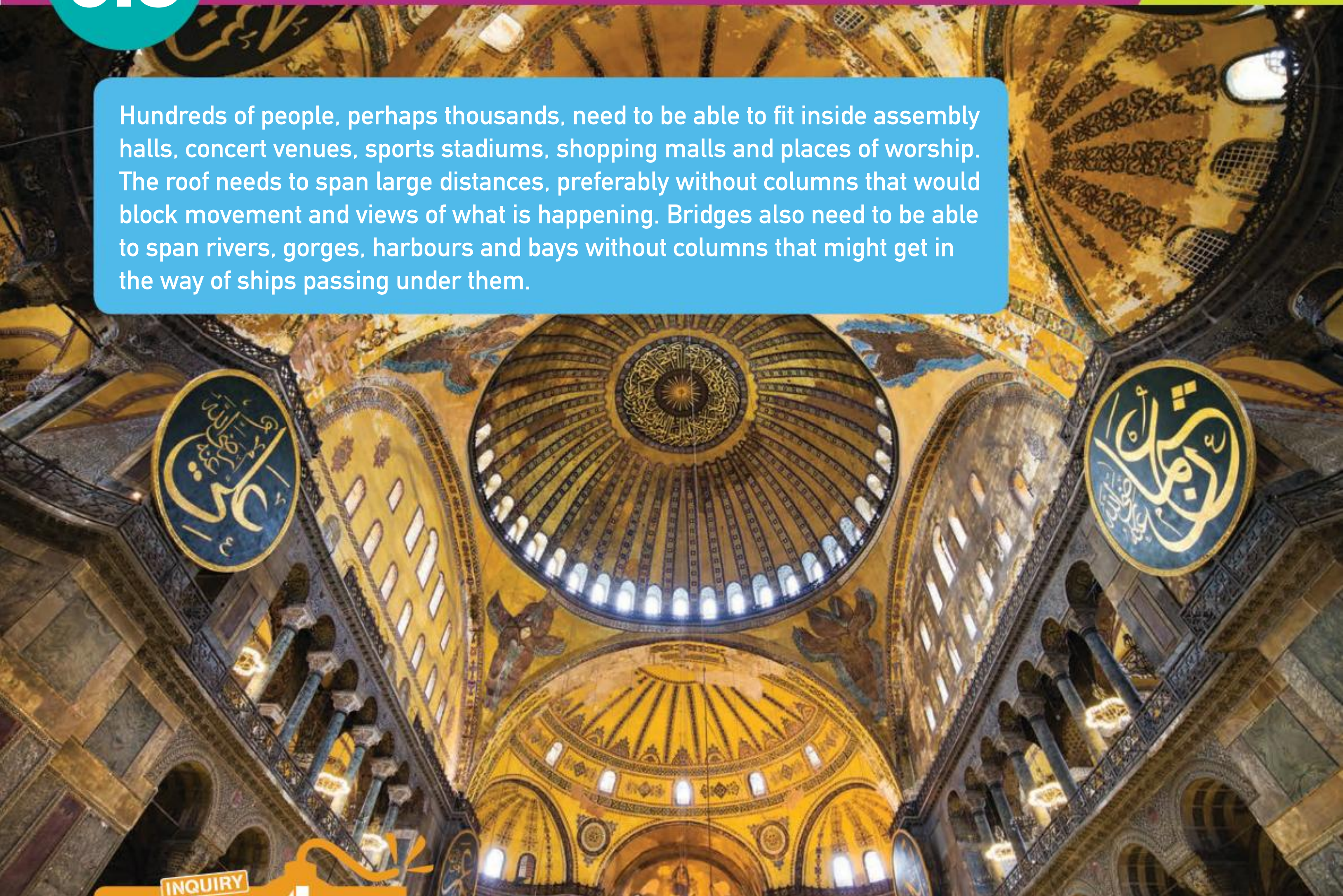
Construct the tallest structure possible using only the materials listed above. You can cut straws and can pin the straws together. Your structure must be able to:

- stand unsupported for at least a minute
- hold a single 50 g mass at its very top.

Discussion

1. **List** the features you used to ensure that your tower kept its shape and did not topple over.
2. **Compare** your tower with the tallest one in the class.
3. **Assess** how your tower could have been made stronger.

9.3 Bridging the gap



Hundreds of people, perhaps thousands, need to be able to fit inside assembly halls, concert venues, sports stadiums, shopping malls and places of worship. The roof needs to span large distances, preferably without columns that would block movement and views of what is happening. Bridges also need to be able to span rivers, gorges, harbours and bays without columns that might get in the way of ships passing under them.

INQUIRY science 4 fun

Arching bodies

Can you model the forces in an arch with your body?

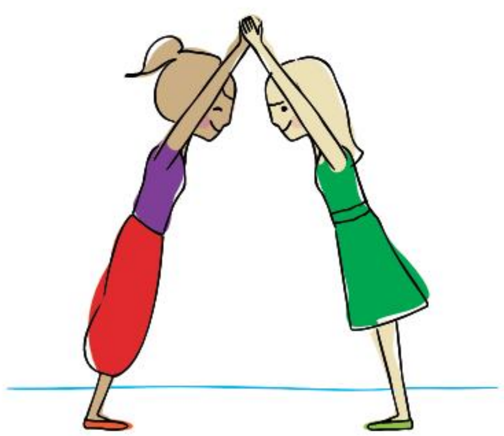
Yes

Collect this …

- No equipment is needed for this activity but a soft ground surface (such as grass or carpet) is suggested in case you fall.

Do this …

1 Pair off against a person of roughly the same size and weight as you.
2 Stand a little apart, facing each other.
3 Grip each other's hands over your heads and lean all your weight into your partner so that you form an arch.
4 Test if you can both stay upright.
5 Once you have done this, move a little further apart and repeat.
6 Keep moving apart until your arch 'fails'.
7 Repeat, but now use other people to help stop your feet sliding. What happens now?



Record this …

Describe what happened.
Explain why you think this happened.

Buildings

Wooden buildings rarely last more than a few centuries because they eventually rot or are eaten by insects such as termites. Steel and reinforced concrete are relatively recent materials, and so any buildings containing them are less than 150 years old. The buildings that remain from the ancient world are made of stone, brick or mud. Three different methods were used to build them.

Post and beam

The easiest way of support a roof is to place a **beam** (also known as a **lintel**) horizontally across two columns or vertical posts.

The columns or posts hold up the roof and are in compression. Timber, steel, concrete, brick, marble and granite perform well under compression and so are good materials to construct columns from.

However, the weight of the beam and the roof on top can cause the beam to sag a little. As Figure 9.3.1 shows, when a beam sags, the:

- lower side of the beam is stretched and so it is in tension
- upper side of the beam squashed and so it is in compression.

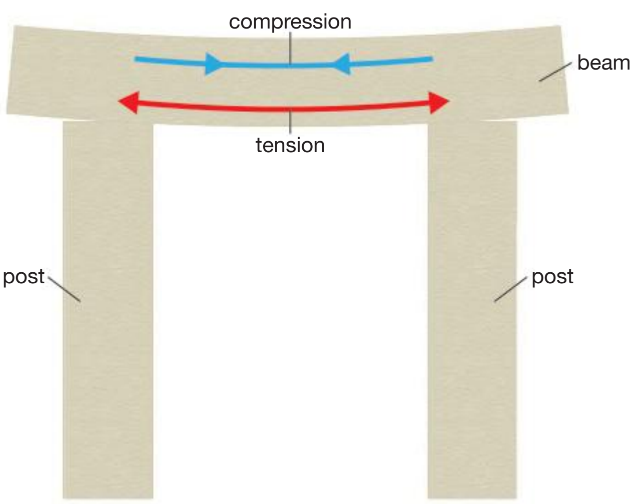


Figure 9.3.1 A horizontal beam sags under its own weight. As a result, the materials used must perform well under both compression and tension.

Timber and steel perform well under compression *and* tension and so both are good materials to construct beams and lintels from (as well as the columns holding them up). For this reason, timber and steel are commonly used over doorways and windows in homes to hold up the wall and roof above them. A steel lintel is shown in Figure 9.3.2.

Figure 9.3.2 Doorways and windows need lintels so that the weight of the wall and roof above them doesn't come crashing down. This steel lintel holds up the wall above the door.

Concrete, brick, marble and granite are strong under compression but quickly crack when placed under tension. Therefore, when used as beams they need a lot of columns to support them so they don't sag and crack. All these columns leave very little room in the building and block any views through it. This is obvious in the Parthenon, shown in Figure 9.3.3.

Figure 9.3.3 Post and beam construction was used to construct the Parthenon of ancient Greece (built around 440 BCE).

Reinforced concrete is concrete poured over steel mesh or steel rods. This is shown in Figure 9.3.4. Concrete is relatively cheap and performs well under compression. Steel is more expensive and heavier, but performs well under both compression and tension. In combining concrete with some steel, reinforced concrete provides a relatively cheap and light material that performs well under compression *and* tension. This makes it the ideal material for use in beams *and* columns.

Figure 9.3.4 Reinforced concrete is strong under both compression and tension because it combines the properties of both concrete and steel.

Roman arch

While the ancient Greeks used the post and beam method to build their temples and monuments, the ancient Romans used a simple semicircular arch like that shown in Figure 9.3.5. All the materials in a **Roman arch** are under compression. This allowed the arch to be constructed from marble, granite, concrete, bricks or mud. Buildings like the church in Figure 9.3.6 could be constructed from many arches.

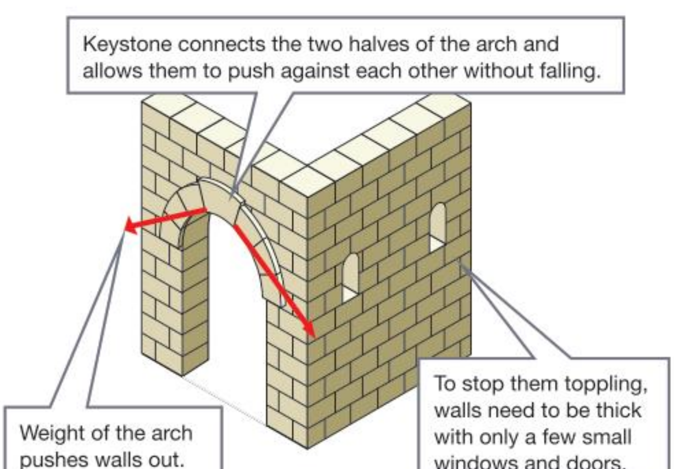


Figure 9.3.5 A Roman arch is semicircular. It needs thick walls to support it.

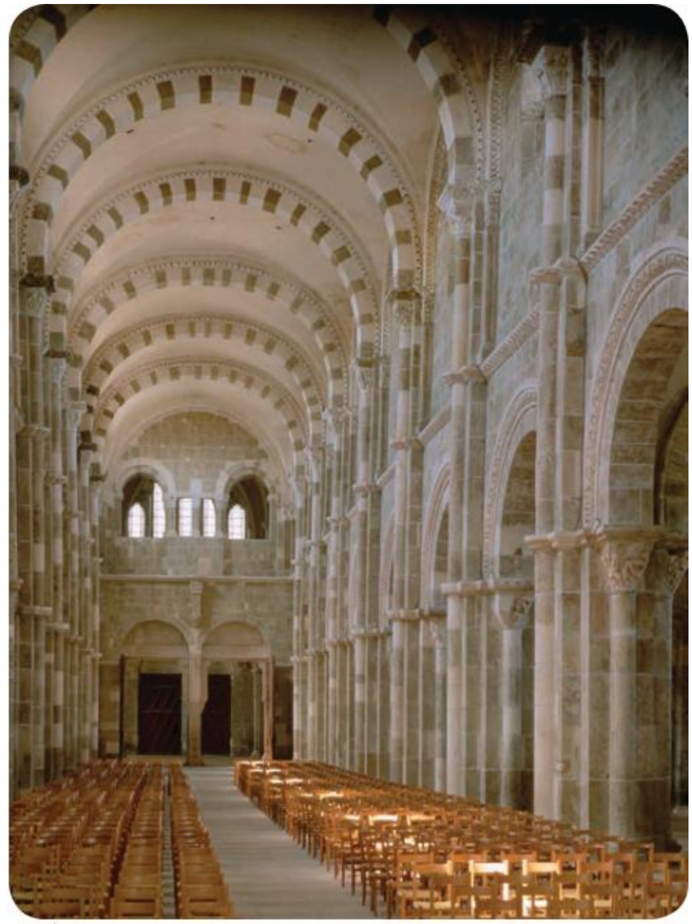


Figure 9.3.6 A series of arches can be used to construct a building such as this church.

The weight of any arch is transferred through its supporting walls to the ground. The weight of a Roman arch pushes the walls of the arch outwards, and so the walls need to be very thick to stop them toppling over. Openings weaken the walls, and so any doors or windows need to be small and few (Figure 9.3.7). This makes the interiors of buildings using Roman arches extremely dark.

Figure 9.3.7 Domes made from three-dimensional Roman arches need thick walls with few openings. An igloo is an example of a dome.

INQUIRY science 4 fun

Egg domes

How strong is the dome formed by an eggshell?

Yes

Collect this …

- 2 eggs
- strong sticky tape (e.g. masking tape or gaffer tape)
- fine-tipped scissors (e.g. fingernail scissors)
- stiff cardboard (e.g. cut from a cereal packet)
- masses or packets and cans from the kitchen cupboard
- kitchen scales or electronic balance

Do this …

1. Stick a strip of tape around the 'waist' of each egg so that the ends don't quite meet.
2. In the gap between the ends of the tape, make a small hole with the end of the scissors. Take care!
3. Use this hole to pour out the contents of the eggs. (Wash your hands thoroughly afterwards.)
4. Starting at the hole, carefully cut along the tape around the 'waist' of the eggs. This will give you four half-eggshells.
5. Place the four half-eggshells on a flat bench and place the sheet of stiff cardboard on them.
6. Slowly add masses or packets and cans, stacking them up on the cardboard.
7. Stop when one or more of the eggshells develops cracks.

Record this …

Describe what happened.

Explain why eggshells arranged like this are so strong.

Gothic arches

Gothic arches are pointed arches. They were invented in 12th century Europe, where they were first used to hold up the roofs of the cathedrals and churches.

All the materials used in a Gothic arch are in compression, so they too can be built from stone, concrete or brick.

As shown in Figure 9.3.8, the weight of a Gothic arch pushes down more vertically on its walls than a Roman arch does. This means the walls are less likely to topple over and so can be made thinner, and with larger windows. **Flying buttresses** are stone struts (supports) that give the walls any extra support they need. The huge stained glass windows and flying buttresses of Gothic buildings make them much brighter than earlier buildings constructed with Roman arches.

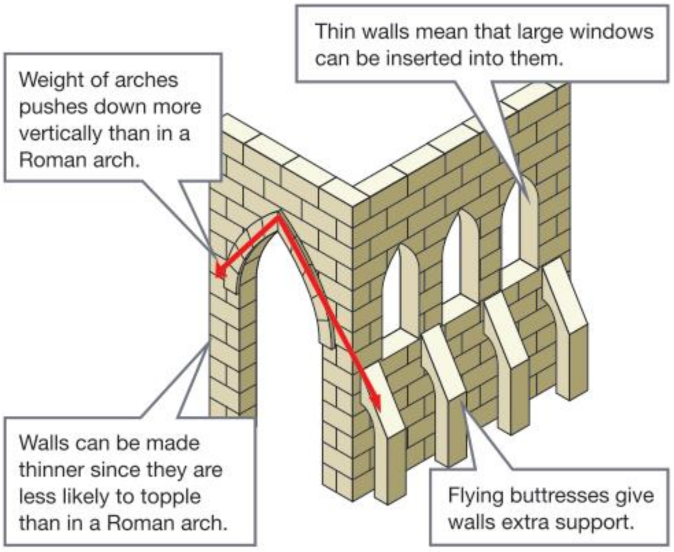


Figure 9.3.8 Gothic arches have pointed tops. They don't need thick walls to keep them toppling over but sometimes use flying buttresses to keep them upright.

Bridges

A simple bridge can be made by placing a log across a gap, but the length of a simple bridge is limited by the length of the log. Stone and brick can be used to form a beam, but (as in buildings) they tend to crack and fail and so need multiple columns to support them.

Roman or Gothic arches can be used to support the weight of a bridge. However, these also need multiple columns to support their arches. This gets in the way of any traffic such as people, cars and ships that must pass under them. An example is shown in Figure 9.3.9.

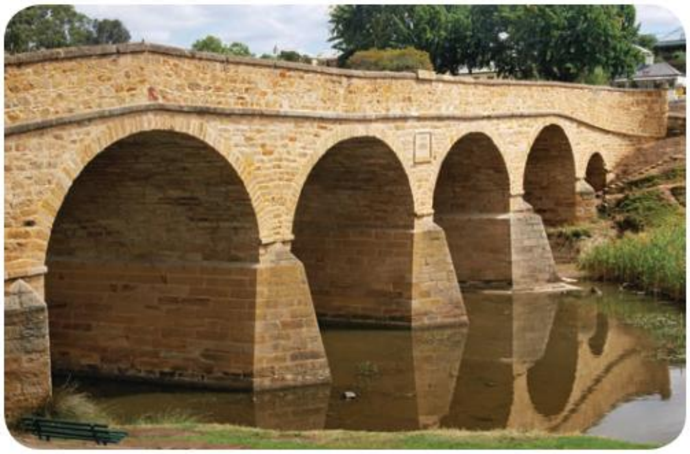
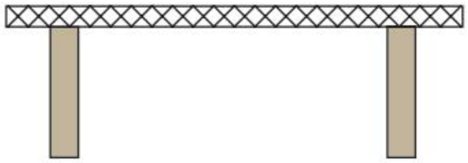
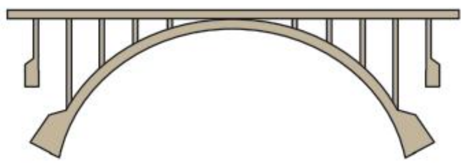


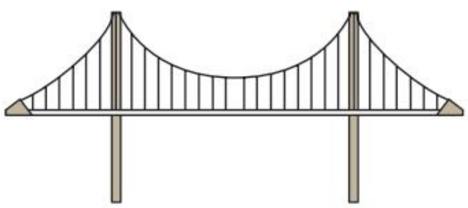
Figure 9.3.9 Old stone bridges were built using much the same methods as stone buildings. This is Richmond Bridge in Tasmania. It is Australia's oldest surviving bridge and was built in 1829.



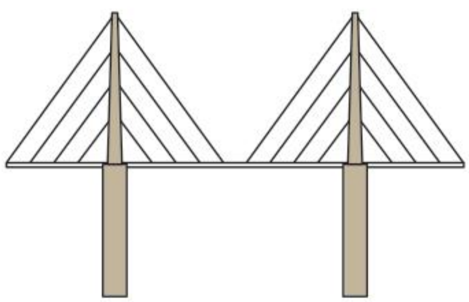
Beam bridge



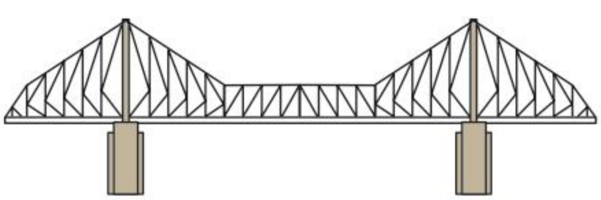
Arch bridge



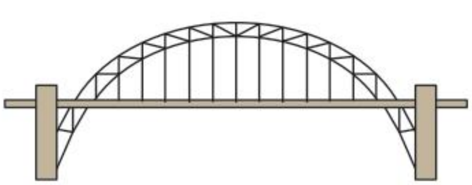
Suspension bridge



Cable-stayed bridge



Cantilever bridge



Bowstring arch bridge

Figure 9.3.10 Steel is an extremely versatile material and can form the uprights, deck and cables of a bridge. For this reason, modern bridges are commonly made of steel and/or reinforced concrete.

Modern bridges

Modern bridges need to span large distances without multiple columns or supports. Modern bridges are commonly made from steel and/or reinforced concrete because these materials act well under both compression and tension. This means steel and reinforced concrete can be used to construct the columns and pylons needed to support the structure's weight and to construct the long decks that form the base of the road or path across the bridge. Steel can also be used to construct cables that can hold the structure in place by pulling upwards against the force of gravity.

Modern bridges commonly use one of the designs shown in Figure 9.3.10.

9.4 9.5

Trusses

The structure of a bridge can be made far lighter and stronger if the beams and supports are not solid but are arranged instead into trusses. A **truss** is an open structure made up of a series of triangles. You can see trusses in use in Figure 9.3.11. Triangles are particularly strong as that they don't twist or distort their shape when weight is applied.

Figure 9.3.11 The trusses on Brisbane's Storey Bridge give it strength but make it relatively light. Trusses use triangles to help them retain their shape.

1 p318 2 p319 3 p320

9.3 Unit review

Remembering

1 **List** the disadvantages of building a bridge:
   a as a post and beam
   b with arches.

2 **Name** each of the structures in Figure 9.3.12.

Figure 9.3.12

3 **List** two materials that would be suitable to build a:
   a column
   b beam.

4 **State** whether the stones used to build Roman and Gothic arches are in compression or tension.

Understanding

5 **Predict** what would happen in the following situations.
   a Two people lean into each other as shown on page 311.
   b They then push their legs out and lean into each other more.
   c Someone else uses a foot to stop them from slipping.

6 **Explain** why the Parthenon in Figure 9.3.3 on page 312 needed so many columns.

7 a **Define** the term *lintel*.
   b **Describe** where lintels are found in a house.

8 **Explain** why timber and steel are good materials to make a beam out of.

9 a **Describe** what reinforced concrete is.
   b **Describe** the advantages of reinforced concrete over normal concrete.

10 A historic church was built using a series of Roman arches. **Explain** why its:
   a walls needed to be very thick
   b windows were very small.

11 **Explain** why stone is an ideal material from which to construct arches.

12 **Explain** the purpose of flying buttresses.

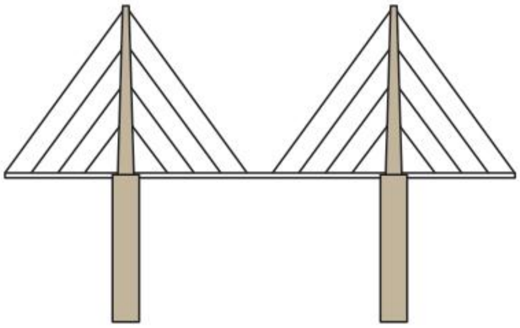
13 Windows weaken a wall. Even so, Gothic churches generally have large stained-glass windows. **Explain** why they don't collapse under the weight of their upper walls and roof.

Applying

14 **Identify** the structures labelled A and B in Figure 9.3.13.

Figure 9.3.13

15 Below is a cable-stayed bridge.
   a Copy the diagram and **identify** where you expect materials to be under compression.
   b **Identify** where you expect materials to be under tension.



16 **Identify** the type of arch used to support Richmond Bridge in Figure 9.3.9 on page 314.

Analysing

17 **Contrast** a:

- **a** Roman arch with a Gothic arch
- **b** suspension bridge with a cable-stayed bridge.

Evaluating

18 The Romanesque was a period of European architecture. **Propose** what architectural feature it used.

Creating

19 **Construct** a diagram showing the compression and tension forces in a beam that sags.

20 **a** **Construct** a diagram showing what would happen to the truss in Figure 9.3.14 (made from a series of squares) if the truss was pushed as shown.

b **Use** your answer to part a to **describe** the advantage of using triangles and not squares in a truss.

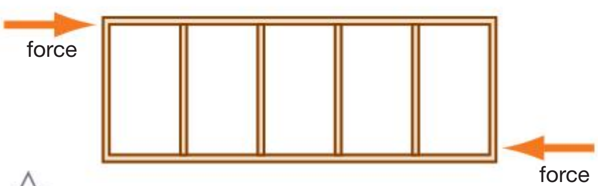


Figure 9.3.14

Inquiring

1. Search the internet for videos showing the wild vibrations of the Tacoma Narrows Bridge before it collapsed.
2. Research the collapse of the Westgate Bridge (Melbourne, Victoria) or the Tasman Bridge (Hobart, Tasmania).
3. Construct a portfolio that contains photos of the following Australian and international bridges:
   - Kurilpa (Queensland)
   - Merivale (Queensland)
   - ANZAC (New South Wales)
   - Gladesville (New South Wales)
   - Studley Park (Victoria)
   - Westgate (Victoria)
   - Batman (Tasmania)
   - Golden Gate (USA)
   - Millau Viaduct (France)
   - Puente de Alamillo (Spain)
   - Bridge of the Americas (Panama)
   - Brooklyn (USA).

   Label each photo with its:
   - **a** year of construction
   - **b** height
   - **c** location
   - **d** purpose (for cars, rail or pedestrians)
   - **e** bridge type (refer to Figure 9.3.10) on page 315.
4. Construct a portfolio that contains photos of the following historic buildings:
   - Hagia Sofia (Turkey)
   - Notre Dame (France)
   - Pantheon (Italy)
   - Pont du Gard (France)
   - Stonehenge (UK).

   Label each photo with its:
   - **a** year of construction
   - **b** height
   - **c** location
   - **d** purpose (such as accommodation, worship, offices)
   - **e** basic structure (such as post and beam, Roman arch, Gothic arch, dome).
5. Construct a portfolio that contains photos of domed buildings such as the Taj Mahal (Agra, India), St Basils (Moscow, Russia), the Dome of the Rock (Jerusalem, Israel), the Pantheon (Rome, Italy) and the Great Stupa (Sanchi, India). Label each of the photos with the type of material the dome is made from.
6. Design a bridge that can span a 20 cm gap. You can only use one sheet of A3 paper and enough sticky tape to hold it together. You cannot use the sticky tape to reinforce your bridge. Load your bridge up with 50 g masses and determine how many it can support before it collapses.

SciFile

Troops … break march!

Wind can make a bridge swing higher and higher (a bit like when you push a playground swing) until it breaks. The effect is called resonance. The rhythm of the steps of troops passing over a bridge can also cause resonance. For this reason, troops crossing a bridge need to 'break step', deliberately walking so that their steps were not all at the same time.

9.3 Practical activities

1 Building bridges

Purpose
To build and compare the strength of different types of bridges.

Materials
- 4 long strips of cardboard (about 30 cm × 10 cm)
- short strip of cardboard (about 20 cm × 10 cm)
- sticky tape
- scissors
- 2 retort stands and bossheads
- string
- 50 g masses

SAFETY

Keep your feet clear of any masses that may fall. Place padding underneath the bridge to soften its fall.

Procedure
1 Shift two tables or desks about 20 cm apart. Once you have this gap, do not change it.

Part A: Post and beam bridge

2 Construct the post and beam bridge shown in Figure 9.3.15 by simply resting a long piece of cardboard across the gap.

3 Add 50 g masses to the centre of the bridge until it 'fails'. Record your mass in a table similar to the one in the results section.

Part B: Arch bridge

4 Construct an arch bridge by bending another long piece of cardboard to form an arch. Tape it to the legs or side of the table or desk as shown in Figure 9.3.15.

5 Secure the arch to the horizontal strip of cardboard with another piece of sticky tape.

6 Once again, add 50 g masses to the centre until the arch bridge fails.

Part C: Cantilever bridge

7 Construct a cantilever bridge by arranging two long strips of cardboard hanging from the desks as shown in Figure 9.3.15. Do not overlap them but add a retort stand at each end to stop them falling.

8 Place a short strip of cardboard on top to form the 'road'.

9 Add 50 g masses again to find what will cause the cantilever bridge to fail.

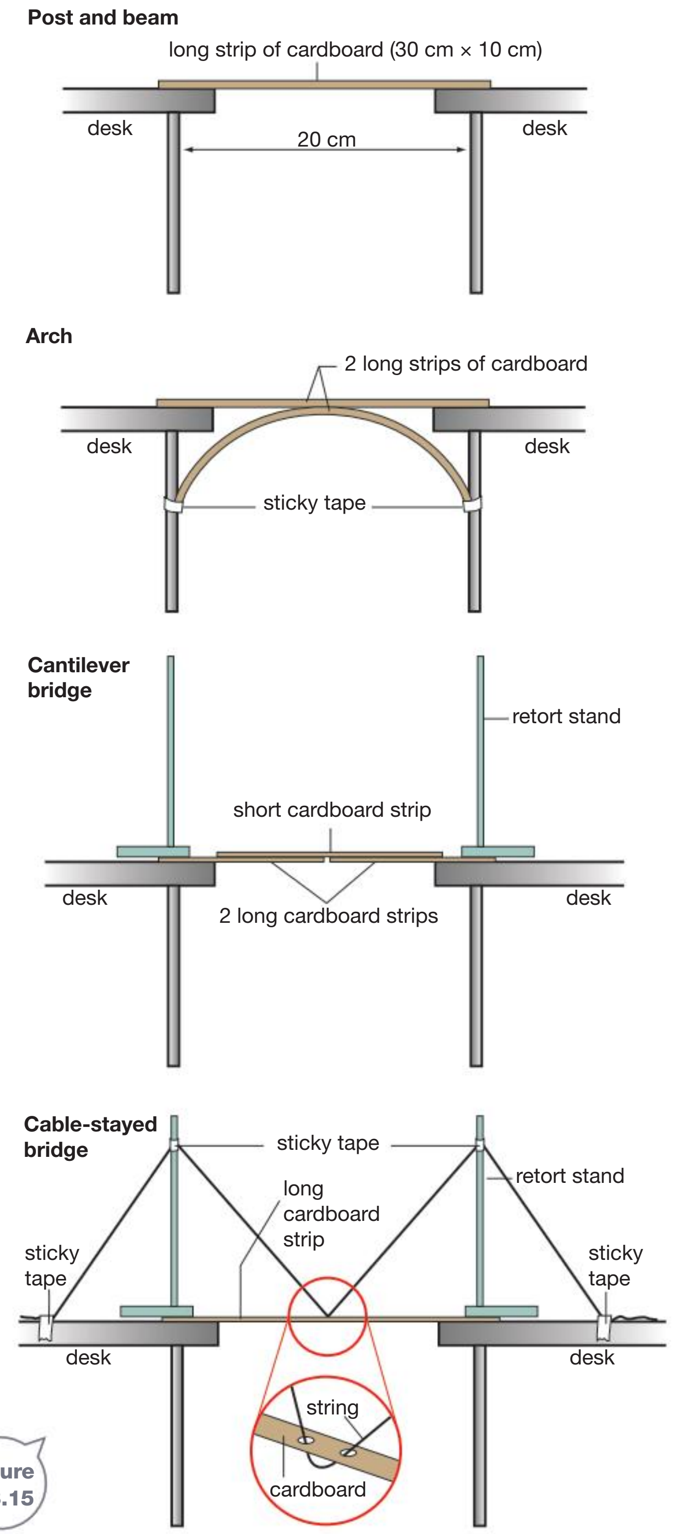


Figure 9.3.15

Part D: Cable-stayed bridge

10 Construct a cable-stayed bridge by placing a long piece of cardboard across the gap and weighing it down at each end with a retort stand as shown in Figure 9.3.15.

11 Tape or tie a length of string as shown.

12 Test the strength of the cable-stayed bridge by adding 50 g masses until it fails.

Results

In your workbook, construct a table like the one shown below in which you will record all your results.

Type of bridge	Mass that caused the bridge to 'fail' (g)
Beam	
Arch	
Cantilever	

Discussion

1 **Rank** the bridges in order from strongest to weakest.

2 Cantilever bridges are easier to build over large gaps than beam (like the one in Figure 9.3.16), arch or cable-stayed bridges. **Propose** reasons why.

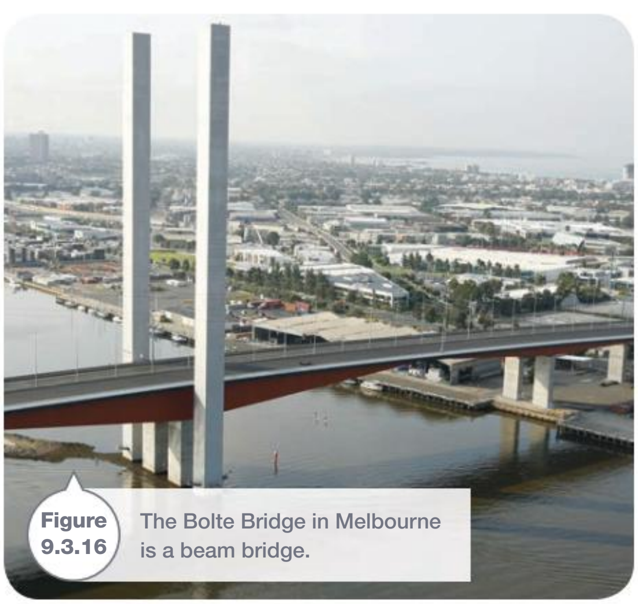


Figure 9.3.16 The Bolte Bridge in Melbourne is a beam bridge.

2 Design your own bridge

Purpose

To design and construct your own bridge.

Materials

- 1 pack of satay sticks
- 1 m string
- wood glue or access to hot glue gun
- metre ruler
- access to various masses

SAFETY

Do not touch the tip of the hot glue gun.

Procedure

1 The task of your prac team is to design and construct a bridge that:
- spans a gap of 60 cm
- is able to hold as high a mass as possible without failing
- uses only the satay sticks (these can be used whole or broken or cut into smaller lengths) and string provided
- uses only the glue provided
- uses only sufficient glue to hold the sticks together and to glue string in place (you cannot coat the sticks in glue).

2 When all bridges are complete, the class will test how much each bridge can hold before it fails.

Discussion

1 **List** the features that you used in your bridge (such as cantilever or truss) to make it stronger.

2 **Compare** your bridge with the one in the class that was most successful. Assess how your bridge could be made even stronger.

3 The bridge you designed yourself was probably stronger than many of the simple bridges you tested in Prac 1. **Explain** why.

3 Trusses

Purpose

To compare the strength of different trusses.

Materials

- icy-pole sticks
- wood glue or access to hot glue gun
- long strip of cardboard (30 cm × 5 cm)
- drawing pins
- newspaper
- 50 g masses

SAFETY

Do not touch the tip of the hot glue gun.

Procedure

1 Each practical team in the class will be given one of three designs of trusses, which they are to build. These are shown in Figure 9.3.17.

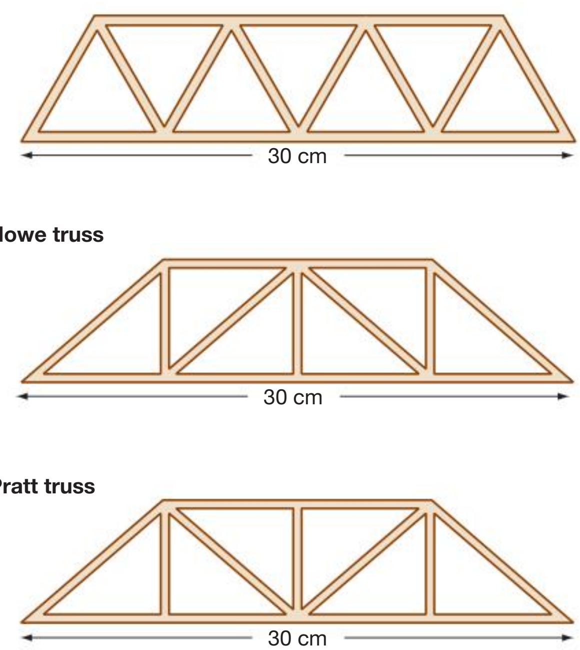


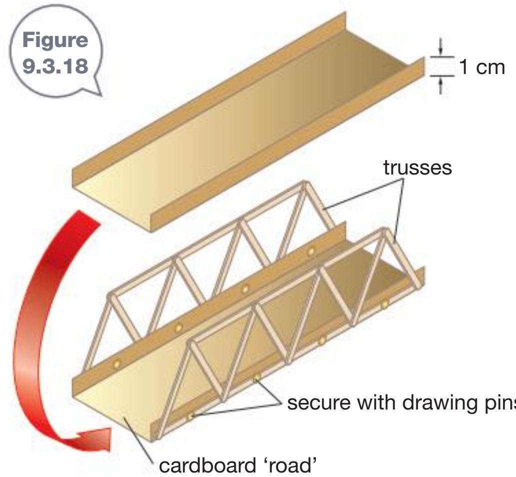
Figure 9.3.17

2 Use icy-pole sticks and wood glue or hot glue gun to construct two trusses of the design that you have been assigned. Build the trusses flat on sheets of newspaper and make sure that both are around 30 cm long. Leave both to dry in a place where they won't be disturbed.

3 Fold each side of the cardboard strip up to form walls 1 cm high.

4 Construct a bridge by pinning one truss on either side of the folded cardboard walls as shown in Figure 9.3.18.

Figure 9.3.18



5 Shift two desks or tables apart and place the truss bridge over the gap.

6 Add 50 g masses to the cardboard 'road' until it fails. Stop if the bridge still hasn't broken when 1.5 kg has been added to it.

7 Collect the results for other truss designs from the other prac teams. Enter all results in a table like the one shown in the results section.

Results

Copy and complete the following table.

Truss type	Mass that caused the bridge to fail
Warren truss	
Howe truss	
Pratt truss	

Discussion

1 **Rank** the truss bridges in order from strongest to weakest.

2 Many older railway bridges are truss bridges, with the truss made of steel. **Propose** one advantage and two disadvantages of these steel truss bridges.

Chapter review 9

Remembering

1 **List** three changes in structures around the home that indicates that the forces in the structure may have become unbalanced.

2 **State** what might happen if the forces on one part of a building become seriously unbalanced because of a cyclone.

Understanding

3 **Explain** why the following materials are ideal for their purpose.
- a timber used to construct a house frame
- b steel used to construct the frame (superstructure) of a skyscraper

4 Sails of ocean-going and racing yachts are often made of Kevlar. **Describe** the advantages Kevlar has over other synthetic materials such as nylon when used for the sails of ocean-going and racing yachts.

5 **Outline** two theories that explain why the builders of the Bent Pyramid changed its angle 45 m from its base.

6 **Outline** the four ways used to determine the top of a skyscraper.

7 **Explain** why most towers made of brick or stone are rarely higher than ten storeys.

8 **Describe** what you need to do to carry out a successful handstand.

9 **Explain** why the Parthenon (Figure 9.3.3, page 312) needs a lot of supporting columns to hold its roof up.

Applying

10 **Identify** a suitable material to use to make a:
- a Roman arch
- b bulletproof vest
- c floor of a skyscraper
- d cable to hold a roof up.

11 **Use** diagrams to **explain** why walls can be thinner with more windows when using Gothic arches than when using Roman arches.

Analysing

12 **Contrast**:
- a compression with tension
- b the characteristics of steel and concrete.

13 **Use** Figure 9.3.10 on page 315 to **classify** the:
- a Sydney Harbour Bridge (Figure 9.1.6 on page 296)
- b Storey Bridge (Figure 9.3.11 on page 315).

Evaluating

14 Mudbricks are made of mud reinforced with plant material such as straw or grass. **Propose** reasons why they are among the oldest building materials ever used.

15 You are more likely to cut your foot if you stand on a broken glass bottle than on a bottle that is intact. **Propose** a reason why.

16 **Propose** advantages and disadvantages of living in a very tall skyscraper.

17 Figure 9.2.7 on page 306 seems to indicate that Willis Tower in Chicago is taller than Petronas Towers in Kuala Lumpur. Yet most records state that Petronas is taller than Willis. **Use** the different ways building heights are measured to **propose** reasons why.

18 Steel framed buildings rarely went higher than 15 storeys until the early twentieth century. **Propose** a reason why.

19 Skyscrapers often have revolving doors at their base. Consider the air flow through a tall building and **propose** a reason why revolving doors are used.

20 Skiing and snowboarding are difficult sports to master and adult beginners are far more likely to fall than children just starting. **Propose** a reason why.

Creating

21 **Construct** a diagram showing what a truss is.

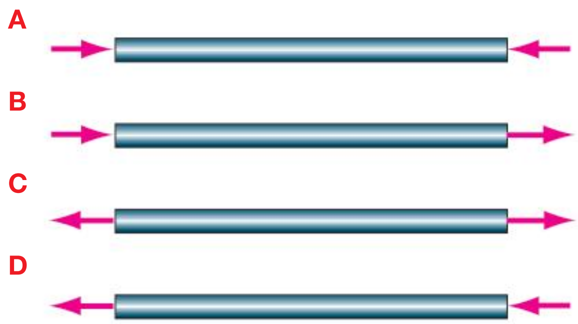
22 **Use** the following ten terms to **construct** a visual summary of the information presented in this chapter.

force	tension
compression	squash
stretch	weight
balanced	unbalanced
structure	failure

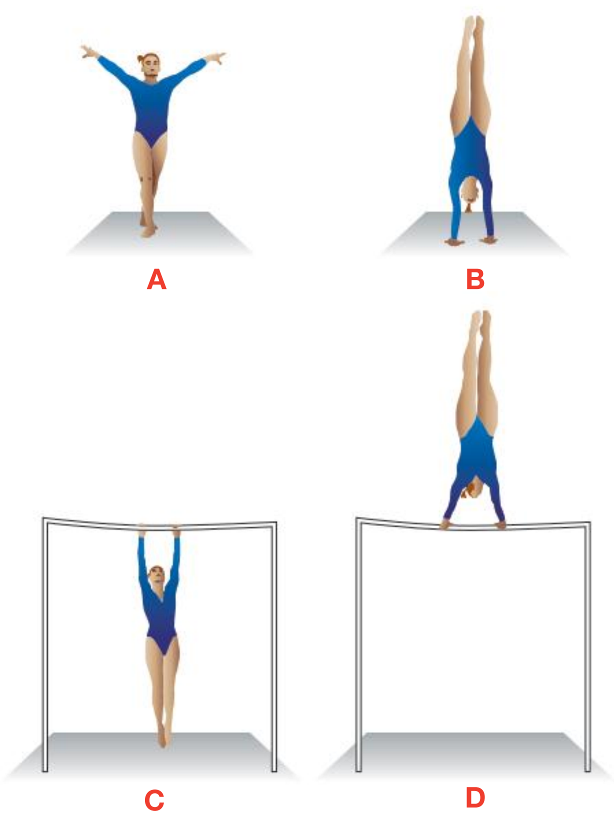
9.6

Thinking scientifically

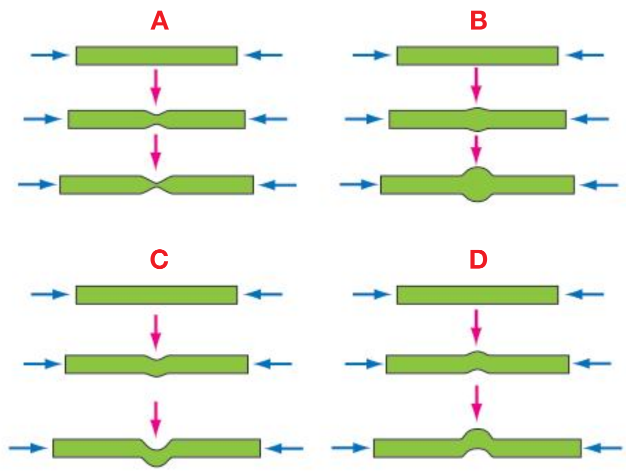
Q1 Tension forces stretch a material while compression forces squash it. State which of the following diagrams most accurately shows compression forces on a material.



Q2 Elaine is a gymnast. The four diagrams below show part of her routine. Identify in which part(s) of the routine her arms are under tension.



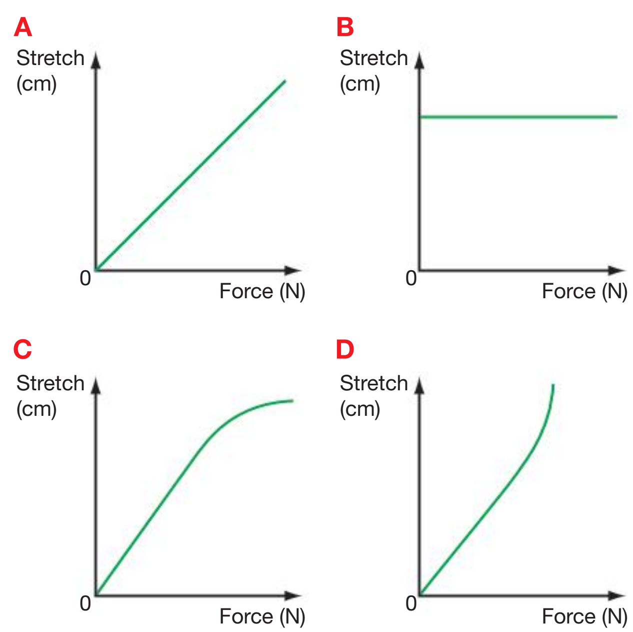
Q3 Increasing the compression on a material will squash it more and more. Eventually it will break. The diagrams show a material placed under so much compression that it eventually snaps. Identify which set of diagrams best shows what would happen just before it broke.



Q4 A practical team measured how much a material stretched when tension was applied to it. Their results are shown below.

Force (N)	0	10	20	30	40	50
Stretch (cm)	0	10	20	30	35	37.5

Identify which of the following sketch graphs best describes these measurements.



Glossary

Unit 9.1

Accelerates: speeds up

Balanced: all forces cancel each other out, zero overall force; no change will result

Compression: forces attempting to squash a material

Decelerates: slows down

Failure: breaking, snapping, crumbling of a material

Force: push, pull or twist; unit, N

Necking: thinning of a material just before it snaps

Newton's first law: the motion of an object will not change if all the forces acting on it are balanced

Newton's second law: an object will accelerate if an unbalanced force is acting on it

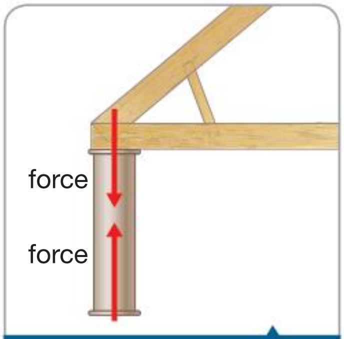
Newton's third law: for every force in a structure, there is an equal and opposite force acting on the structure

Stress: measure of how concentrated a force is on a material: stress = $\frac{\text{force}}{\text{area}} = \frac{F}{A}$

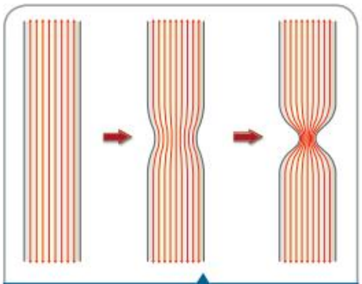
Tension: forces attempting to stretch a material

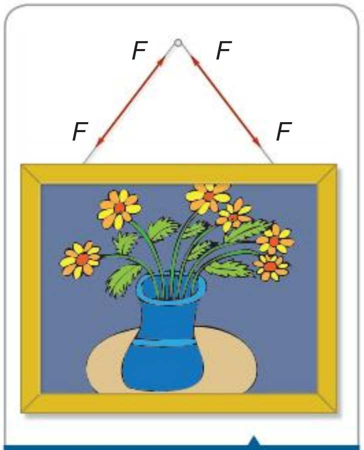
Unbalanced: forces do not cancel each other completely; an overall force exists, causing a change

Weight: gravitational force on a mass; unit, N



Compression


Necking



Tension

Unit 9.2

Centre of gravity: point in an object in which all of the mass the object can be thought to be concentrated; the object's weight can be thought to act through here

Centre of mass: point in an object in which all of the mass the object can be thought to be concentrated; the object's weight can be thought to act through here

Elevator: lift, used to go up and down a skyscraper

Superstructure: frame of a skyscraper


Superstructure

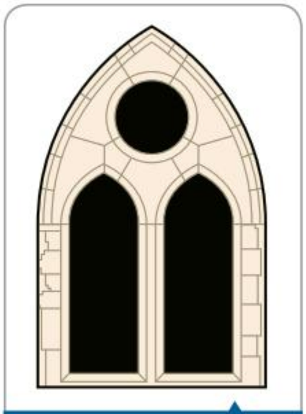
Unit 9.3

Beam: lintel, used over windows and doors to hold up the weight of the wall above it

Flying buttress: a structure that provides extra support for walls, used with Gothic arches

Gothic arch: pointed arch

Lintel: beam used over windows and doors to support the weight of the wall above it

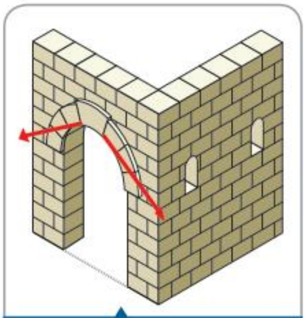

Gothic arch

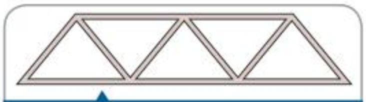

Lintel

Reinforced concrete: concrete with steel rods and/or mesh within it

Roman arch: semicircular arch

Truss: lightweight structure made from triangles, commonly used in bridges


Roman arch


Truss

10 Forensic science

HAVE YOU EVER WONDERED…

- why police record eyewitness accounts of a crime as soon as possible?
- how images of suspects are constructed?
- what police can tell from fluff collected from a crime scene?
- why DNA is considered the ultimate 'fingerprint'?
- why Australian banknotes are plastic and not paper?

After completing this chapter students should be able to:

- explain how science inquiry skills are used in forensics to investigate and evaluate evidence
- apply specific skills for the use of scientific instruments
- use modelling and simulations, including digital technology, to investigate situations and events
- outline the effect of a range of factors, such as temperature and catalysts, on the rate of chemical reactions
- describe the role of DNA as the blueprint for controlling the characteristics of organisms
- describe the impact of developments in genetic knowledge
- describe how computers have made possible the analysis of DNA sequencing
- outline the applications of gene technologies
- discuss the use of genetic testing.

10.1 Crime scene

Crime ranges from shoplifting, theft and forgery to assault and murder. All these crimes leave telltale clues that point to those most likely to have committed the crime. The analysis of these clues is the work of forensic scientists. The information that they obtain from these clues is then used against suspects in court. Sometimes these clues are used to defend them.

INQUIRY science 4 fun

Sandpit tracks

What can footprints and a track tell you?

Yes

Collect this …

- access to a sandpit (such as a long-jump pit)
- rake

Do this …

1 Rake over the sandpit so that it is smooth.

2 Walk slowly across the pit.

3 Walk across the pit again, parallel to your original tracks, but try:

  a walking faster

  b walking backwards

  c changing direction midway.

4 Compare the:

  a tread of the footprints with the sole of your shoes

  b depth of the footprints (for example, did the faster run produce deeper prints?)

  c spacing of the footprints.

Record this …

Describe what you saw.

Explain what you think caused each of the features you saw.

First on the scene

The first authorities to arrive at a crime scene will usually be the police. They will quickly cordon off (rope off) the crime scene, call for back-up from other police, detectives, crime scene units, ambulance and fire brigade and start interviewing eyewitnesses (people who were there).

CSU

A **crime scene unit (CSU)** is a team of specialist police, photographers and forensic scientists trained in collecting and analysing evidence. Normally the CSU does not deal with less serious crimes like burglary but concentrates on more complex and serious crimes such as **homicide** (where another human is killed), terrorist attacks, **arson** (when a fire is started deliberately) or sexual assault.

Every piece of evidence from a crime scene is a clue, and the CSU thoroughly searches the area to ensure that nothing is missed. Figure 10.1.1 shows three different ways the CSU can do this. Every piece of evidence is then marked and photographed while in position.

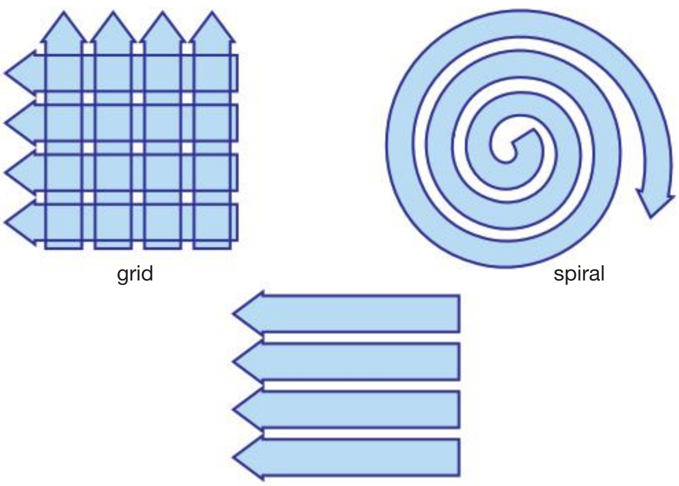


Figure 10.1.1 Three different methods are used by crime scene units to ensure that the crime scene is thoroughly searched.

The crime scene is then cleared and everything is sent away to be analysed by forensic scientists specialised in particular fields, such as **pathology** (the study of disease and cause of death), **ballistics** (the study of guns and bullets), **toxicology** (the study of the effects of poisons and chemicals on the body), fingerprints, fibres, chemistry and dentistry.

The materials found at a crime scene can be classified broadly as either physical evidence or trace evidence.

Physical evidence

Anything that is reasonably large and easy to see is **physical evidence**. It includes dead bodies, bullets, bullet-holes (like those in Figure 10.1.2), weapons, tool marks, tracks, damaged furniture, fingerprints or blood splatters.

Figure 10.1.2 Bullets and the holes they make are physical evidence.

Corpses

A **corpse** is a dead body. A corpse is easy to identify if an ID card, a driver's licence, credit cards or a Medicare card are found on or near it. Photos of the person can be matched with the body and card numbers can be checked against home addresses. A mobile phone will hold numbers of friends and relatives who can be called. They can then view the body and confirm its identity.

Even without these forms of identification, police can be reasonably certain about who the person was. For example, a body found in a burnt-out house is most likely to be one of the people who lived there. Similarly, the body in the driving seat of a badly damaged car was probably the registered owner or someone closely related to them. Hire cars are even easier to track since the driver's name and address will be left at the hire-car company.

SciFile

ICE

Many people include ICE in the directory of their mobile phone. ICE stands for **I**n **C**ase of **E**mergency and contains the number that you want police to contact if you are found ill or unconscious or have been in a serious accident. Who have you got as your ICE contact?

Evidence of time of death

A series of changes in a corpse begins immediately after death and can be used to determine how long a person has been dead. This information is vital for investigators since it will confirm the day (and possibly the hour) in which the crime was committed. This then allows police to narrow their range of suspects of who committed the murder.

One obvious change is body temperature. A healthy living human has a **core body temperature** of 37°C. After death, this falls at a rate of about 0.8°C every hour until it reaches room temperature (the exact rate of cooling depends on the victim's clothing and the surrounding temperature). This means that a body will cool completely within one day.

Other changes that can be used to determine the time of death are the:

- extent of rigor mortis (stiffening of muscles)
- colour of the skin (shown in Figure 10.1.3)
- extent of decomposition
- type and life-cycle stage of insects present on and around the body.

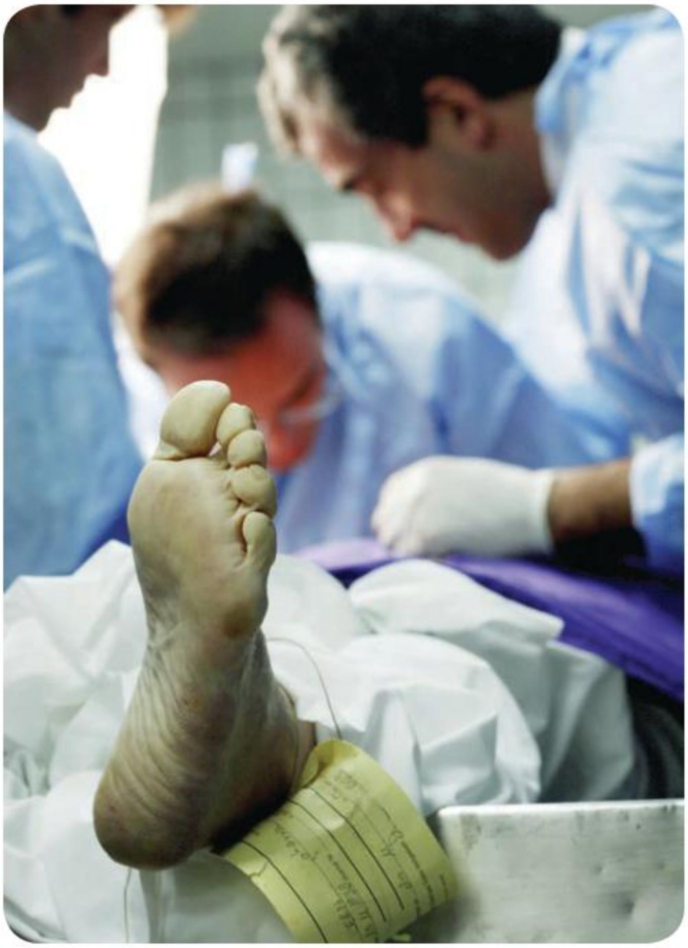


Figure 10.1.3 Skin takes on a greenish appearance within two days of death because bacteria are starting to decompose the body.

Tool marks

Every type of tool leaves its own characteristic impression or **tool mark**. For example, the jemmy bar being used in Figure 10.1.4 will leave scratches, dents and cuts in the window frame and sill. Different marks would have been left by a screwdriver, hammer, axe, knife or chisel.

Tool marks depend on:

- the type of tool being used
- whether the material being marked is hard (such as wood or bone) or soft (such as fabric, paper, skin, fat or muscle)
- the sharpness of the individual tool. For example, a sharp saw will produce a fine, crisp cut in wood, while a blunt one will rip the wood and produce a ragged edge
- faults in the tool such as missing teeth or heavy wear patterns.

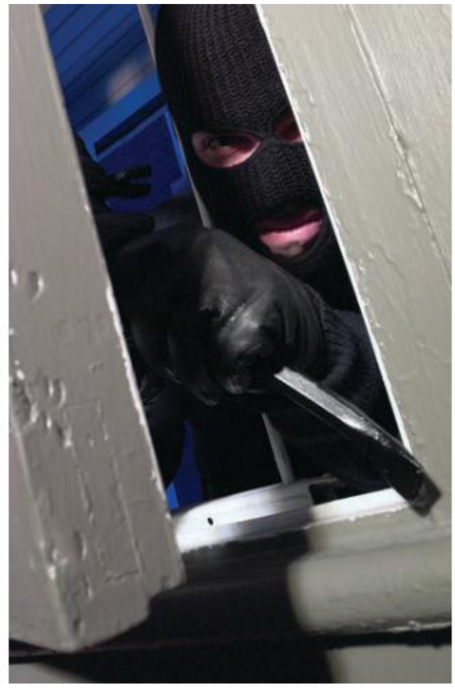


Figure 10.1.4 The marks on a window frame allow investigators to determine whether a screwdriver or a jemmy bar was used to lever open a window. These will be photographed and compared with tools collected from the suspect or the suspect's residence.

Track impressions

Footprints and impressions from shoes and tyres are often left behind at a crime scene. A **positive impression** is an image that is exactly the same as the pattern on the shoe or tyre. Positive impressions are left on hard surfaces by feet, shoes and tyres that are dirty or soaked with water, oil or blood. A **negative impression** is formed if the suspect crossed damp sand, mud, snow, grease or congealing (thickening) blood. This is because the material only gathers in gaps in the tread of the shoes or tyres.

All impressions are photographed next to a ruler to indicate their actual size. You can see this in Figure 10.1.5. Negative impressions will have wet plaster poured into them to form a mould that can be taken back to the laboratory for analysis.

Figure 10.1.5 The make and style of shoe that a criminal wore can be determined from its prints. Even more information comes from cuts, stones, scuffing and wear on the sole.

Collecting fingerprints

In the grooves of your fingerprints are glands that secrete (release) sweat, oils and amino acids. A little of these secretions is left behind as an image of the fingerprint whenever something is touched or picked up. **Non-porous** materials like metal and glass do not absorb sweat, oil or amino acids and so clear fingerprints are most likely to be found on:

- metallic objects such as doorknobs, forks, saucepans, knives and guns
- glass and ceramics such as drinking glasses, windows, mirrors, bathroom tiles, cups, mugs and plates
- the plastics that make up light switches, car dashboards, steering wheels and broom and brush handles
- painted surfaces such as cars and front doors and their surrounds
- polished or varnished surfaces of furniture and stair railings.

As Figure 10.1.6 shows, fingerprints are revealed by brushing special types of powder onto the surface so that it sticks to the oils left behind. Black carbon powder is dusted onto light-coloured and clear surfaces and white aluminium powder is brushed onto dark surfaces.

1 p332

Figure 10.1.6 Black carbon powder is brushed onto glass to show fingerprints on its surface.

Porous materials such as fabrics, stone or raw timber absorb body fluids, making it difficult to find fingerprints on them. However, fingerprints can still be revealed by brushing them with chemicals that react with the secretions of the fingerprint. For example, ninhydrin is a chemical that reacts with amino acids, turning the fingerprint a bluish purple. Light can also help to reveal fingerprints, as Figure 10.1.7 shows.

Figure 10.1.7 Some types of light cause fingerprints to fluoresce or glow. Here an investigator is searching for fingerprints left by the 2002 Bali bombers.

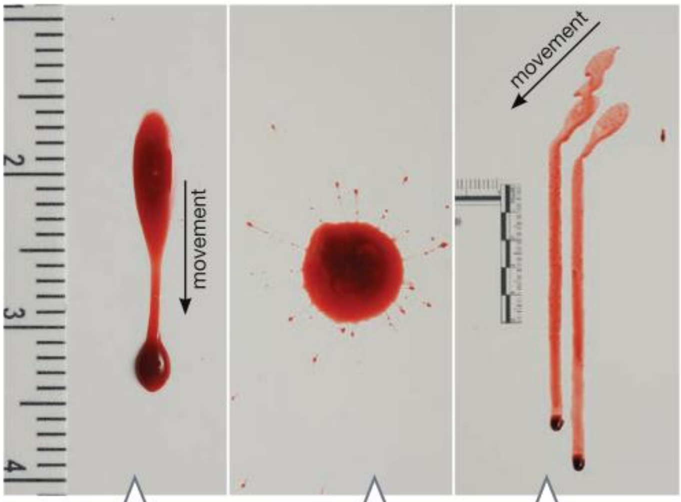
SciFile

Superglue fingerprints

Superglue reacts with the oils that make up fingerprints and superglue vapour is sometimes blown onto prints to make them stickier and more visible. Sealed objects such as fridges and cars can be filled with superglue vapour, revealing all the prints inside them.

Blood splatters

Drops of blood tell investigators a lot about what happened at a crime scene. As Figure 10.1.8 shows, they change shape and size depending on the height and direction they fall from.



Directional: elongated drips indicate the direction the blood was moving when it hit a horizontal surface

Drip stain: circles indicate that the blood dropped vertically from a short distance

Flow pattern: indicates the direction the blood was moving when it hit a vertical surface

Figure 10.1.8 Blood splatters change shape depending on the direction they hit a surface

10.2

Trace evidence

Microscopic materials found at the crime scene are known as **trace evidence**. Trace evidence is incredibly useful to investigators since the criminal cannot see it and so cannot collect it or wipe it away.

Fibres

Fibres are strands of natural materials such as hair, fur, fluff, wool and cotton, and synthetics such as nylon and polyester. Wherever you go, a few hairs are likely to fall from your head and body and a few threads are likely to drop from your clothes. These get trapped in the carpet, on furniture and on other people's clothes. A violent struggle will cause even more fibres to drop. Investigators can collect these fibres by picking them up with sticky tape or by using a specialised vacuum cleaner.

A microscope is then used to compare fibres with those from other crime scenes and those of the victim and suspects. As Figure 10.1.9 shows, fibres can be identified from their characteristic surfaces.

Fibres do not prove that a particular person was at the crime scene. Many people have the same shirt, jeans or dress and the same colour and type of hair. For this reason, fibres are only **circumstantial evidence**—they point to a suspect but cannot be used as proof that they were there.

2 p333

Seeds

Microscopic grains of pollen and seeds found at a crime scene can be compared with plants nearby and in the areas in which the suspects live. This helps investigators to piece together what happened. For example, a body that has been shifted might have seeds from another area on it.

DNA

Wherever you go, you leave a little bit of yourself behind. It might be a few cells of skin, a smear of body oil, sweat, a strand of hair, a few flakes of dandruff or saliva. Saliva is being collected in Figure 10.1.10. **DNA** (deoxyribonucleic acid) is a chemical present in the nucleus of body cells. Everyone has different DNA. This makes DNA the 'ultimate fingerprint'.

Some of the DNA found at a crime scene will come from the victim, some may come from people known to be innocent and some will probably come from the suspect. This proves that the suspect was there at some time.

Figure 10.1.10 The saliva on this cigarette stub will contain the DNA of whoever smoked it.

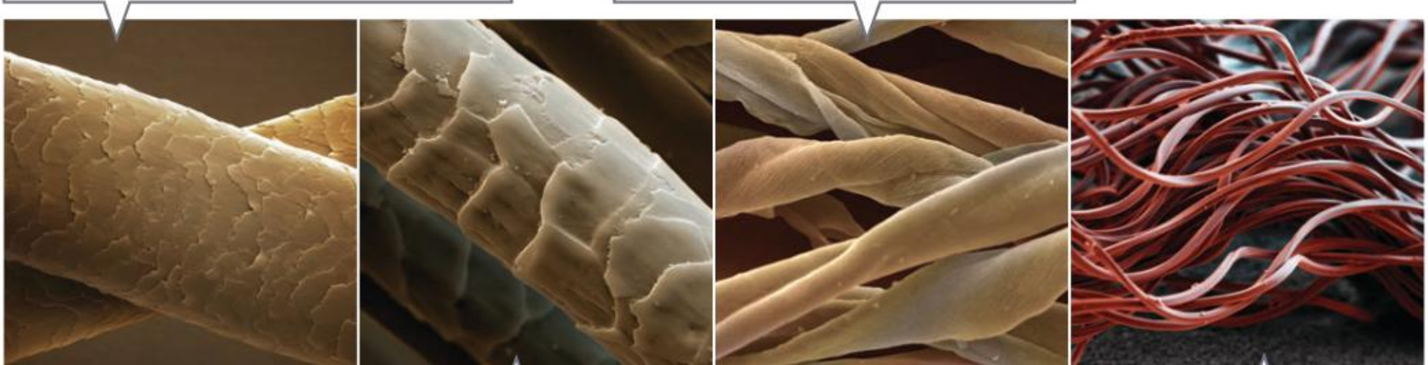


Figure 10.1.9 Fibres can be easily identified since each type has its own characteristic surface texture. These images were taken with a scanning electron microscope (SEM).

10.1 Unit review

Remembering

1 **List** the materials that are left behind on a surface that form a fingerprint.

2 **Name** the chemical used to highlight fingerprints on:
- a light-coloured surfaces
- b dark surfaces
- c porous materials.

3 Many criminals clean up a crime scene before they leave it. Even so, they probably leave behind traces that will help identify them. **List** what these traces might be.

Understanding

4 **Explain** why the CSU makes sure they search every part of a crime scene.

5 A firm, green banana has fallen off a tree.
- a **Identify** the signs that could be used to determine how long the banana has been off the tree.
- b **Explain** how these changes in a banana relate to determining the time of death of a body.

6
- a **State** what the core temperature of a healthy human is.
- b **State** how much the temperature of a corpse usually drops per hour after death.
- c **Calculate** what the temperature would be at 1 hour, 2 hours, 3 hours etc. after death. Stop calculating when you reach 24 hours.

7 **Explain** why fibres can only ever be considered circumstantial evidence.

Analysing

8 **Analyse** the two crime scenes shown in Figure 10.1.11 and **list** 20 differences.

9 **Compare** the impressions the following shoe tracks would make by **listing** their similarities and differences:
- wet shoes walking across dry concrete
- dry shoes walking across thick grease
- dry shoes walking across snow.

10 **Classify** the following as physical or trace evidence.
- a DNA
- b broken window
- c pollen

11 Imagine running across a sandpit. As you run, you place different pressure on different parts of your foot, producing a print of different depths. **Analyse** the distribution of pressure on your feet as you:
- a run forwards
- b run backwards
- c turn quickly.

Evaluating

12 Fingerprints are rarely found on clothes. **Propose** a reason why.

13 **Propose** what may have happened at a crime scene if the following are found.
- a broken furniture
- b only a few fingerprints and all of them smudged

Figure 10.1.11 Spot the differences between these two crime scenes.

14 The two people in Figure 10.1.12 were both seen at a crime scene.

a **Identify** who would be easier for an eyewitness to describe.

b **Justify** your choice.

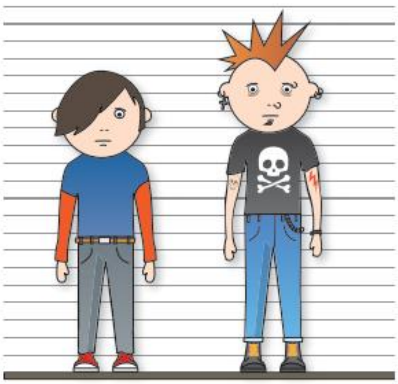


Figure 10.1.12

15 CSU teams wear gloves, masks and full body suits whenever they collect evidence that might contain DNA. **Propose** reasons why.

Creating

16 a From memory, **construct** a detailed eyewitness description of:

i your maths teacher

ii what happened between getting up and arriving at school this morning

iii your family car

iv the room in which you last had English.

b **Assess** how well you remembered in part **a**.

17 The pattern of blood splatters and drips from a wound can help investigators determine exactly where injuries happened.

a Copy Figure 10.1.13 into your workbook.

b Add lines to **construct** a diagram that locates where in the room the person was wounded. One has already been done for you.

Figure 10.1.13

Inquiring

1 Many conspiracy theories surround the assassination of US President John F. Kennedy in 1963, largely because of conflicting evidence, eyewitness accounts and the strange history of the main suspect. Research and prepare a case study for this assassination. Include the following.

a Name the main suspect and describe what happened to him.

b Summarise his history.

c Propose reasons why many think that he was part of a bigger plot.

d Watch the Zapruder film and summarise what you saw in it.

e Outline the magic bullet theory.

f Describe what the *grassy knoll* is and what people said about it.

g Assess the material you found and classify it as reliable or unreliable evidence.

2 Use the key words *eyewitness games* to search the internet to find interactive games that test how accurate your memory is.

3 Use the keyword *edheads* to find games that test your skills as a forensic investigator.

4 When walking, taller people take longer steps than shorter people.

a Design a way of determining the height of someone based on the length of their steps.

b Show your plan to your teacher and get their approval to run your experiment.

5 Design an investigation that compares the stages that different fruit go through when they decompose. Take note of what happens inside it by making cuts on its surface or by taking a slice out of it. Over a week, record changes in colour, texture, odour and any insects that are seen on it.

10.1 Practical activities

1 Lifting fingerprints

Purpose

To detect fingerprints on different surfaces.

Materials

- variety of objects with different surfaces of different colours (such as glass microscope slide, white tile, glossy wrapping paper, soft-drink can, fabric)
- sheets of newspaper
- carbon powder (or manganese dioxide)
- talcum powder
- soft fine-haired brush
- plastic teaspoon
- broad, clear sticky tape
- white and black cards

Procedure

1. Cover your workbench top with newspaper.
2. Hold each different material or object in your fingertips and then place each on the newspaper.
3. Use the teaspoon to sprinkle carbon or talc onto each object. Choose carbon for light-coloured objects and talc for dark.
4. Use the brush to *gently* dust off excess powder.
5. Place a strip of sticky tape over any prints that you find.
6. *Gently* peel off the tape and stick it onto the card that will best show the print.

Discussion

1. Some of your lifted fingerprints might only be partial (not complete). **Explain** why.
2. **Identify** the types of materials on which no prints were found.
3. **Explain** why prints are difficult to lift from porous materials.

SKILL BUILDER

Using a microscope

1. Adjust the mirror or diaphragm so that the maximum amount of light is passing through the sample.
2. Select the objective lens with the lowest magnification.
3. Looking at the microscope from its side, adjust the coarse-focusing knob to bring the stage and objective lens as close to each other as possible.
4. Looking through the eyepiece, turn the coarse-focusing knob so that the stage and objective lens move further apart.
5. Keep doing this until the specimen is in focus.
6. Adjust the fine-focusing knob to sharpen the focus on the specimens.
7. If you can't focus the microscope, then go back to step 4 and start again.

2 Analysis of fibres

Purpose

To compare different types of fibres.

SAFETY

Some fabrics release poisonous gases when burning.

Do part B in a fumehood or outside.

Wear safety glasses at all times in part B.

Materials

Part A: Under the microscope

- labelled samples of different fabrics made of:
  - natural fibres (such as wool, cotton, linen, silk)
  - synthetic fibres (such as nylon, polyester, rayon)
- labelled samples of other fibres (such as human hair, fur, coir)
- clear sticky tape
- tweezers or pins
- access to stereomicroscope or monocular microscope

Part B: Flame tests

- metal tongs
- matches
- bench mat

Procedure

Part A: Under the microscope

1. Remove an individual thread (about 2 cm long) from each fabric sample.
2. Most threads are made from a number of individual fibres. Use the pin or tweezers to tease them apart.
3. Peel off a strip of clear sticky tape and pat it against the thread so that it sticks.
4. Place the stuck fibres under the microscope and focus to obtain a clear image.

Part B: Flame tests

5. Cut or tear a strip about 2 × 1 cm from each fabric.
6. Use tongs to hold a strip over the bench mat. Hold a lighted match under the strip.

Results

1. In your workbook sketch and label each fibre, taking note of its surface
2. Record your observations for each fabric when placed in the flame. Did it catch fire, melt or char? What colour was the flame and smoke? What was left?
3. **Compare** the surface of each fibre with the simplified diagrams shown in Figure 10.1.14 and classify each.

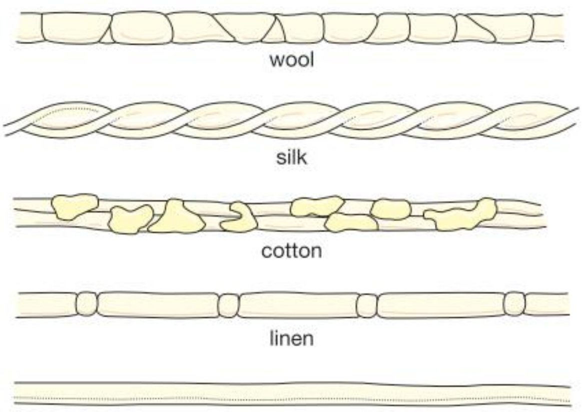


Figure 10.1.14

Discussion

1. **Explain** why fibres are considered to be trace evidence.
2. **Compare** the surfaces of the natural fibres with those of the synthetic fibres.
3. **Classify** the fibres you tested as fibres that burn, fibres that melt or fibres that char (go black but with no flame).

10.2 Victims and suspects

A lot can be learnt from a body. Its features and proportions help forensic scientists to identify it and marks on it can suggest the cause of death. Likewise, forensic science can provide investigators with the evidence they need to successfully identify and convict those who committed the crime.

INQUIRY science 4 fun

Teeth impressions

Can you be identified from your teeth?

Collect this ...

- 'jelly' lollies such as jelly frogs or snakes (one per student)

Do this ...

1 Carefully bite *once* into the jelly lolly. If possible, bite right through it.

2 Compare the teeth impression with your actual teeth. Did it have the same number?

Record this ...

Describe any differences between your teeth impression and your actual teeth.

Explain how teeth impressions might be used to solve a crime.

Autopsy

A corpse will be sent from the crime scene to the coroner's office where forensic pathologists perform an **autopsy**. This is done to:

- confirm the identity of a 'known' body or to find out who an 'unknown' body is
- determine or confirm the cause of death.

The main steps in an autopsy are shown in Figure 10.2.1.

Identifying bodies

Visual confirmation of a body is often impossible if it has been in a fire or explosion or has been in the water or bush for some time. Identification is even more difficult if there is nothing to link the body with its surroundings. Investigators must then try to match it with descriptions and photos of missing people on police files. If the person has been missing for a long time, then the task is even harder. The information on the database will then be inaccurate.

To aid identification, pathologists carrying out the autopsy will:

- take fingerprints where possible from the body. These can then be compared with fingerprints on police files or those found around the house or apartment where the person thought to be the victim lived
- inspect any remaining tissue for identifying marks such as birthmarks, tattoos and scars. These can then be compared with marks seen on the likely victim in family photos or on the database of missing persons
- take samples or photos of clothing and jewellery. These can then be compared with those worn by the likely victim when last seen alive
- extract DNA from any remaining tissue and compare it with DNA collected from the clothing, toothbrush or hairbrush of the likely victim. If the person has been missing for a long time, then their home is likely to have been cleaned out, leaving none of their DNA. Their direct relatives will have similar DNA and so comparison may need to be with them.

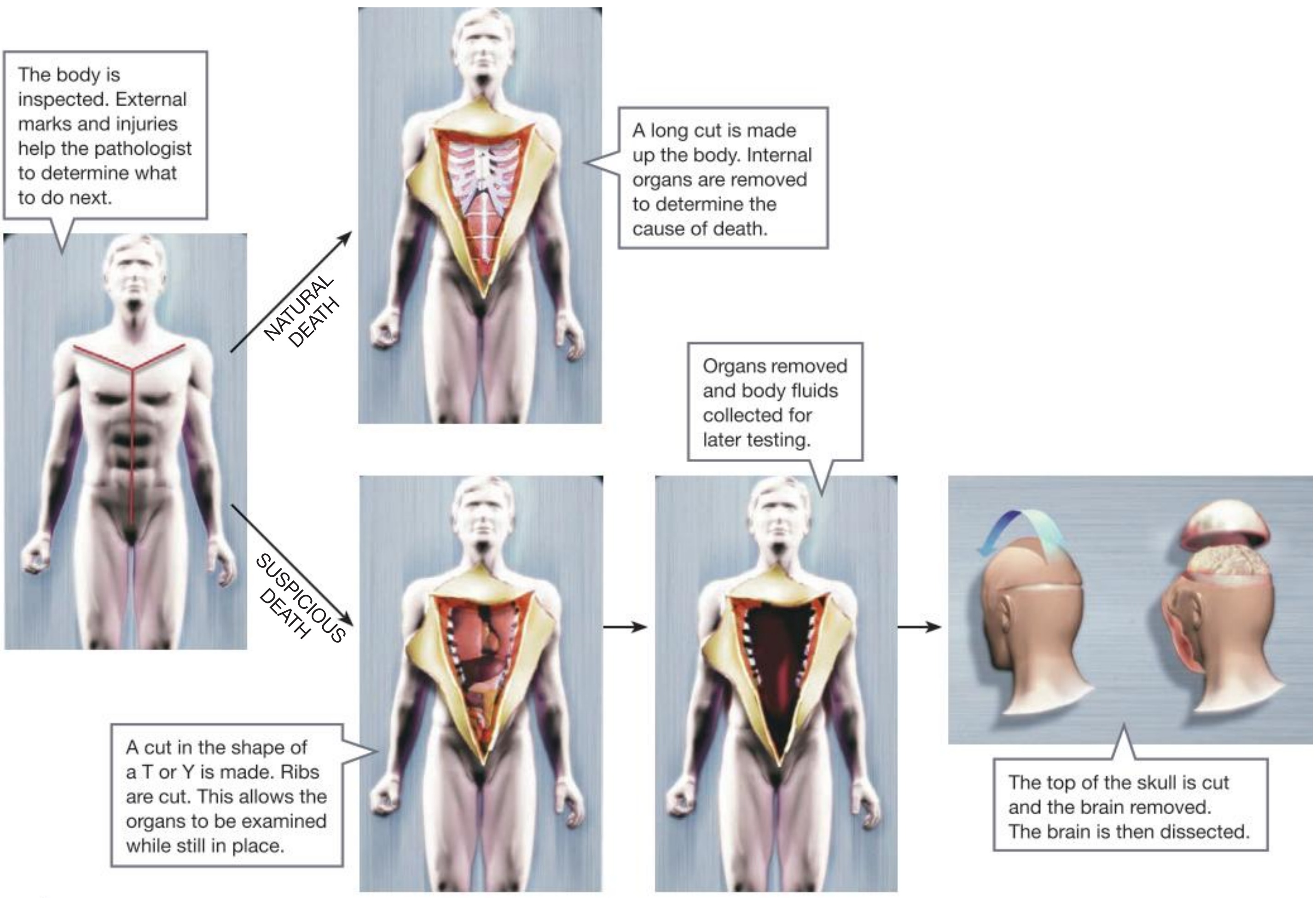


Figure 10.2.1 An autopsy is a systematic dissection of a corpse. The exact order and degree of dissection depends on whether the victim is thought to have died naturally or from foul play.

Identifying skeletons

DNA deteriorates with time, especially when exposed to intense heat. There might even be no tissue left on the skeleton to analyse on corpses that were not discovered for a long time. Investigators then compare the medical and dental records of the likely victim with the injuries and dental work found on the skeleton. Badly broken bones commonly have pins, plates and screws inserted in them (like those in Figure 10.2.2) to help them repair. Finding these in a skeleton can confirm its identity, as can replacement hips or knees.

Figure 10.2.2 This artificial knee and the pegs used to fix it to the bones are clearly visible on an X-ray. They would quickly confirm the identity of a body.

SciFile

Anthropometry

Alphonse Bertillon became chief of criminal investigation for the Paris police after he developed a way of identifying people from their body proportions. His system (called **anthropometry** or the **Bertillon system**) was widely used from 1882 to 1905 until a twin brother was incorrectly jailed!

Jewellery, belt buckles and buttons left on the skeleton will also give an idea of the victim's sex and age. Their style changes every 10 years or so and will also suggest roughly when the person died.

If none of this if possible, then the age and sex of the corpse can be determined from the size and density of large bones such as the pelvis, skull and femur (the main bone of the leg). Figure 10.2.3 shows a forensic scientist taking some of these measurements.

p344

Figure 10.2.3 Measurements of a skeleton can provide information about the sex and age of the victim.

10.3

Cause of death

A forensic pathologist must determine whether death was natural or caused by someone or something else. Each cause of death such as shooting, stabbing and drowning leaves its tell-tale signs.

Shooting

Bullets may still be in a body or may have exited and lodged in furniture or walls nearby. This allows the path of the bullet to be determined. Shotguns shower a victim with multiple pellets. A single wound suggests that the shotgun was close while a scattering of wounds like those in Figure 10.2.4 suggests that the victim was shot from a distance. If there are burn marks from the exploding gunpowder this would indicate that the gun was shot from close range.

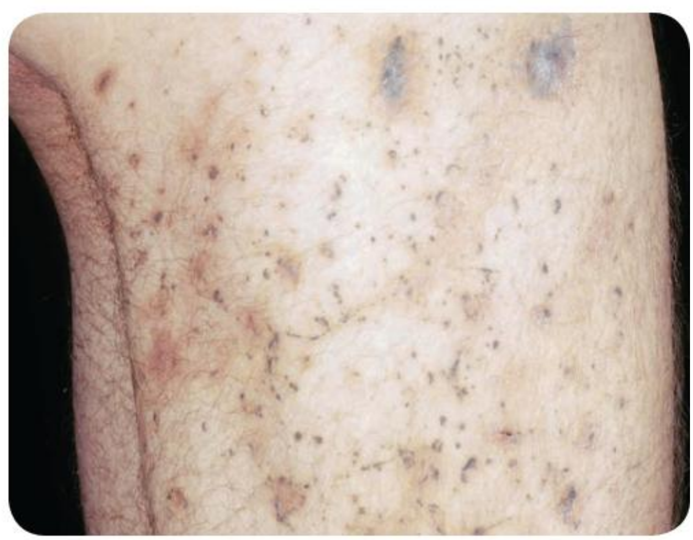


Figure 10.2.4 These wounds are from the pellets of a shotgun. They are spread out, indicating that the shooter was some distance from the victim. If the shooter was close, then the individual wounds would join to form one large wound.

Wounds

Knives leave their own tool marks on the body. For example, the wound produced by a straight-edged knife is different from one with a serrated edge. The depth of the wound gives an idea of the force used in the attack, and its angle suggests the direction of the attack. (Sometimes the angle will even suggest that it was not an attack at all but a horrible accident.) Where the wounds are located also provides information about the attacker. Wounds on the right side of the chest, for example, suggest that the attacker was left-handed. Wounds on the right of the back suggest the attacker was right-handed.

Bruises like those in Figure 10.2.5 indicate that a blunt object was used as the weapon.

Figure 10.2.5 Skin bruises badly if punched, kicked or hit. The skin won't be pierced but it might split and bones underneath are likely to fracture.

Drowning

Water will be in the lungs and stomach of a victim who has drowned. This water will contain **diatoms**. These are small single-celled organisms that are partly made of silica, a very hard material that forms a variety of shapes. Some are shown in Figure 10.2.6. Each creek, lake or dam has different-shaped diatoms and their shape can pinpoint the location of a drowning and whether the body was shifted after death.

Figure 10.2.6 Diatoms come in an amazing variety of shapes, as this scanning electron microscope (SEM) image shows. The characteristic shapes of diatoms can point to where a drowning occurred.

Identifying suspects

Photographs

Photographs are excellent for proving identity and are used in passports, driver's licences and student identification cards. They are not as useful for identifying suspects. This is because:

- the only photos police have will be those who have already been found guilty of previous crimes. First offenders won't yet have their photos on file
- an eyewitness needs to sift through hundreds of photographs. This exposure can lead to **retroactive interference**, a process in which eyewitnesses involuntarily merge images in their memory to form a 'suspect' who looks nothing like the person who committed the crime.

Identikit

Sketched portraits have long been used as a method of identification. At first these sketches were drawn by professional artists from descriptions from eyewitnesses. However, the quality of these portraits depended as much on the ability of the artist as it did on the accuracy of the eyewitness account.

Identikit became widely used after 1959. It used sets of pre-drawn facial features (eyes, mouth, chin shape etc.) that slotted together to form a portrait. Identikit had many advantages over artist-drawn portraits. It:

- allowed a realistic image to be constructed at any police station
- did not depend on the ability or availability of an artist
- allowed various combinations of features to be tried to trigger the memory of the eyewitness.

Figure 10.2.7 Computer software allows realistic images of suspects to be produced by dragging across different facial features from its database of images.

Today, police use computerised versions of Identikit like the one shown in Figure 10.2.7. The computer-composite images are fast, can be digitally enhanced to make them even more realistic and can be three-dimensional. Some are incredibly accurate, like the one in Figure 10.2.8 on page 338.

2 p345

Figure 10.2.8 This computer-generated Identikit image of a criminal helped to catch him in 2005. It shows a remarkable similarity to the real man.

Home-grown FACE

In 1989, Australia was the first country to produce a coloured computerised version of Identikit. Called FACE, it allowed police to take laptop computers to the crime scene and immediately identify criminals. FACE helped to identify the three men who had set off explosives in the 2002 terrorist bombing in Bali.

SciFile

Proving the suspect was there

For a prosecution to be successful, police need to be able to prove that a suspect was at the scene of a crime. This can be done in a number of ways, including:

- electronic tracking
- fingerprints
- DNA.

Electronic tracking

Security cameras and **CCTV** (closed circuit TV) are now common in shopping centres, banks, train stations and airports, outside nightclubs and even in city streets and lanes. Video from these can prove that a suspect was at the scene at the time of the crime. They may even show the suspect carrying out the crime.

Biometric facial recognition technologies that allow a CCTV to scan a crowd and identify known offenders are now being trialled. Most of these techniques compare the positions of points on the face with those of known criminals. Figure 10.2.9 shows how it's done.

When switched on, your mobile phone can enable your phone company to locate you to within 10–50 metres. This allows police to track suspects (and victims) and gives an easy way of proving that the suspect was close to the scene at the time the crime happened.

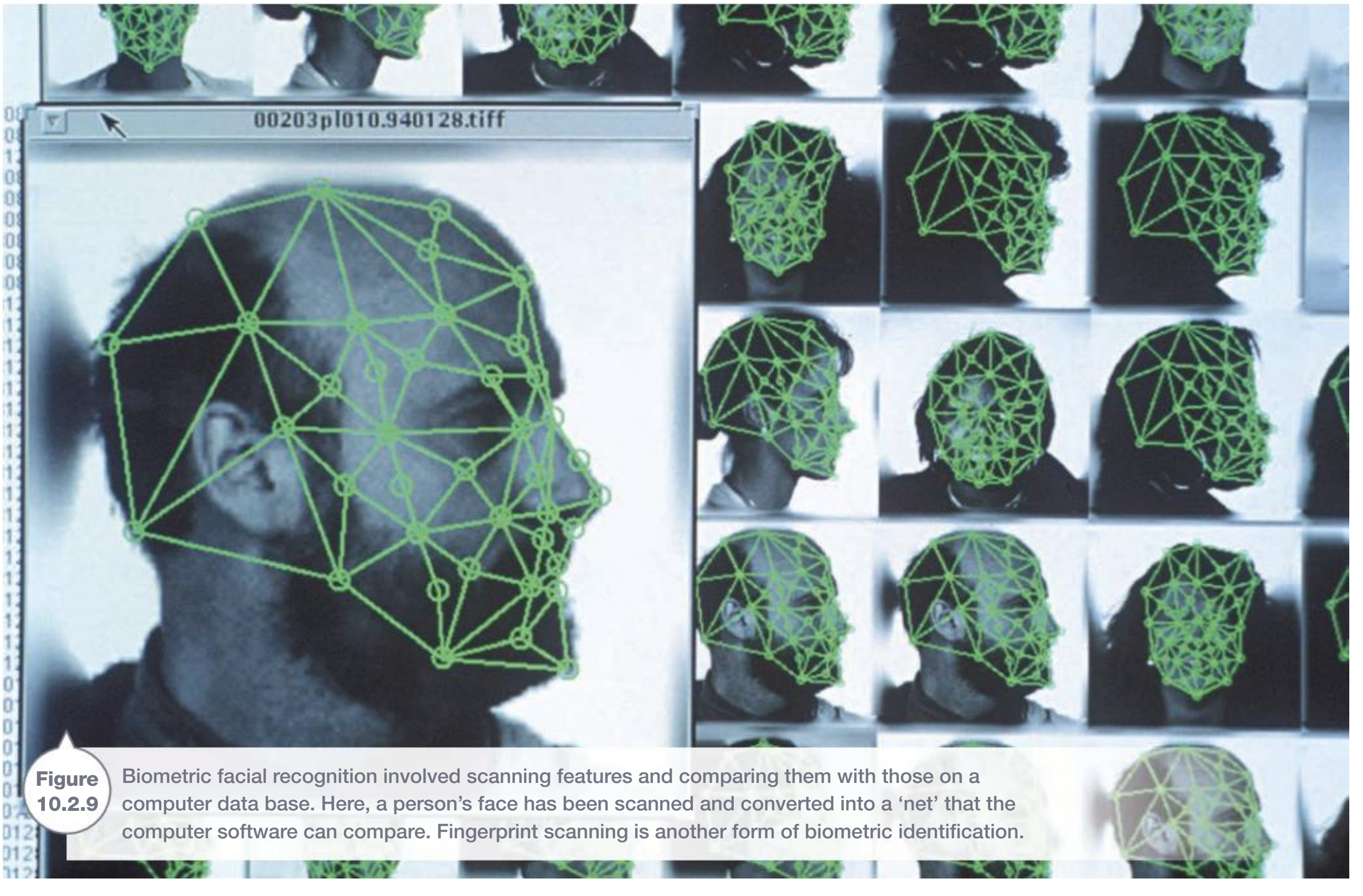


Figure 10.2.9 Biometric facial recognition involved scanning features and comparing them with those on a computer data base. Here, a person's face has been scanned and converted into a 'net' that the computer software can compare. Fingerprint scanning is another form of biometric identification.

Photos or video of unlawful behaviour sometimes ends up on social networking sites. Once there, it can be used as evidence in court. For example, in 2009, police used a video posted on Facebook to convict a 20-year-old Victorian man of hoon (dangerous) driving. His $21 000 Ford Falcon utility was confiscated, his licence was disqualified for 18 months and he was fined $2000.

SciFile

Warning, warning!

Some police districts in the United Kingdom have been trialling CCTV cameras that speak! Police watch the cameras at all times and use small speakers to warn people who are misbehaving that they are being watched.

SKILL BUILDER

Taking fingerprints

Good fingerprints can end up being smudged or with too much or too little ink. To take a good fingerprint, follow these steps.

1. Roll your thumb across the damp surface of the inkpad.
2. As Figure 10.2.10 shows, roll it *once* across white paper.
3. If the print is smudged or has too much ink, then *do not* get more ink but 'dry' your thumb by rolling out more prints of it.

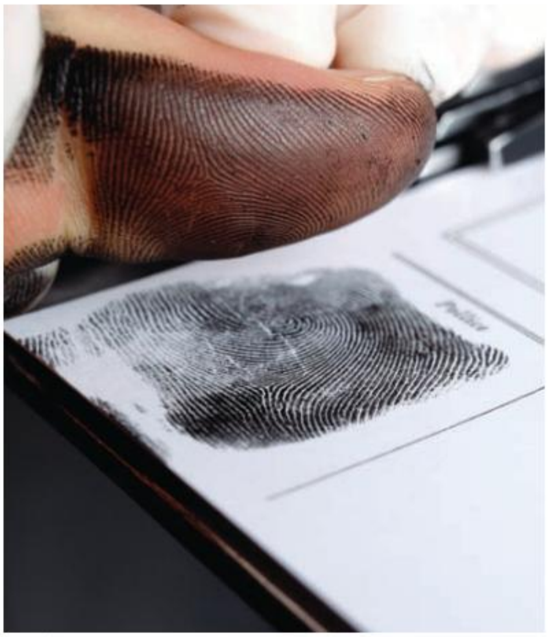


Figure 10.2.10 Roll your finger and don't squash it.

INQUIRY science 4 fun

Taking fingerprints

Can you take good fingerprints?

Yes

Collect this ...

- ink pad
- white paper
- scissors
- glue or sticky tape

Do this ...

1. Refer to the Skillbuilder and follow its steps to produce two good thumbprints.
2. Repeat with another finger.
3. Cut out the best two images of your thumb and two of your finger.
4. Paste one of each into your workbook, writing your name above them.
5. Swap the others with someone else in the class. Paste theirs in your workbook too, writing their name above theirs.
6. Construct a tally of the different types of fingerprints in your class. From this tally, identify which type is:
   a. most common
   b. least common.

Record this ...

Describe the fingerprints you produced. Are they loops, arches, whorls or composites?

Explain what you think your results suggest about finding suspects based on their fingerprints.

Fingerprints

No two sets of fingerprints from different people have ever been found to be the same. This makes fingerprints an excellent method of identifying suspects or proving that they were at the scene of a crime. The patterns that fingerprints form can be classified as **loops**, **whorls**, **arches** or **composites**. These are shown in Figure 10.2.11 on page 340.

Before computers, fingerprints were unlikely to be stored outside the state or country of the suspect. Also, manual comparison of fingerprints was difficult since it is slow and prone to mistakes. For these reasons, some criminals were able to move about undetected, committing crimes as they went. Computers have overcome most of these problems by storing, sharing, comparing and matching fingerprints across different states and countries.

SciFile

Same but different

Identical twins do not have identical fingerprints. However, their fingerprints do share more similarities than found between non-twin brothers and sisters.

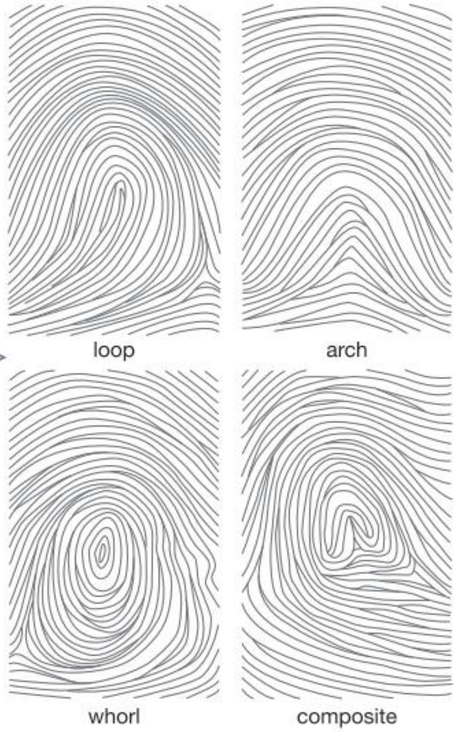


Figure 10.2.11

The four basic fingerprint types: loops, whorls, arches and composites. About 60–65% of all fingerprints are loops, about 35% are whorls and 5% are arches. Composite fingerprints are even more uncommon.

DNA profiling

DNA can be extracted from even the tiniest samples of flesh, blood, hair, saliva or semen left at a crime scene. For example, a knife used in an attack will contain the DNA of the victim in blood on its blade and the DNA of their attacker in sweat and oils on its handle. Everyone has different DNA and everyone's DNA produces a different autoradiogram. One is shown in Figure 10.2.12. An **autoradiogram** is produced by chopping up DNA and then separating its fragments. This process is called **gel electrophoresis**, and is shown in Figure 10.2.13. Computer programs then run matches against DNA on police databases.

Finding a suspect's DNA at a crime scene is proof that they were there at some time. However, it does not suggest when they were there or for what reason.

3 p345
10.4

Figure 10.2.12

An autoradiogram codes DNA as a series of black bars. If the pattern of the bars in a suspect matches those from a crime scene, then it proves they were there at some time.

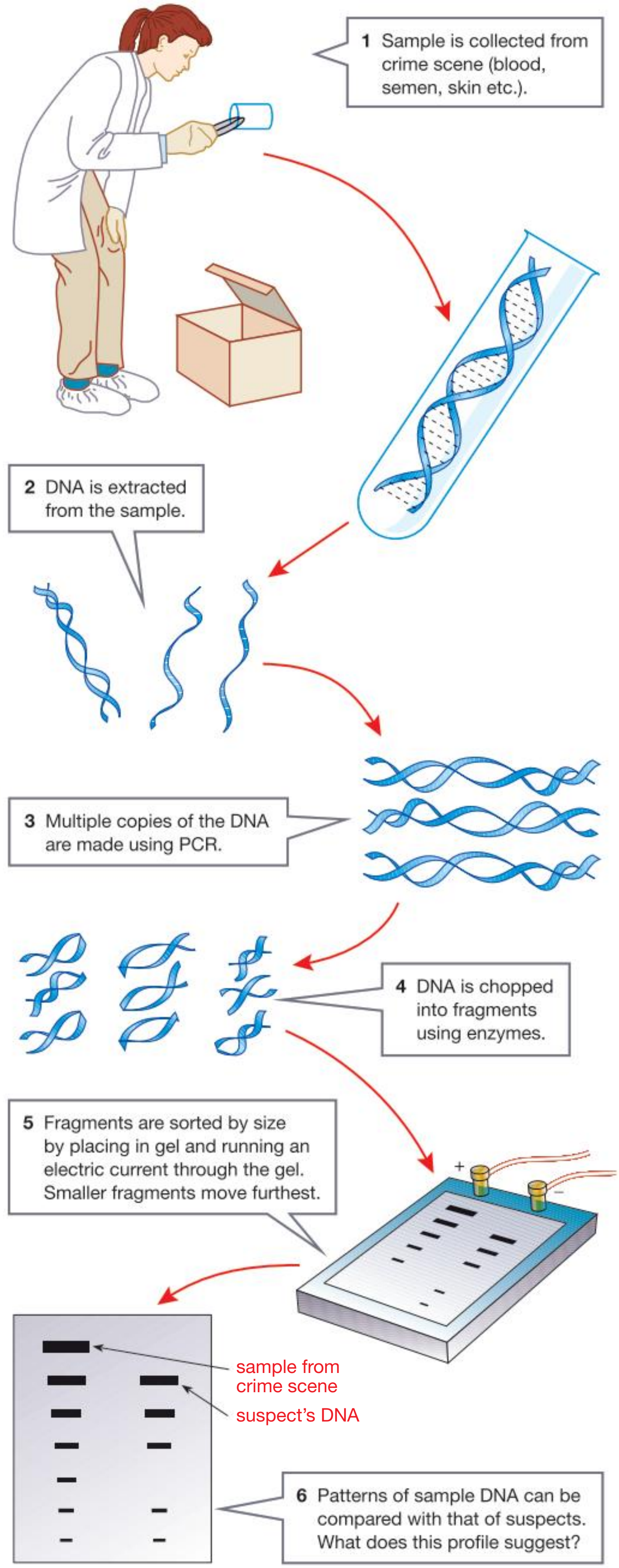


Figure 10.2.13

DNA from a crime scene is extracted, copied, chopped and then separated using gel electrophoresis. The end result is an autoradiogram.

SCIENCE AS A HUMAN ENDEAVOUR

Use and influence of science

New poisons

Figure 10.2.14 Dioxins failed to kill Victor Yushchenko in 2004 but he still bears the scars of the assassination attempt. These two photos were taken 5 months apart.

There is a long history of using poisons for assassinations (political murders). Assassins in ancient Rome commonly used poisons to kill opponents. Poisonous mushrooms killed the Roman emperor Claudius, and his successor Nero used cyanide to kill relatives who threatened his power. Family dinners were simply murder!

Since ancient Roman times antinomy, arsenic, lead, mercury and thallium have all been used to kill. However, the symptoms of these poisons are now so well known that doctors quickly realise that they are not dealing with simple illness. Police quickly realise that an attempted assassination has taken place. For these reasons, assassins have recently used some very different poisons.

Ricin

Ricin is a poison extracted from castor beans that is about 200 times more deadly than cyanide. Its symptoms are similar to natural diseases and vary depending on whether it has been eaten, injected or breathed in. There is no test that will confirm its presence and there is no known antidote (cure).

In most cases, ricin has been detected before it had a chance to poison anyone. For example, ricin was found in mail sent to the White House in 2003. Ricin was used in the bizarre assassination of Georgi Markov in 1978 in London (UK). Markov had defected (escaped) from communist Bulgaria seven years earlier and wrote anti-communist books and plays. Markov collapsed after being 'accidentally' jabbed in the leg by a passerby with the tip of an umbrella. It probably looked like the one shown in Figure 10.2.15. Markov died three days later. An autopsy found in his calf a tiny metallic pellet that had been drilled out and which contained traces of ricin. It seems that the umbrella was a specially designed gun and the passerby an assassin. There was a similar, failed, assassination attempt ten days earlier in Paris on another Bulgarian defector, Vladimir Kostov. The KGB (the Soviet secret police) is thought to have been behind both incidents.

10.5

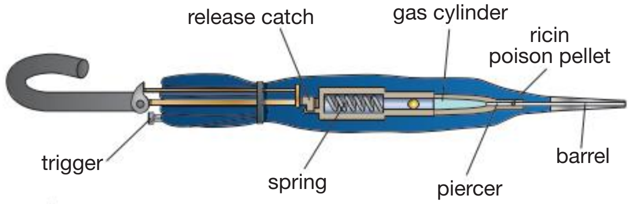


Figure 10.2.15 An artist's impression of the umbrella 'gun' used to shoot Georgi Markov in 1978.

Dioxins

Dioxins are poisonous chemicals that are present in tiny quantities in cigarette smoke, plastics and some industrial wastes. In 2004, assassins used dioxins in an attempt to kill Victor Yushchenko while he was campaigning to become President of the Ukraine. He suddenly fell ill with suspected food poisoning. Five days later he developed lesions and ulcers on his face, chest and stomach and throughout his digestive tract. Blood tests showed extremely high levels of dioxins in his blood. He survived, eventually won the election and became president in 2005. Figure 10.2.14 on page 341 shows him before and after being poisoned.

Radioactive poisons

Radioactive materials are incredibly dangerous and exposure to them is usually accidental or highly controlled. For example, radiotherapy uses controlled doses to kill cancerous cells. However, the radioactive element **polonium-210** was used to kill Alexander Litvinenko (Figure 10.2.16) in London in 2006. Litvinenko once worked for the KGB but had defected to the United Kingdom. There he was highly critical of the Russian government, and its then-president Vladimir Putin. Litvinenko fell seriously ill soon after meeting with two ex-KGB officers for lunch. Polonium-210 was found in his urine and 3 weeks later he was dead. No-one is sure how Litvinenko was poisoned but investigators are certain that it was deliberate. This is because polonium emits **alpha rays**, a type of nuclear radiation that is easily blocked. If exposure was accidental, then his clothes and skin would have stopped it entering his body.

A nuclear reactor is needed to produce radioactive materials such as polonium-210, probably putting the murder well beyond the normal assassin and organised crime. It is thought that only a government or secret service would be able to access such materials.

In 2007, the United Kingdom charged Andre Lugovoy with the murder of Litvinenko. He was one of the ex-KGB officers who had lunch with Litvinenko the day he fell ill. Russia has refused to extradite (release) him for trial.

Figure 10.2.16 Alexander Litvinenko before and after he was poisoned with polonium-210. Polonium emits radioactivity in the form of alpha rays. Traces of polonium-210 were found in his urine, the restaurant where he ate, his home, his office, a hotel and two aircraft he travelled on.

10.2 Unit review

Remembering

1 **State** two pieces of evidence that might suggest a murder happened well away from where a body is found.

2 **State** how accurately authorities can locate you using the signal from your mobile phone.

Understanding

3 **Explain** how a belt buckle or buttons on a skeleton can help in determining the sex of a long-dead murder victim and when the murder may have happened.

4 It's much easier to confirm the identity of a body found in a burnt-out house than one found in the bush. **Explain** why.

5 **Explain** what DNA found at a crime scene:
- a tells police
- b doesn't tell police.

6 Hairbrushes and toothbrushes are often taken by forensic investigators. **Explain** why they would take them from the:
- a home of a missing person
- b homes of their blood relatives.

7 **Explain** how investigators determine if a shotgun blast came from close or far away.

8 **Explain** how Facebook led to the confiscation of a Ford Falcon utility in 2009.

9 **Explain** why Alexander Litvinenko's exposure to polonium-210 could not have been an accident.

Applying

10 **Use** Figure 10.2.17 to **identify** the origin of:
- a trace evidence 1
- b trace evidence 2.

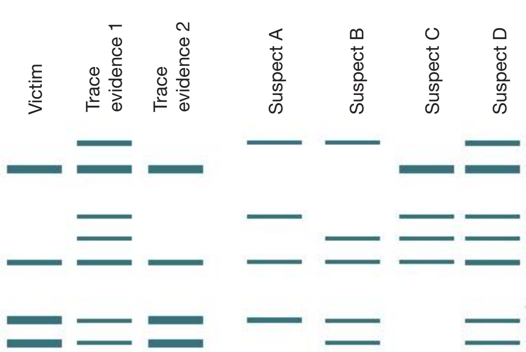


Figure 10.2.17

11 **Identify** what type of murder weapon was used if:
- a there is a clear entry and exit hole on the body
- b there is a 'peppering' of wounds
- c the person was complaining of stomach problems before they died.

Evaluating

12 **Propose** reasons why CCTV cameras are commonly located in:
- a large shops
- b banks
- c petrol stations.

13 Facial recognition software will eventually allow CCTV to track people, whether they are known offenders or innocent people going about their daily business. **Evaluate** whether this is fair and give your opinion on whether it should be allowed.

14 **Propose** how a mobile phone can be used to fake an alibi, suggesting that suspect was well away from a crime scene when they were really there.

15 Some people argue that YouTube has encouraged young people to undertake very dangerous activities, like those found in films such as *Jackass*.
- a **Propose** reasons why YouTube might be able to do this when earlier technologies did not.
- b **Assess** whether it is a good idea to upload a video of a dangerous activity onto YouTube.

16 Doctors first thought that victims of ricin, dioxin and polonium poisoning had simply eaten something that had 'gone off'. **Propose** the advantages this gives an assassin.

Creating

17 **Construct** or trace diagrams to contrast whorls, loops and arches.

Inquiring

1 Perform an interactive autopsy on an artificial human by searching for a *virtual autopsy* site on the internet.

2 Use the following as key words to search the internet to find forensic games to play.
- Identikit games
- fingerprint games
- DNA fingerprint or DNA matching games

3 DNA has sometimes led to the wrong person being found guilty. Research the case of Farah Jama and outline what went wrong.

4 Research cases in which DNA has proven that protected species of whales have sometimes ended up as sushi.

5 At one time, the law didn't require evidence to prove the guilt of a suspect. Investigate what trial by ordeal was and how it was used in law.

10.2 Practical activities

1 Measuring the body

Anthropometry is the measurement of the human body.

Purpose

To determine whether anthropometry accurately predicts height.

Materials

- dressmakers' tape measure or string and metre ruler
- access to skeleton (or photo of skeleton)
- calculator

Procedure

1. Use Figure 10.2.19 to locate the femur, noting where the bone begins and ends.
2. In pairs, use the tape measure to determine the length of each other's femur. Alternatively, mark the length on the string and then use the ruler to measure its length. Record its length in a table like that shown below.
3. Measure your actual height and that of your partner (in centimetres). Record the height in the table.
4. In a similar way, measure the femur on the skeleton and its overall height, recording each measurement in the table.

Results

1. In your workbook, construct a table like that shown below for all your results:

	Length of femur (cm)	Actual height (cm)	Calculated height (cm)
Me			
My prac partner			
Skeleton (male)			
Skeleton (female)			

2. Anthropometry uses the following mathematical formulas to predict the height of a person based on the length of their femur:

For males:

predicted height (cm) = femur length × 2.38 + 69.089

For females:

predicted height (cm) = femur length × 2.317 + 61.412

Use these formulas to calculate your predicted height and that of your partner.

3. Assume the skeleton was male. Use its femur length to calculate its likely height.
4. Repeat the calculation, but this time assume the skeleton was female.

Discussion

1. **Compare** your actual height with the height predicted by the formula.
2. **Assess** how accurate the formula was.
3. **Compare** the actual height of the skeleton or poster-skeleton with the predicted heights for males and females.
4. **Use** this information to **identify** the skeleton as male or female.

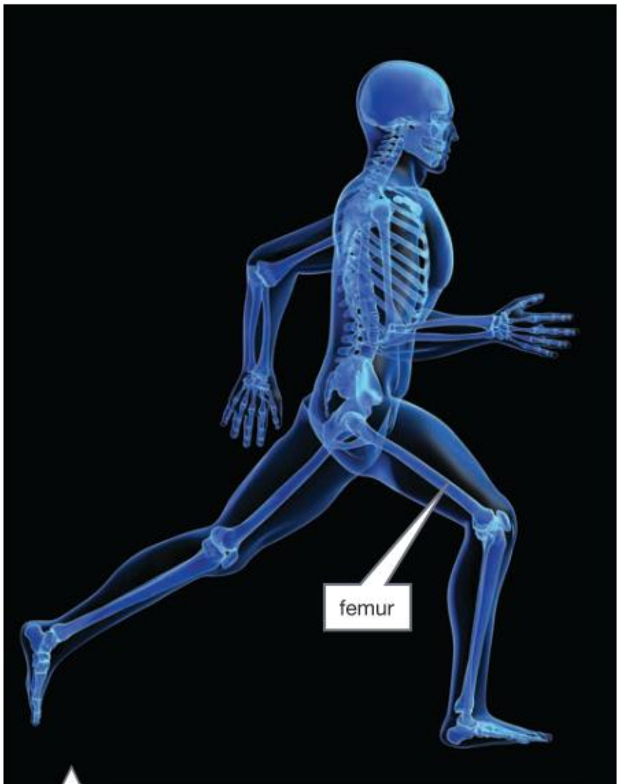


Figure 10.2.18 The femur is sometimes known as the thigh bone. It goes from your hip to your knee.

2 Identikit

Purpose

To construct an Identikit.

Materials

- access to digital camera (tripod optional)
- access to computer and printer
- access to photocopier
- A4 paper
- scissors or Stanley knife
- sticky tape or glue

SAFETY

Be extremely careful with a Stanley knife. Always cut against a hard surface. Retract its blade when not in use.

Procedure

1 Set up a corner in which each person in the class is to have their photo taken. Ensure that:
   - the corner is bright
   - it has a plain background
   - it has a seat
   - the tripod is set 1–2 metres from the seat. If you do not have a tripod, then mark the spot from which the photos are to be taken.

2 Photograph each person in the class. Zoom the lens in or out to ensure that their face (including hair) takes up most of the screen on the digital camera.

3 Print out all the photos in black and white, either individually or in groups of two or four photos per A4 sheet. Photocopy all the photos so that every 4–6 students have a complete set. Cut each photo into sections as shown in Figure 10.2.19. Use features from different people to construct different and imaginary faces.

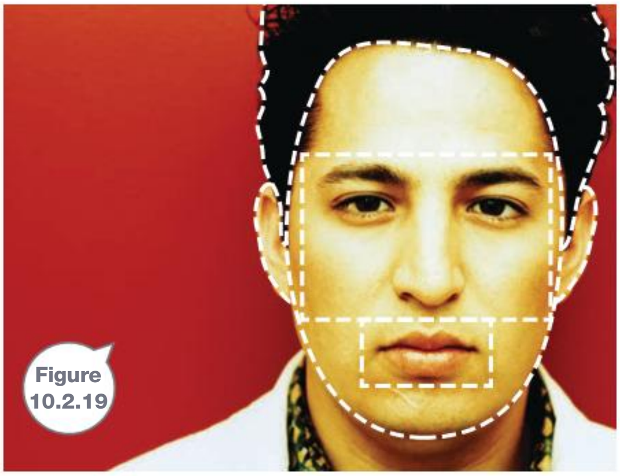


Figure 10.2.19

4 Alternatively, use an appropriate program on your computer to cut, paste and edit parts of different people to form imaginary faces.

Results

When you have a face that 'works', stick it onto a fresh sheet of A4 paper. Alternatively, save and print one of your digital faces.

Discussion

1 **Assess** how realistic the faces were that you constructed.

2 **Assess** whether any of them looks like someone in your school. By coincidence, they often do!

3 **Identify** what other features you would need to construct images of everyone in your school.

3 Gel electrophoresis

Purpose

To use gel electrophoresis to separate dyes.

Materials

- rectangular plastic container (such as a margarine or takeaway food container)
- hard plastic (such as that found in ice-cream containers)
- aluminium foil
- scissors
- power pack
- 2 electric leads with alligator clips
- food dyes (blue, red, green and yellow)
- felt-tip pens (blue, red, green and yellow)
- filter paper
- hotplate or Bunsen burner, tripod, bench mat and gauze mat
- 0.1% sodium hydrogen carbonate buffer solution (0.2 g sodium hydrogen carbonate in 200 mL water)

SAFETY

Tie long hair back.

Turn Bunsen burner flame to yellow or off when not in use.

All chemicals, including sodium hydrogen carbonate should be considered to be toxic.

Gel electrophorsis continued on next page

Gel electrophorsis continued

- 1% agar (1 g agar in 100 mL sodium hydrogen carbonate buffer solution)
- cling wrap

Procedure

1. Cut the plastic container down so that its walls are about 3 cm high.
2. Cut the hard plastic to form a comb that fits across the plastic container with two 'prongs' holding it in place. There should be about 6–8 teeth in the comb. Trim the teeth so that they don't touch the container bottom. It should look like that shown in Figure 10.2.20.
3. Cut off aluminium foil to form two strips about 5 × 8 cm in size.
4. Fold the foil over the ends of the plastic container. The strips should cover the ends and should reach the bottom inside the container.
5. Heat the 1% agar until it boils then let it cool.
6. Meanwhile, prepare samples of food dye or felt-tip pens. To do this, paint or draw 1 cm diameter spots of different colours onto filter paper.
7. Pour agar gel into the plastic container until it reaches a depth of 1 cm.
8. Place the comb across the container, about 2 cm from one end. The agar gel should reach just below the top of the comb's teeth.

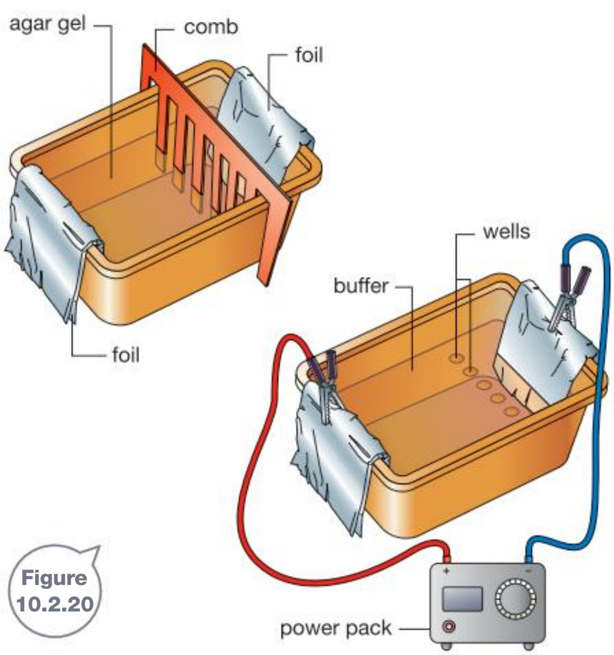


Figure 10.2.20

9. Leave the gel to set. This should take about 15 minutes or it can be covered in plastic cling wrap and left overnight in the refrigerator.
10. When the gel is set, carefully remove the comb.
11. For each of the colours prepared in step 6, cut rectangular strips small enough to fit in the 'wells' left behind when the plastic comb was removed.
12. Insert a strip in each of the wells.
13. Carefully pour about 100 mL buffer solution over the gel so that it is completely covered.
14. Connect the aluminium strip to the negative terminal of the power pack and the positive terminal to the other strip. Set the power pack to 4.5 V.
15. Keep the power pack on for about 45 minutes or until colours have obviously separated.

Results

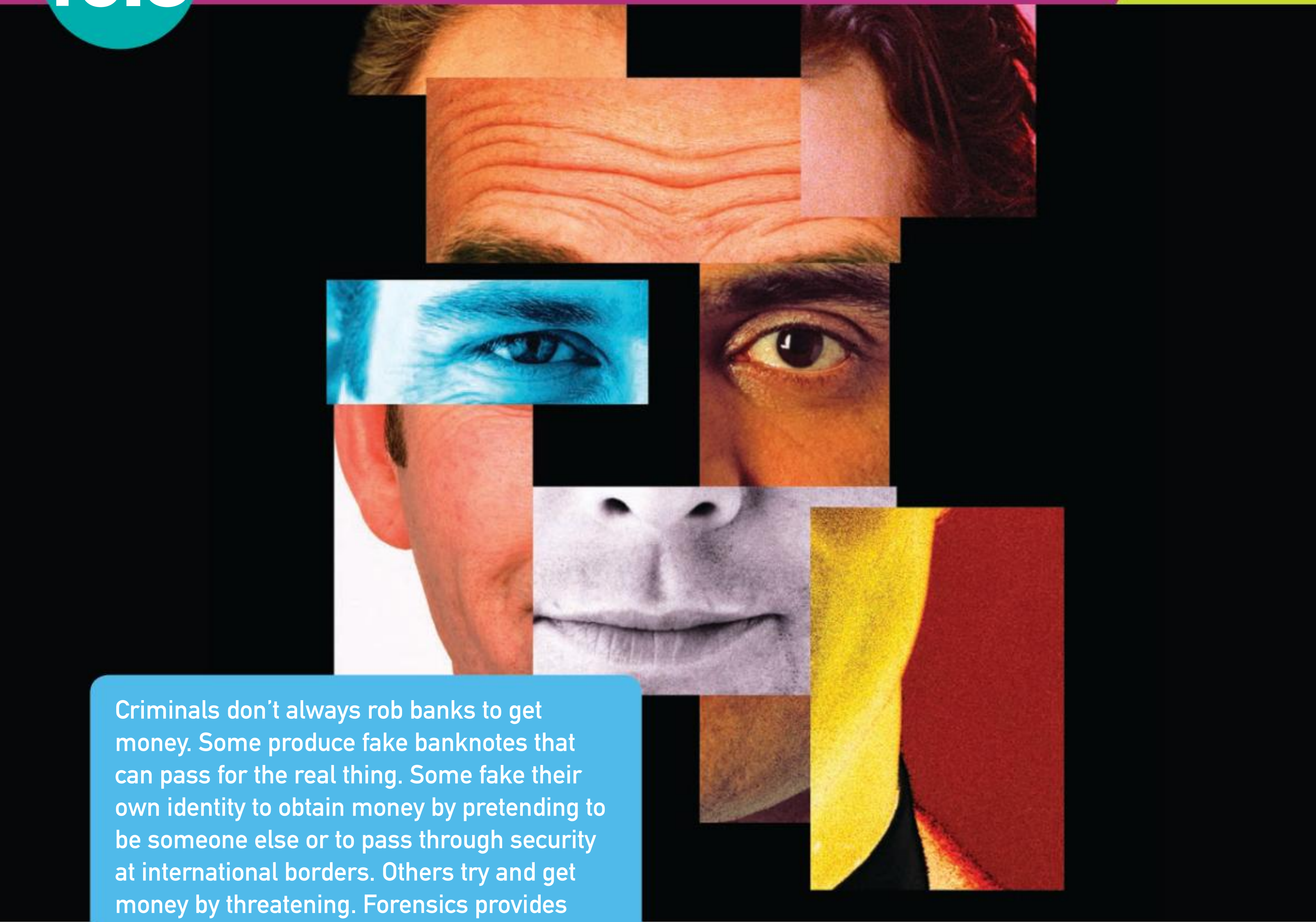
Measure how far each of the colours moved (in mm) down the gel. Record your measurements in a table like that below.

Sample	Distance colour moved (mm)
Blue food dye	
Blue pen	
Red food dye	
Red pen	
Green food dye	
Green pen	
Yellow food dye	
Yellow pen	

Discussion

1. The voltage causes the dye particles to move towards the positive terminal. Small particles move the furthest, while large particles move more slowly. **Use** this information to **list** the samples in order from smallest to largest particles.
2. **Compare** the size of the particles of the same colour dye and pen (for example, compare the red food dye with the red pen).
3. **Propose** whether the dye particles are charged positive or negative.
4. **Justify** your answer.
5. **Compare** the results obtained here with an autoradiogram like that shown in Figure 10.2.12 on page 340.

10.3 Fakes and extortion



Criminals don't always rob banks to get money. Some produce fake banknotes that can pass for the real thing. Some fake their own identity to obtain money by pretending to be someone else or to pass through security at international borders. Others try and get money by threatening. Forensics provides ways of detecting what and who is fake and who is making threats.

False identities

Knowing the true identity of a person is vital whenever they:

- cross an international border
- claim money from the government (such as Centrelink), institutions (such as banks, insurance companies) or individuals (such as the inheritance from a will)
- gain access to high-security institutions (such as bank vaults, military installations and biochemical laboratories)
- gain access to sensitive files (such as those held by hospitals, state and federal police, espionage (spy) organisations such as ASIO or ASIS).

Identity fraud is when someone pretends to be someone else. It costs Australia billions of dollars each year and so increasingly complex methods are being used to stop it.

Documents proving identity

Passports, driver's licences and credit cards are easy ways of proving your identity. All these documents have features to ensure they are secure and cannot be used by anyone but their 'owners':

- Passports once had photos pasted into them but this proved too easy to change or replace. Modern passports (and driver's licences) contain scanned images that are difficult to alter.
- Passports now have an electronic chip in their centre page that contains the name, sex, nationality, date of birth and a digital version of the passport-holder's photograph. This chip is activated when scanned and its details can be checked against the passport's front page. These 'chipped' passports are known as **ePassports** and Australia was one of the first countries in the world to introduce them. The 'chip' symbol in Figure 10.3.1 on page 348 indicates that the document is an ePassport.

- Modern credit and identity cards usually include features such as holograms (like the ones in Figure 10.3.2) that make them difficult to reproduce. Credit cards also include magnetic strips and chips that contain the customer's details and a personal identification number (PIN). Signatures are easily forged while only the true owner of the card should know its PIN.

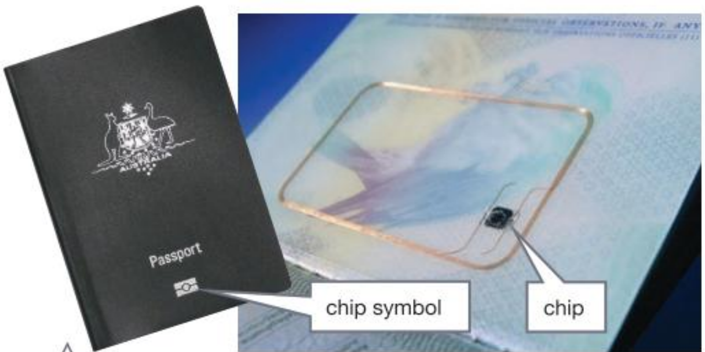


Figure 10.3.1 ePassports carry a chip that contains all your information and a digital version of your photo.

SciFile

Mission very possible!

In 2009, two well-dressed men entered an expensive jewellery store in London (UK) and left with £40 million ($78 million) of watches, rings, bracelets and necklaces. Although their images were recorded by CCTV cameras, it is thought that they were wearing rubber masks like those used in *Mission: Impossible*!

Figure 10.3.2 Credit cards and identity cards commonly have holograms that make them more difficult to fake.

Biometric facial recognition

Most people identify you by your face. Biometric facial recognition software allows a computer to do this too. It measures the position of your facial features and compares them with those of photographs on file. International airports around Australia and many airports overseas have special self-service gates (**Smartgates**) that photograph travellers and identify them with the digital photo on the chip in their ePassports. You can see a Smartgate in Figure 10.3.3.

Figure 10.3.3 Smartgates scan your face and use biometric recognition software to match it with the image in your ePassport.

SciFile

Want chips with that?

In 2004, microchips were implanted under the skin of important lawmakers in Mexico that give them (and only them) access to computer files containing sensitive information on criminal activity. Some European nightclubs now give VIP access and service to members who are implanted with microchips containing their personal details.

Fingerprint scans

Most countries have increased their border security since the terrorist attacks of 11 September 2001 (commonly known as '9/11'). For example, all visitors entering and leaving the USA via its international airports have their fingerprints scanned. These are then checked against files of known terrorists. Also, scanned fingerprints and whole handprints are also increasingly being used to sign in and out of work and as a 'key' to access computers, secure facilities or bank accounts (Figure 10.3.4). Access is only gained if the match is positive.

Figure 10.3.4 Fingerprint scanners are now used in some shops and banks overseas to match prints with customers' banking details. Money is then directly debited from their account.

Iris and retina identification

The **iris** is the coloured ring of muscle in the eye that controls the size of the pupil. As Figure 10.3.5 shows, its patterns and colouring are incredibly complex. Each person has unique iris patterns and each eye has a different pattern. For these reasons, the iris provides a far better method of identification than a fingerprint. It is also impossible to fake—the iris contains 266 identifiable features and constantly moves, whereas a fake eye remains static.

The **retina** is at the rear of the eye and its pattern of blood vessels is even better than the iris as proof of identity. Although more difficult to obtain, retina scans are more accurate than iris scans.

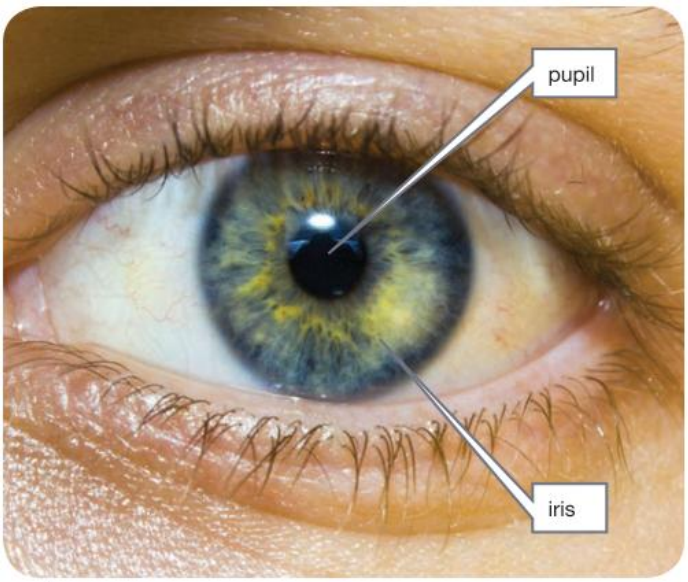


Figure 10.3.5 The iris gives the eye its colour. It has 266 identifiable features and it does not change with age. This makes it an accurate way of identifying someone.

Forgery

Counterfeit (fake) banknotes are relatively rare because real notes include special features that make them difficult to reproduce. Some of these features are shown in Figure 10.3.6 on page 350.

Australia was the first to use **polymer film** (plastic) notes. They are harder to counterfeit and last four or five times longer than paper ones—while a paper $5 note had an average life of about 6 months, a plastic one lasts more than 3 years.

Organised crime groups are usually the only ones with sufficient money to purchase the technology, materials and skills needed to produce realistic counterfeit banknotes.

Realistic counterfeit banknotes are difficult to detect by shop assistants and bank tellers unless they know what to look for. It might be the feel of the paper used, its colours or its serial number. (Real banknotes all carry different serial numbers, whereas counterfeits usually have the same serial number.) Unfortunately, these differences may only become apparent after many fake notes have already been passed off as real.

SciFile

Obviously fake!

The USA has never had a $1 million banknote. However, this did not stop Alexander D. Smith from trying to pass this fake one as a real note in 2007!

INQUIRY science 4 fun

Inspecting banknotes

Can you find the anticounterfeit features on a banknote?

Yes

Collect this …

- banknote (it doesn't need to be Australian)
- magnifying glass or stereomicroscope
- ultraviolet (UV) light (optional)

Do this …

1. Carefully inspect the banknote. Take note of the features shown in Figure 10.3.6 on page 350.
2. Use the magnifying glass or stereomicroscope to find microprinting and the UV light for fluorescing inks.

Record this …

Describe what you found.

Explain how these features stop counterfeiting.

SciFile

Drug money

In many large cities in the USA, up to 93% of the banknotes have been found to have traces of the illegal drug cocaine on them. Perhaps in the future, fake US banknotes will be detected because they have no traces of cocaine!

Intaglio printing
A raised form of printing that can be felt with your fingers

Australian banknotes have their portraits, denomination number and the word *Australia* in intaglio printing.

Material
Paper banknotes are printed on special paper with its own characteristic feel.

Australian banknotes are printed on polymer film (plastic). They last longer than paper notes and are harder to counterfeit.

Optically active devices
Images that are holographic (producing multicolour effects) or clear

All Australian banknotes have an image of a seven-pointed star that is only complete when held up to the light.

Figure 10.3.6 One side of an Australian $10 note, highlighting the features that make it near-impossible to counterfeit.

Australian banknotes use a second optical device. The $10 note has a windmill while the $50 note has a lyrebird.

Microprinting
Very small printed details such as sentences and initials that cannot be reproduced by a colour printer or photocopier. A magnifying glass is needed to read it.

The $10 note has the poem 'The Man from Snowy River' on its front. The Australian $5 note has an early version of 'Advance Australia Fair' on its back.

Not shown
Metal band: This is often inside the layer of the paper and can be felt and seen under backlighting.
Water mark: Hidden images in paper notes that are only seen when the note is held up to the light. The $50 note has the Australian coat of arms.
Serial numbers: Prominent letters and/or numbers on one or both sides of the note. Each number is different. Counterfeit notes often all have the same serial number. The $10 note has two serial numbers on one side, each in a different font.
Fluorescing inks: These inks glow under ultraviolet light. Parts of the serial number of the $10 note fluoresce (glow).

Fake documents and extortion

Criminals sometimes use fake signatures and documents to gain access to inheritances and insurance policies and to commit business fraud. They sometimes also use **extortion** (threats and blackmail) to get what they want. Forensics can help to determine:

- if a signature or document is real
- who wrote a threatening letter or email or who posted offending material on the internet.

Handwriting

Everyone's handwriting has characteristic features that can be used to identify who wrote or signed a document. Some of these features are shown in Figure 10.3.7.

INQUIRY science 4 fun

Fake signatures

Can you fake someone's signature?

Yes

Collect this …

- pen
- paper (preferably lined)

Do this …

1. Write your signature on a piece of paper.
2. Swap signatures with another classmate and then try and reproduce their signature.
3. Take particular notice of the features shown in Figures 10.3.7 and 10.3.8.

Record this …

Describe what happened.
Explain why you think signatures are difficult to forge.

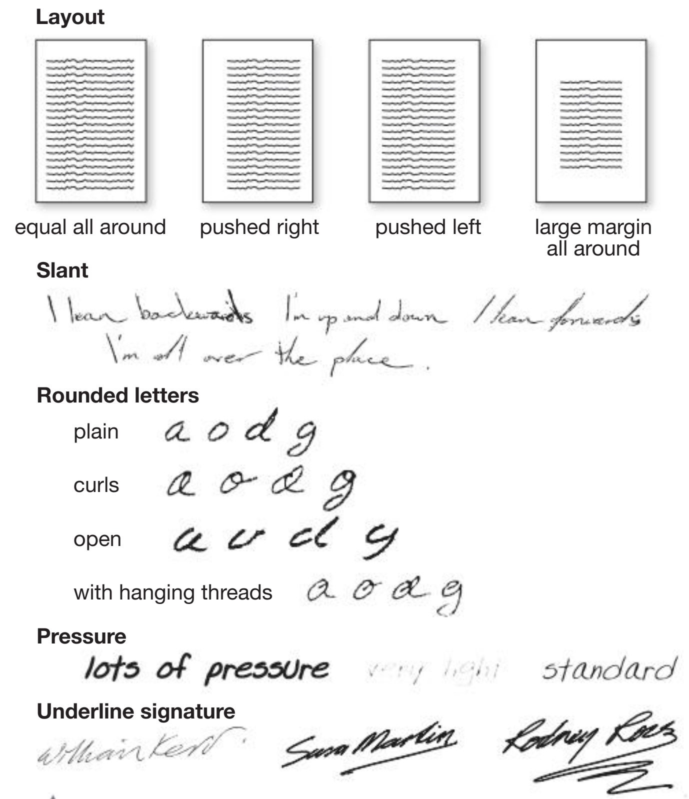


Figure 10.3.7 Handwriting changes with a person's age, but its basic features do not.

You can alter your handwriting but the way you construct each letter tends to remain the same. For example, Figure 10.3.8 shows different ways to construct the letter E.

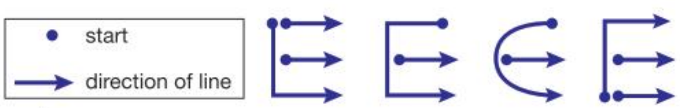
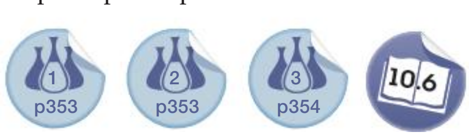


Figure 10.3.8 How do you construct the letter E?

Papers and inks

Papers differ in their texture, absorbencies, the presence of watermarks and weight (often referred to as grams per square metre or GSM). All these characteristics affect the way an ink spreads and is absorbed and the way each individual letter appears.

Inks differ too. For example, different black inks contain different combinations of colours: some black inks contain blue while others have brown in them. **Chromatography** uses a solvent such as water or alcohol to dissolve and separate an ink into its component pigments. This is what has happened in Figure 10.3.9. In this way, the ink used to forge a signature or letter or to write or print a threat can be matched with a suspect's pen or printer.



Electronic documents

Everything you do on a computer is recorded on your computer hard drive in **binary code**, using the numbers 0 and 1. When you delete a file, all you delete is the way you access it. The original coding and information is still there. This means that every document, email, Twitter or Facebook entry will still be there, to be retrieved if and when needed by forensics investigators.

SciFile

Blackbox

The operation of most modern cars is controlled by computers, which also store information such as the car's speed, braking pressure and steering. All this information can be downloaded after an accident and might soon be used by police to charge drivers and allow insurance companies to reject insurance claims.

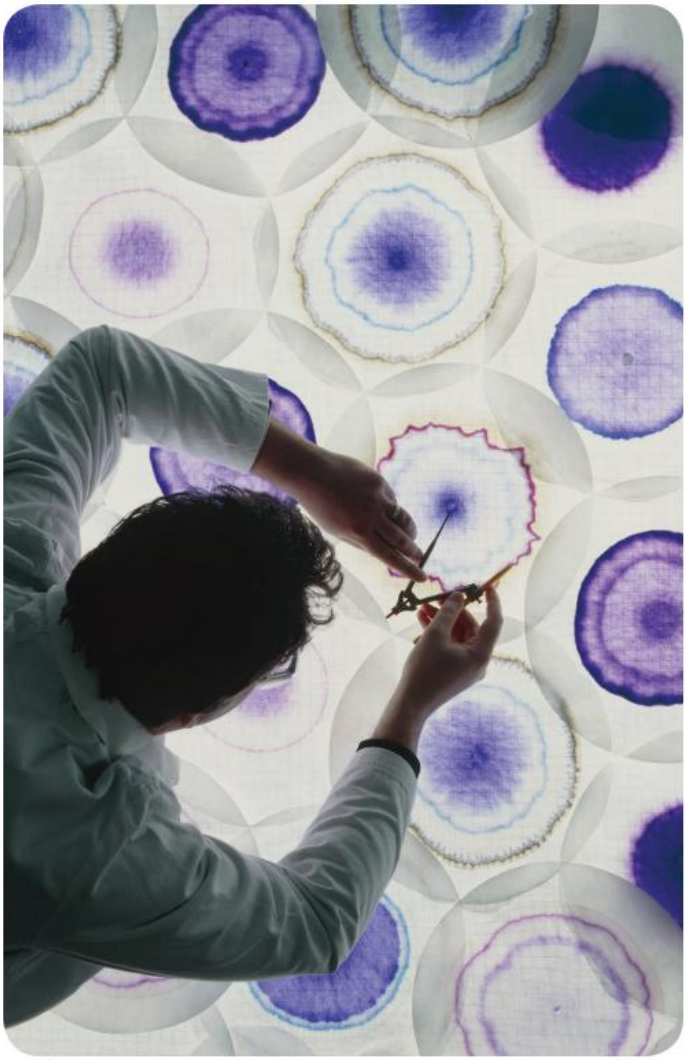


Figure 10.3.9 Chromatography separates pigments and dyes and produces strips or rings of colours. Here a forensic scientist is investigating the pigments used to make up different brands of black ink.

10.3 Unit review

Remembering

1 People fake their identity for many reasons. **List** reasons that are connected to:
   a money
   b security
   c information.

2 **State** where these are in the eye.
   a the iris
   b the retina

3 **State** how many features can be identified in an iris.

4 **Recall** the features used in Australian banknotes by matching the following features with their descriptions.

a	intaglio	i	holograms and windows
b	fluoresce	ii	tiny printed text
c	microprinting	iii	raised text
d	optically active devices	iv	glow

5 **List** features that might alert someone that a banknote is fake.

6 **Name** the process by which the ink of a pen is separated.

Understanding

7 **Explain** the advantages of ePassports over 'normal' passports.

8 **Explain** why microchips are inserted under the skin of:
   a Mexican lawmakers
   b some nightclub patrons.

9 Old-style driver's licences were slips of paper with no photo. **Predict** some of the problems this caused.

Applying

10 **Identify** the pen used to write a threatening letter from the results shown in Figure 10.3.10 of a chromatography experiment. Note that each strip was left in the solvent for a different time.

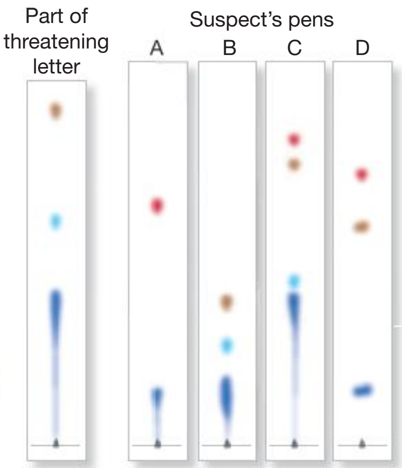


Figure 10.3.10

Analysing

11 **Compare** iris and retina identification with fingerprinting.

12 Write each letter of the alphabet in capitals, and **analyse** how you constructed them. Add arrows, similar to Figure 10.3.8 on page 351, showing how each letter was constructed.

Evaluating

13 Many cats and dogs have microchips inserted under their skin and a tattoo in their ear. **Propose** reasons why.

14 Imagine a future where everyone has microchips inserted under their skin at birth.
   a **List** as many advantages as you can think of.
   b **List** as many disadvantages as you can think of.
   c Based on your lists, **assess** whether implanting everyone with microchips is a good idea or not.
   d **Justify** your choice.

Creating

15 **Construct** a simple sentence and write it in four very different handwriting styles.

Inquiring

1 Research what Note Printing Australia (NPA) is and where it is located.

2 Research which other countries use polymer or plastic banknotes.

3 Investigate the so-called 'Hitler Diaries' and explain how they were eventually found to be fake.

4 Search the internet for videos showing chromatography separating dyes.

5 Use the key term *fake bank notes* to research a group of criminals that was printing counterfeit notes. Find:
   - the country the criminals were operating in
   - when they were operating
   - how much fake money is thought to have been passed as real
   - how the fakes were discovered.

10.3 Practical activities

1 Chromatography

Purpose

To use chromatography to determine which pen wrote a threatening letter.

Materials

- at least three different coloured biros or felt-tipped pens
- pencil
- 250 mL or larger beaker
- filter paper strips
- methylated spirits
- icy-pole stick
- paperclips

SAFETY

Methylated spirits is flammable so keep it away from naked flames or sparks.

Procedure

1. On one end of a filter strip, write in pencil the brand name or colour of a pen you are about to test.
2. Use a pen to draw a large dot about 1.5 cm from the other end of the filter strip.
3. Repeat with the other pens and colours, using a separate piece of filter paper for each.
4. Add about 1 cm of methylated spirits to the beaker.
5. Attach the filter strips to the icy-pole stick with paperclips and arrange as shown in Figure 10.3.11.
6. Leave the strips to soak up the methylated spirits for 20–30 minutes.
7. Unclip the strips and allow to them to dry.

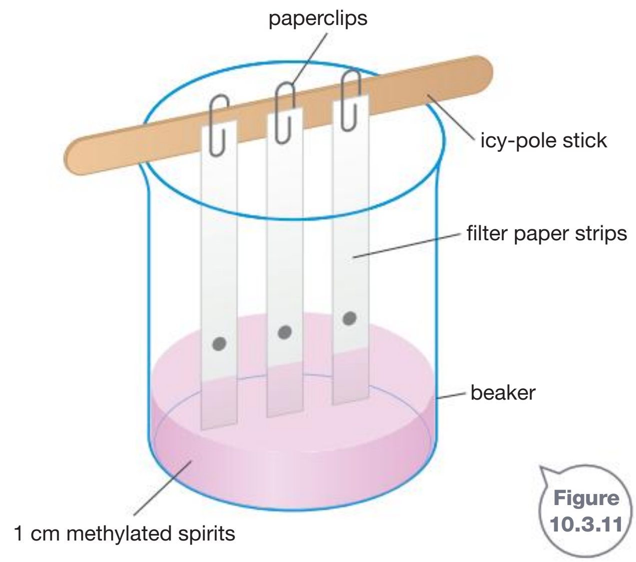


Figure 10.3.11

Results

List the colours that are mixed together to make up each ink.

Discussion

1. **Describe** what the methylated spirits did to the inks.
2. If you had two pens of the same colour but different brands, **compare** the colours that made up each ink.
3. **Explain** how chromatography could be used to determine who wrote a threatening letter.

2 Smartie colours

Purpose

To design a way of separating the different food dyes present in the coloured shells of Smarties®.

Materials

- Smarties of different colours
- materials as chosen by students

Procedure

The food dyes used in Smarties tend to 'run' when they get wet. Use this information to design a way of separating the colours present in the coloured candy shells of Smarties. Once you have written your procedure, have your teacher check it before attempting your experiment.

Results

1. Construct a diagram showing your experimental set-up.
2. Construct diagrams showing your results.

Discussion

List the colours used to form the different food dyes that colour the candy shells of Smarties.

3 Reading a burnt note

Purpose
To retrieve messages written on a note that has been burnt.

Materials
- ballpoint pen (not a felt pen)
- sheet of paper
- sheet of greaseproof paper
- bench mat or metal tray
- long barbecue matches
- spray bottle containing a mix of 1:3 parts glycerine and water

SAFETY

Do not spray the mixture near people.

Procedure
1. Use the ballpoint pen to write a long message or a list of words on the paper.
2. Lightly scrunch up the note. Don't scrunch it too much or too tightly.
3. Place the scrunched paper on the bench mat or in the metal tray.
4. Set fire to the paper and allow it to burn. *Do not* blow on the paper. It doesn't matter if the flame goes out.
5. When the flame has died out, *carefully* transfer the burnt paper onto the greaseproof paper. Try not to disturb the ashes.
6. Gently spray the burnt paper with the glycerine/water mix until it is wet.
7. Carefully smooth the paper back and look for your writing.
8. Repeat the experiment but try different colours and makes of pens.

Results
On another clean sheet of paper, write down what you can see on the burnt note.

Discussion
1. The ink in ballpoint pens contains dyes, some metal and solvents that evaporate, allowing the ink to dry. **Use** this information to **identify** what is probably left behind on the note.
2. **Propose** a reason for the glycerine/water mix.
3. **List** the problems in this experiment that could make it impossible to read the message on the note after burning.
4. **Explain** how this method could be used to prove that a criminal has been practising forged signatures.
5. **Create** a scenario (story) in which a criminal might be writing notes and then destroying them.

Chapter review 10

Remembering

1 **Name** a major event that caused border security to be increased in many countries.

2 Australia uses plastic instead of paper for its banknotes. **State** two reasons why.

3 **List** the information included in the chip in an ePassport.

Understanding

4 **Define** the terms:

- **a** homicide
- **b** arson
- **c** ballistics
- **d** corpse
- **e** anthropometry
- **f** assassination
- **g** counterfeit
- **h** fluoresce.

5 Nothing is moved from a crime scene until it is marked and photographed. **Explain** why.

6 **Explain** why DNA is considered to be the 'ultimate' fingerprint.

7 **Explain** what retroactive interference is and how it can make identification unreliable.

8 **Describe** what happens when you delete something from your computer.

Applying

9 **Identify** places around your house where investigators would be likely to find large quantities of your DNA.

10 **Calculate** roughly how long a body has been dead for if its temperature is:

- **a** 35°C
- **b** 29°C
- **c** 17°C.

Analysing

11 **Contrast** physical evidence with trace evidence.

12 **Classify** the fingerprints in Figure 10.4.1 as arch, loop, whorl or composite.

Evaluating

13 A body has been found a long way from water. An autopsy showed that the person had drowned.

- **a** **Propose** what evidence would have been found to show that the person had drowned.
- **b** **Propose** a way investigators could find out where the person drowned.

14 A male body is found in the bush. There is a band tattooed around his right arm and a large dark birthmark down the right side of his face. He is wearing a leather jacket and his driver's licence is in its pocket. X-rays show that he has pins in his left ankle and fillings in his back teeth. **Assess** each of these pieces of evidence and **rank** them from most useful to least useful for identifying the body.

15 Ricin could be considered to be the 'ideal' poison for an assassin. **Propose** a reason why.

16 **Propose** what information managers might look for in a chip under the skin of patrons coming into their nightclubs.

17 Imagine a scheme in which everyone in Australia had their DNA taken and their DNA autoradiograms stored on government databases or on identity cards.

- **a** **Propose** a list of advantages and disadvantages of such a scheme.
- **b** **Assess** whether or not you would support a scheme like this.

Creating

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

crime scene
physical evidence
trace evidence
corpse
diatoms
DNA
fibres
victim
suspect
drowning

10.7

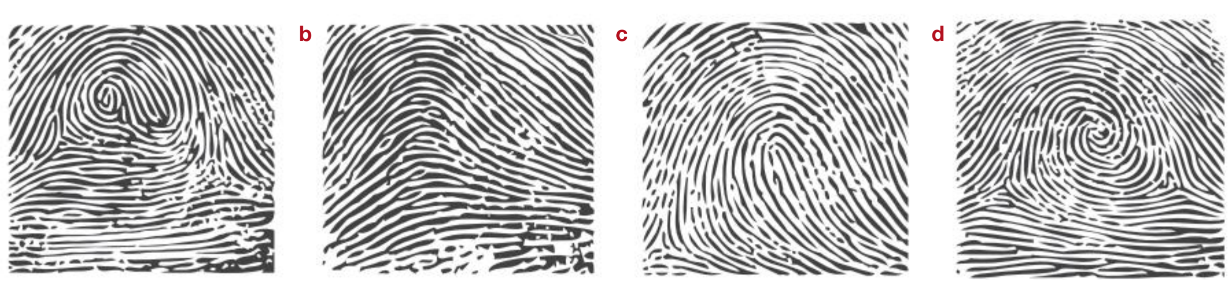
a


Figure 10.4.1

Thinking scientifically

Q1 In a laboratory, forensic scientists are attempting to reproduce the wounds of a stabbing attack. To do this they use a kitchen knife to quickly stab a piece of beef bought from the butcher. Which is the most likely result from this experiment?

A A flattening of the tissues
B A shallow cut across the tissues
C A deep, rectangular hole
D A deep, circular hole

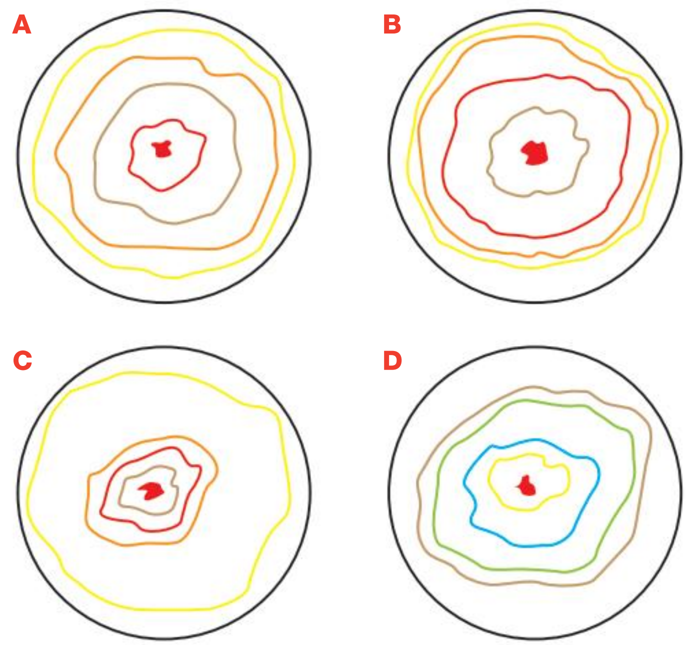
Q2 A corpse is found face up in a multistorey carpark in the inner city. In the autopsy, evidence is found that indicates that the corpse was murdered elsewhere. Which of the following pieces of evidence does *not* indicate this?

A Diatoms are found in the lungs of the corpse.
B DNA from someone else was found on the clothing of the corpse.
C Fresh pollen from dandelion flowers is found throughout the clothing of the corpse.
D Blood has pooled (collected) across the belly and chest of the corpse.

Q3 A splash of red liquid has been found on clothing belonging to the main suspect of a murder. Chromatography was used to separate the colours that made up the splash. It produced a strip of filter paper as shown below.

At the murder scene was a pool of spilt red drink. Chromatography was used to test this sample and other samples of red drinks (samples A, B, C, D). Samples of the different drinks were placed in the centre of a circle of filter paper.

Identify which sample matched the liquid found on the suspect.



The following information applies to questions 4–6. Various samples of DNA were found at a crime scene. A part of their DNA autoradiograms are shown below.

Q4 Identify which DNA autoradiogram A–D came from the victim.

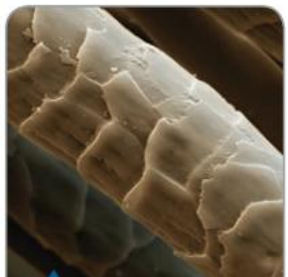
Q5 Identify the person A–D who had never been at the crime scene.

Q6 Identify the suspect(s) in the case.

Glossary

Unit 10.1

Arson: deliberate lighting of a fire
Ballistics: the study of guns and ammunition
Circumstantial evidence: evidence that points to a suspect but doesn't prove they are guilty
Core body temperature: 37°C for a healthy human
Corpse: dead body
Crime scene unit (CSU): specialists who collect and bag evidence
DNA: deoxyribonucleic acid
Fibres: strands of material such as hair, wool or polyester


Fibres

Fingerprints: patterns of ridges and grooves on the fingers and toes
Homicide: murder or manslaughter of another human
Impressions: track marks
Negative impression: an impression formed by material gathering in recesses, such as the grooves in a tyre or shoe
Non-porous: doesn't absorb liquids such as body oils
Pathology: the study of disease and cause of death


Impressions

Physical evidence: large pieces of evidence
Porous: absorbs body oils
Positive impression: an exact image, such as the pattern of a shoe or a tyre
Tool mark: characteristic mark left by a tool
Toxicology: the study of the effects of poisons and chemicals on the body
Trace evidence: microscopic evidence such as fibres or DNA

Unit 10.2

Alpha rays: form of nuclear radiation
Anthropometry: study of body size and proportions
Arches: a form of fingerprint in the shape of arches


Arches

Assassination: political murder
Autopsy: dissection of a body to determine cause of death
Autoradiogram: identifying pattern that represents DNA patterning
Bertillon system: a form of anthropometry in which body size and proportions are measured
Biometric facial recognition: when a face is scanned and computer-matched with stored images of faces
CCTV: closed circuit TV
Composite: a form of fingerprint
Diatoms: microscopic organisms found in water, each with a different shape
Dioxins: a form of poison


Identikit

Gel electrophoresis: a process in which DNA is cut then analysed to produce an autoradiogram
Identikit: form of identification in which facial features are slotted together
Loops: a form of fingerprint in the shape of loops


Loops

Polonium-210: radioactive material, used once as a poison
Retroactive interference: changes in the memory of an eyewitness after looking at other images
Ricin: a form of poison
Whorls: a form of fingerprint in the shape of whorls


Whorls

Unit 10.3

Binary code: the way a computer stores information: 0 and 1
Chromatography: the use of solvents to separate colours of ink and other materials
Counterfeit: fake (usually refers to a banknote)
ePassport: a passport that includes a chip recording personal information


Fluoresce

Extortion: threats and blackmail
Fluoresce: shining due to special light (e.g. UV)
Identity fraud: pretending to be someone else
Intaglio: raised printing
Iris: coloured ring of muscle in the eye that controls the size of the pupil


Iris

Polymer film: plastic used to make banknotes
Retina: back of the eye
Smartgate: gate that electronically reads ePassports

Index

C

Index

Index

I

J

K

L

M

N

Index

Index

T

U

V