NELSON
CENGAGE Learning

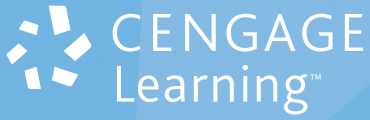
Nelson iScience

for the Australian Curriculum

10

Sandra Bishop Neil Champion Xenia Pappas
Deb Smith Annie Termaat

nelsonnet



COPYRIGHT NOTICE

Copyright in this work is owned by Cengage Learning Australia ("the work"). A condition of purchase of this electronic version of the work is that you agree to respect the copyright in the work, abide by the *Copyright Act 1968* and specifically agree not to transfer, sell, assign, misuse, copy or transmit an electronic or other version of the work to any third party.

Please note: This product is accompanied by a licence (single user, network or adoption) governing the terms and conditions of its use.

This is a legal agreement between the you, (the "Customer") and Cengage Learning Australia Pty Limited (ABN 14 058 280 149) (the "Licensor") which provides the terms and conditions of this non-exclusive licence and the limited warranty for the Product. Use of the Product indicates an acknowledgement that the Customer has read and agreed to be bound by the terms and conditions of this Agreement. If you do not agree to these terms and conditions, return the Product to the place of purchase within 15 days of the date of purchase (with proof of purchase) for a full refund

1. **Licence Grant**
   You do not receive title to the Product. Copyright in the Product (which includes all images, photographs, video, animations, audio, music and text incorporated in the Product, including all of the accompanying printed material) is owned by the Licensor and/or its suppliers and is protected by Australian copyright laws. The Licensor grants you a non-exclusive licence to use the Product subject to the restrictions and terms set out in this Agreement.

2. **A Licence allows you to:**
   Use the Product on your computer. The Customer represents that they shall in no way place the Product in the public domain or in any way compromise our copyright in the Material. You agree to take reasonable steps to protect our copyright.

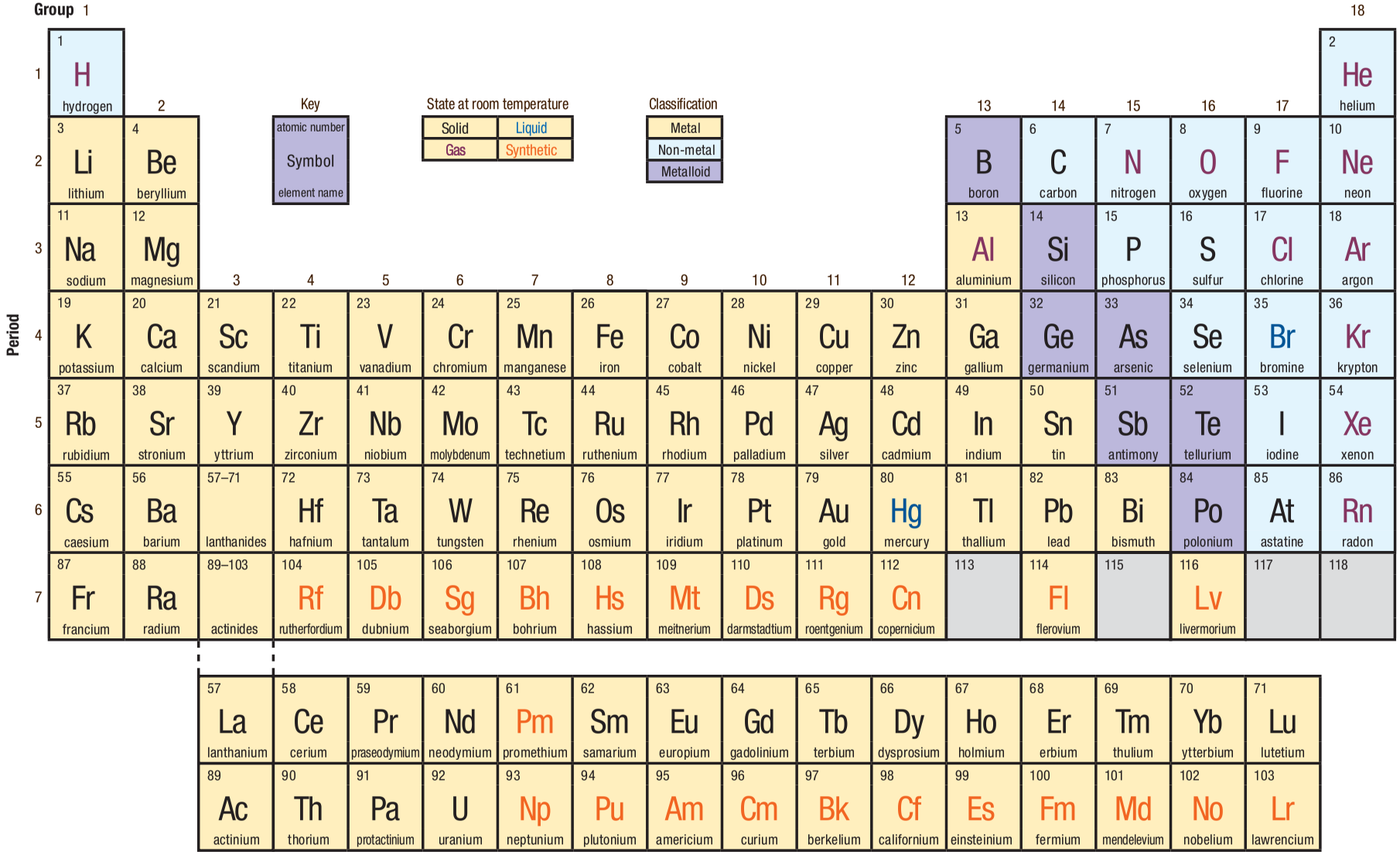
3. **You may not:**
   Alter, modify, translate, reverse engineer, decompile, or adapt the software or create derivative works based on the Product.

   Make further copies by any means technological, electronic, digital whatsoever without the written permission of the Licensor.

   Rent or transfer all or any part of your rights under this Agreement. Remove or alter any copyright or other proprietary notice or label attached to the software.

4. **Termination**
   Any failure to comply with the terms and conditions of this agreement will result in the automatic termination of this licence. Upon termination of this licence for any reason, the Customer must destroy or return to the Licensor all copies of the software and accompanying documentation.

5. **Warranties**
   To the extent permitted by law, the Licensor's liability for any breach of the warranty or any term implied by law into this licence is limited to the lowest cost of replacing the goods, acquiring equivalent goods or having the goods repaired.


Group 1
18
Period
Key
atomic number
Symbol
element name
State at room temperature
Solid
Liquid
Gas
Synthetic
Classification
Metal
Non-metal
Metalloid
1 H hydrogen
2 He helium
3 Li lithium
4 Be beryllium
5 B boron
6 C carbon
7 N nitrogen
8 O oxygen
9 F fluorine
10 Ne neon
11 Na sodium
12 Mg magnesium
13 Al aluminium
14 Si silicon
15 P phosphorus
16 S sulfur
17 Cl chlorine
18 Ar argon
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
37 Rb rubidium
38 Sr stronium
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
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
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 darmstadtium
111 Rg roentgenium
112 Cn copernicium
113
114 Fl flerovium
115
116 Lv livermorium
117
118
57 La lanthanium
58 Ce cerium
59 Pr praseodymium
60 Nd neodymium
61 Pm promethium
62 Sm samarium
63 Eu europium
64 Gd gadolinium
65 Tb terbium
66 Dy dysprosium
67 Ho holmium
68 Er erbium
69 Tm thulium
70 Yb ytterbium
71 Lu lutetium
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 fermium
101 Md mendelevium
102 No nobelium
103 Lr lawrencium

Nelson iScience

for the Australian Curriculum

10

Sandra Bishop Neil Champion Xenia Pappas
Deb Smith Annie Termaat

NELSON CENGAGE Learning

Australia • Brazil • Japan • Korea • Mexico • Singapore • Spain • United Kingdom • United States

NELSON
CENGAGE Learning

Nelson iScience 10 for the Australian Curriculum
1st Edition
Sandra Bishop
Neil Champion
Xenia Pappas
Deb Smith
Annie Termaat

Publishing editor: Eleanor Gregory
Project editor: Jocelyn Hargrave
Cover designer: Kar Heng Goh
Text designer: Kar Heng Goh
Cover image: Shutterstock.com
Permissions researcher: Helen Mammides
Production controller: Jem Wolfenden
Typeset by: MPS Limited, a Macmillan Company

Any URLs contained in this publication were checked for currency during the production process. Note, however, that the publisher cannot vouch for the ongoing currency of URLs.

© 2012 Cengage Learning Australia Pty Limited

Copyright Notice
This Work is copyright. No part of this Work may be reproduced, stored in a retrieval system, or transmitted in any form or by any means without prior written permission of the Publisher. Except as permitted under the *Copyright Act 1968*, for example any fair dealing for the purposes of private study, research, criticism or review, subject to certain limitations. These limitations include: Restricting the copying to a maximum of one chapter or 10% of this book, whichever is greater; providing an appropriate notice and warning with the copies of the Work disseminated; taking all reasonable steps to limit access to these copies to people authorised to receive these copies; ensuring you hold the appropriate Licences issued by the Copyright Agency Limited ("CAL"), supply a remuneration notice to CAL and pay any required fees. For details of CAL licences and remuneration notices please contact CAL at Level 15, 233 Castlereagh Street, Sydney NSW 2000,
Tel: (02) 9394 7600, Fax: (02) 9394 7601
Email: info@copyright.com.au
Website: www.copyright.com.au

For product information and technology assistance,
in Australia call **1300 790 853**;
in New Zealand call **0800 449 725**

For permission to use material from this text or product, please email
aust.permissions@cengage.com

National Library of Australia Cataloguing-in-Publication Data
Nelson iScience 10 : for the Australian Curriculum / Annie Termaat ... [et al.]

9780170189071 (pbk.)
Includes index.
For secondary school age.

Science--Study and teaching (Secondary)--Australia.

Termaat, Annie.

500

Cengage Learning Australia
Level 7, 80 Dorcas Street
South Melbourne, Victoria Australia 3205

Cengage Learning New Zealand
Unit 4B Rosedale Office Park
331 Rosedale Road, Albany, North Shore 0632, NZ

For learning solutions, visit **cengage.com.au**

Printed in China by China Translation & Printing Services.
1 2 3 4 5 6 7 16 15 14 13 12

Contents

Introduction vi
Acknowledgements vii
How to use *Nelson iScience* ix
Curriculum grid xiv

1 Genetics: chemistry from our ancestors

What do you already know about genetics? 2
Genetics 3
DNA: coding for life 7
Working with genes 11
Sexual reproduction: a source of variation 19
Mendel: the father of genetics 20
How genes influence one another 27
Sex-linkage 27
Pedigrees: another way to visualise inheritance 28
Karyograms: a snapshot of chromosomal health 29
Genetic research 31
Unit review 35

2 Evolution

What do you already know about evolution? 38
What is biodiversity? 39
Evidence from the past 40
Evidence from living species 50
Evidence from plate tectonics and biogeography 54
Explaining evolution 57
Acceptance of the theory of natural selection 62
Artificial selection as evidence for evolution 65
Genetics and evolution 66
Unit review 69

3 Organising and classifying elements: understanding structure

What do you already know about atoms? 72
The atomic story so far 74
Where do the elements come from? 75
Development of the periodic table 77
Electrons drive the chemistry of atoms 86
Electron arrangement and the periodic table 91
Explaining the properties of elements 93
Explaining metallic properties 95
Reactivity of metals 98
Unit review 103

4 What a reaction!

What do you already know about chemical reactions? 106
Review: patterns in chemical reactions 108
Products of chemical reactions 113
Metal meets non-metal 118
Extracting metal 125
Getting the reaction going 128
Fuels and pharmaceuticals 134
Unit review 142

5 The big universe

What do you know about measuring space and time? 146
How do we understand the origin of the universe? 147
Big bang theory 149
Cosmic background radiation 155
Astrometry: measuring the universe 159
Fate of the universe 180
Unit review 181

6 Global systems

What do you already know about global systems? 184
Investigating how human activity affects global systems 185
Greenhouse effect: causes and effects 194
Depletion of the ozone layer 196
What is climate change? 198
Long-term effects of biodiversity loss 207
Unit review 209

7 Force to go

What do you already know about motion and its causes? 212
Analysing motion 212
Road safety science 224
Causes of motion 230
Net force 238
Unit review 243

8 Energy and systems

What do you already know about energy and systems? 246
Energy 247
Forms of energy 250
A car as a system 255
Energy in car production 256
Car safety systems 259
Electrical energy production 265
Electrical generation systems 266
Electricity production: other primary energy sources 275
Unit review 281

Appendixes **283**
Glossary **288**
Index **298**

Introduction

The Australian Curriculum – Science provides the opportunity to immerse students in the wonder and awe of science. It emphasises that science is a creative and collaborative human endeavour that helps students make sense of their world. Having an understanding of science assists students to be effective and successful members of society, especially in this rapidly changing technological world. More than this, the Australian Curriculum – Science enables students to gain practical and thinking skills that they can benefit from throughout their life.

The authors of the *Nelson iScience* series have embraced the Australian Curriculum – Science and produced a truly 21st-century science resource for secondary students. *Nelson iScience* provides a resource that fully integrates the overarching ideas, general capabilities, cross-curriculum priorities and three strands of the Australian Curriculum – Science into the fascinating story of Science.

Nelson iScience combines higher-order thinking tools and ICT to promote innovative and creative problem-solving and approaches to learning science. It builds on the collaborative nature of learning by enabling students to learn with and from one another by sharing their work, ideas and thoughts through the vast capabilities of ICT.

Nelson iScience has adopted a differentiated practical approach to the learning of science, providing many opportunities for hands-on and minds-on activities. Many of these activities challenge students, assisting them in organising their thoughts and understandings. Many others require students to unpack information and ideas and repackage or manipulate them to show their understanding. It provides each student with many and diverse opportunities to excel.

Whether students continue with the study of science or not, they are sure to learn lifelong and valuable lessons and skills that are transferrable from the *Nelson iScience* series.

Acknowledgements

Neil Champion would like to thank his wife Gaye for her patience during the gestation of this work.

Xenia Pappas would like to thank her husband Chris, and her colleagues Brema Samuel and Jenn Alabaster at Korowa Anglican Girls' School.

Reviewers for *Nelson iScience 10*

The publisher and authors would like to thank the following people for providing invaluable information and advice.

Gary Bass, Macleod Secondary College, Victoria

Katrina Walker, Moama Grammar, New South Wales

Mia Sharma, Sydney Girls' Grammar School, New South Wales

Rob Farr, Brigidine College, New South Wales

Steve Zander, Christ Church Grammar, Western Australia

The publisher and authors would also like to gratefully credit or acknowledge permission to reproduce material from the following sources.

AAP/David Crosling: p. 279 left; AAP/Julian Smith: p. 213 lower; AAP/Snowy Hydro: p. 277 top; AAP/Spencer Green: p. 42 top; Alamy/Arco Images GmbH: p. 217 right; Alamy/Bubbles Photolibrary: p. 236; Alamy/Krystyna Szulecka: p. 217 left; Alamy/Masterpics: p. 20 lower right; Alamy/Matthew Heinrichs: p. 109 top; Alamy/Motion Pictures: p. 245; Alamy/Patti McConville: p. 262 lower; Alamy/Peter Haigh: p. 45; Alamy/Phil Degginger: p. 87 lower; Alamy/THE Print Collector: p. 57; Auscape/Jean-Marc La Roque: p. 216 centre; Auscape/Klein J. L. & Hubert M. L.-BIOSPHOTO: p. 40 top; Auscape/Mark Spencer: p. 200; Australian Astronomical Observatory photograph by David Malin: p. 75; Barnaby Norris: p. 148 lower left; Corbis/Alison Wright/National Geographic Society: p. 62; Corbis/Bettmann: p. 168; Corbis/Heritage Images: p. 40 left; Corbis/John Carnemolla: p. 278 lower right; Corbis/Mark Garlick/Science Photo Library: p. 150 lower; Corbis/Peter Ginter/Science Faction: pp. 150 top, 261; Corbis/Roger Ressmeyer: p. 151; Corbis/Ted Soqui: p. 42 lower; Ernst Haeckel – Creative Commons: p. 51; Photograph courtesy of Justin Ennis: p. 162 lower left; Getty Images/Jupiterimages: p. 262 top; Getty Images/Science Photo Library: p. 274 left; Getty Images: pp. 3, 20 top right, 41 lower left, 58 top, 59, 60 top, 99, 146, 149, 154, 173, 186 lower right, 191, 207 left, 211, 213 top, 230, 255 right, 266, 276 lower, 279 right; Government of WA, Dept of Premier and Cabinet: p. 48 lower left; iStockphoto/Russell Tate: p. 263; iStockphoto/Willi Schmitz: p. 109 lower; iStockphoto: pp. 74, 119, 139, 233 right, 279; Lonely Planet Images/John Hay: p. 216 lower; NASA: pp. 76 right, 148 lower right, 162 top, 197; National Archives of Australia/NAA: A1200, 11258503: p. 278 left; National Geographic Society: p. 41 right; Newspix/News Ltd/John Grainger: p. 255 left; Phototake/Robert B. Slobins: p. 120; Rare Book Library, Sydney University: p. 58 lower; Science Photo Library/A. Barrington Brown: p. 6 lower right; Science Photo Library/Adam Hart-Davis: p. 31 right; Science Photo Library/American Institute of Physics: p. 167 lower right; Science Photo Library/Andrew Lambert Photography: pp. 73 right, 82, 95; Science Photo Library/Dr George Beccaloni: p. 63 top left; Science Photo Library/European Space Agency/CPOM/UCL: p. 203 right; Science Photo Library/James Steveson: p. 274 right; Science Photo Library/Luke Dodd: p. 148 top left; Science Photo Library/Mehau Kulyk: p. 153; Science Photo Library/Mount Stromlo and Siding Spring Observatories: p. 167 top left; Science Photo Library/NASA/JPL-Caltech/UCLA: p. 174; Science Photo Library/NASA/WMAP Science Team: p. 158 top; Science Photo Library/Pascal Goetgheluck: pp. 67 top, 137; Science Photo Library/Patrick Dumas/Look at Sciences: p. 70; Science Photo Library/Pr G. Gimenez-Martin: p. 18; Science Photo Library/Russell Croman: p. 162 lower right; Science Photo Library/Vaughan Fleming: p. 13; Science Photo Library: pp. 6 top right &

centre left, 27, 87 top, 95, 130; Shutterstock.com: pp: 1, 15, 19, 21, 29, 31 left, 34 top, 37, 39, 43, 44, 47, 48 lower right, 49, 55 top, 63 top right & lower right, 65, 66, 67 lower, 68, 69, 71, 72, 105, 108, 114, 118, 128, 129, 140, 145, 158 lower, 183, 185, 186 top left & lower left, 187, 189, 190, 203 left, 205, 207, 214, 215, 216 top, 233 left & centre, 237, 260, 264, 278 top right; smart-elements.com/Jurgen Bauer: p. 73 left; The Stars of the Milky Way. Detail of painting by Banapana Maymuru from Yirrkala. Photo P. Tweedie, with Permission Buku-Larrngay Mulka: p. 147; Travis Metcalfe and Ruth Bazinet, Harvard-Smithsonian Center for Astrophysics: p. 76 left; 2008 ©UCAR, illustration by Steve Dayo: p. 204; Wellcome Institute Library, London: p. 25.

Text permissions

Poem by arrangement with The Dorothea Mackellar Estate, c/o Curtis Brown (Aust) Pty. Ltd.: p. 77.

Curriculum grid, p. xiv: © Australian Curriculum, Assessment and Reporting Authority 2012.

For all Australian Curriculum material except elaborations: This is an extract from the Australian Curriculum.

Elaborations: This may be a modified extract from the Australian Curriculum and may include the work of the author(s).

ACARA neither endorses nor verifies the accuracy of the information provided and accepts no responsibility for incomplete or inaccurate information. In particular, ACARA does not endorse or verify that:

- The content descriptions are solely for a particular year and subject;
- All the content descriptions for that year and subject have been used; and
- The author's material aligns with the Australian Curriculum content descriptions for the relevant year and subject.

You can find the unaltered and most up to date version of this material at **www.australiancurriculum.edu.au/**. This material is reproduced with the permission of ACARA.

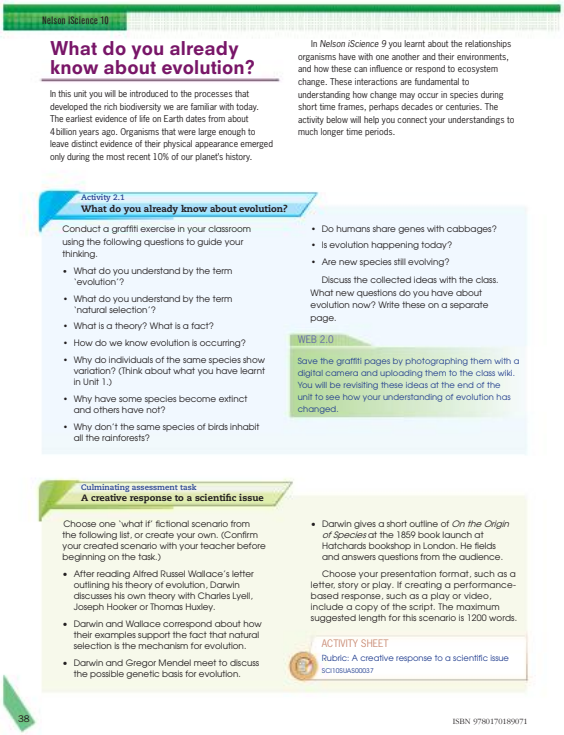
How to use *Nelson iScience*

The *Nelson iScience* series has been authored by practising teachers from across Australia to meet the requirements of the Australian Curriculum – Science. The *Nelson iScience* series integrates the three strands of the Australian Curriculum, while developing and reinforcing the overarching ideas, general capabilities and cross-cultural dimensions.

Nelson iScience has been designed for use by the students of the 21st century. *Nelson iScience* seamlessly integrates the use of Web 2.0 technology in the science classroom to research, analyse, record, collaborate and present material. Higher-order thinking skills are developed and reinforced throughout the series, providing students with strategies to manipulate information and ideas to tackle issues and assist problem-solving.

The *Nelson iScience* series has a clear, uncluttered and easy-to-follow design.

Each unit begins with a **unit opening page** that features a unit question based around one of the overarching ideas of the Australian Curriculum – Science. The unit question provides a framework on which teachers build students' knowledge. Each overarching idea is further developed in subsequent units, showing that these key aspects of science bridge scientific knowledge and understanding across all disciplines of science.



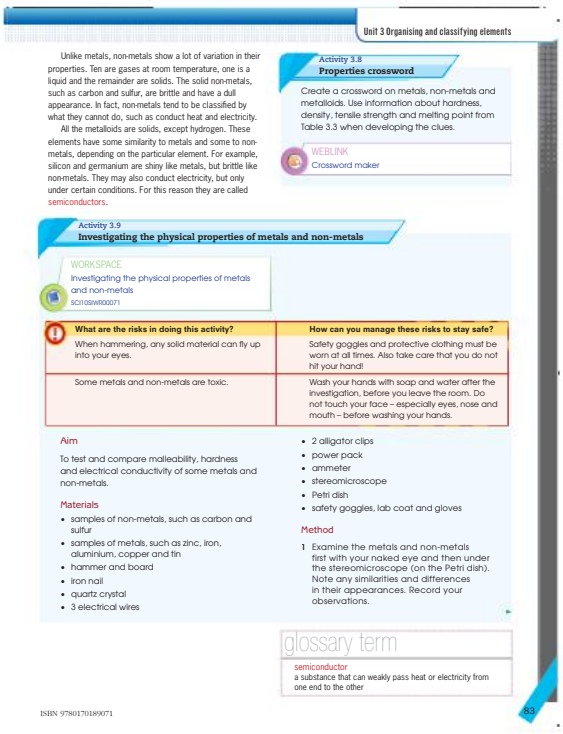
Students are challenged to think about **'What do you already know about ...?'** at the start of each unit. This is designed to determine what understandings and skills each student brings into each topic, and enables teachers to customise the unit to build on their students' current knowledge and skills.

The **culminating assessment task** is presented towards the beginning of each unit so that students can plan their time to complete the task. The culminating assessment task is designed to assess the understandings and skills presented in each unit. Each culminating assessment task is accompanied by an **assessment rubric** so that students are aware of the criteria on which they will be assessed.

Web 2.0 boxes throughout the units give ideas on how Web 2.0 applications can be used to assist with the delivery or presentation of content and student learning.

Activity boxes occur throughout each unit, providing practical minds-on or hands-on activities to reinforce student's learning. **Safety audit boxes** within activities alert teachers and students to any risks associated with completing the activity. Activity boxes build up and reinforce valuable skills related to the science inquiry skills strand. Many activities are suitable for homework or extension exercises.

Glossary terms are conveniently located at the bottom of each double-page spread.



Unit 3 Organising and classifying elements

Unlike metals, non-metals show a lot of variation in their properties. Ten are gases at room temperature, one is a liquid and the remainder are solids. The solid non-metals, such as carbon and sulfur, are brittle and have a dull appearance. In fact, non-metals tend to be classified by what they cannot do, such as conduct heat and electricity.

All the metalloids are solids, except hydrogen. These elements have some similarity to metals and some to non-metals, depending on the particular element. For example, silicon and germanium are shiny like metals, but brittle like non-metals. They may also conduct electricity, but only under certain conditions. For this reason they are called semiconductors.

Activity 3.8
Properties crossword

Create a crossword on metals, non-metals and metalloids. Use information about hardness, density, tensile strength and melting point from Table 3.3 when developing the clues.

WEBLINK
Crossword maker

Activity 3.9
Investigating the physical properties of metals and non-metals

WORKSPACE
Investigating the physical properties of metals and non-metals
SCI10SW000071

What are the risks in doing this activity?	How can you manage these risks to stay safe?
When hammering, any solid material can fly up into your eyes.	Safety goggles and protective clothing must be worn at all times. Also take care that you do not hit your hand!
Some metals and non-metals are toxic.	Wash your hands with soap and water after the investigation, before you leave the room. Do not touch your face – especially eyes, nose and mouth – before washing your hands.

Aim

To test and compare malleability, hardness and electrical conductivity of some metals and non-metals.

Materials

- samples of non-metals, such as carbon and sulfur
- samples of metals, such as zinc, iron, aluminium, copper and tin
- hammer and board
- iron nail
- quartz crystal
- 3 electrical wires
- 2 alligator clips
- power pack
- ammeter
- stereomicroscope
- Petri dish
- safety goggles, lab coat and gloves

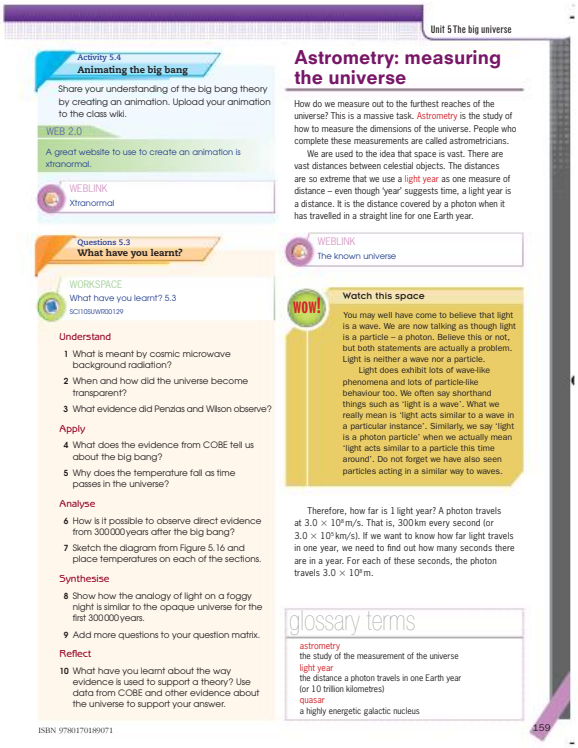
Method

1 Examine the metals and non-metals first with your naked eye and then under the stereomicroscope (on the Petri dish). Note any similarities and differences in their appearances. Record your observations.

glossary term

semiconductor
a substance that can weakly pass heat or electricity from one end to the other

ISBN 9780170189071



Unit 5 The big universe

Activity 5.4
Animating the big bang

Share your understanding of the big bang theory by creating an animation. Upload your animation to the class wiki.

WEB 2.0

A great website to use to create an animation is xtranormal.

WEBLINK
Xtranormal

Questions 5.3
What have you learnt?

WORKSPACE
What have you learnt? 5.3
SCI10SUW000129

Understand

1 What is meant by cosmic microwave background radiation?
2 When and how did the universe become transparent?
3 What evidence did Penzias and Wilson observe?

Apply

4 What does the evidence from COBE tell us about the big bang?
5 Why does the temperature fall as time passes in the universe?

Analyse

6 How is it possible to observe direct evidence from 300 000 years after the big bang?
7 Sketch the diagram from Figure 5.16 and place temperatures on each of the sections.

Synthesise

8 Show how the analogy of light on a foggy night is similar to the opaque universe for the first 300 000 years.
9 Add more questions to your question matrix.

Reflect

10 What have you learnt about the way evidence is used to support a theory? Use data from COBE and other evidence about the universe to support your answer.

Astrometry: measuring the universe

How do we measure out to the furthest reaches of the universe? This is a massive task. Astrometry is the study of how to measure the dimensions of the universe. People who complete these measurements are called astrometricians.

We are used to the idea that space is vast. There are vast distances between celestial objects. The distances are so extreme that we use a light year as one measure of distance – even though 'year' suggests time, a light year is a distance. It is the distance covered by a photon when it has travelled in a straight line for one Earth year.

WEBLINK
The known universe

WOW!

Watch this space

You may well have come to believe that light is a wave. We are now talking as though light is a particle – a photon. Believe this or not, but both statements are actually a problem. Light is neither a wave nor a particle.

Light does exhibit lots of wave-like phenomena and lots of particle-like behaviour too. We often say shorthand things such as 'light is a wave'. What we really mean is 'light acts similar to a wave in a particular instance'. Similarly, we say 'light is a photon particle' when we actually mean 'light acts similar to a particle this time around'. Do not forget we have also seen particles acting in a similar way to waves.

Therefore, how far is 1 light year? A photon travels at 3.0×10^8 m/s. That is, 300 km every second (or 3.0×10^5 km/s). If we want to know how far light travels in one year, we need to find out how many seconds there are in a year. For each of these seconds, the photon travels 3.0×10^8 m.

glossary terms

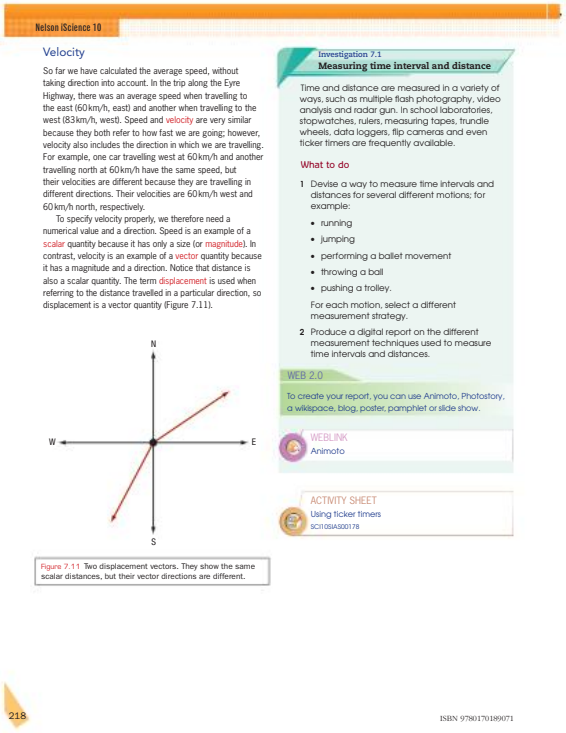
astrometry
the study of the measurement of the universe
light year
the distance a photon travels in one Earth year (or 10 trillion kilometres)
quasar
a highly energetic galactic nucleus

ISBN 9780170189071

Wow! boxes provide interesting and engaging information related to the content of the unit.

What have you learnt? boxes break the unit content into smaller chunks. They allow students to review and assess their learning. Questions are categorised according to Bloom's taxonomy, designed to extend each student's thinking and understanding.

Investigation boxes challenge students to research topics, or design and perform open-ended experiments either individually or in groups. Investigation boxes build up and reinforce valuable skills related to the science inquiry skills strand.



Nelson iScience 10

Velocity

So far we have calculated the average speed, without taking direction into account. In the trip along the Eyre Highway, there was an average speed when travelling to the east (60 km/h, east) and another when travelling to the west (83 km/h, west). Speed and velocity are very similar because they both refer to how fast we are going; however, velocity also includes the direction in which we are travelling. For example, one car travelling west at 60 km/h and another travelling north at 60 km/h have the same speed, but their velocities are different because they are travelling in different directions. Their velocities are 60 km/h west and 60 km/h north, respectively.

To specify velocity properly, we therefore need a numerical value and a direction. Speed is an example of a scalar quantity because it has only a size (or magnitude). In contrast, velocity is an example of a vector quantity because it has a magnitude and a direction. Notice that distance is also a scalar quantity. The term displacement is used when referring to the distance travelled in a particular direction, so displacement is a vector quantity (Figure 7.11).

Figure 7.11 Two displacement vectors. They show the same scalar distances, but their vector directions are different.

Investigation 7.1
Measuring time interval and distance

Time and distance are measured in a variety of ways, such as multiple flash photography, video analysis and radar gun. In school laboratories, stopwatches, rulers, measuring tapes, trundle wheels, data loggers, flip cameras and even ticker timers are frequently available.

What to do

1 Devise a way to measure time intervals and distances for several different motions; for example:
- running
- jumping
- performing a ballet movement
- throwing a ball
- pushing a trolley.

For each motion, select a different measurement strategy.

2 Produce a digital report on the different measurement techniques used to measure time intervals and distances.

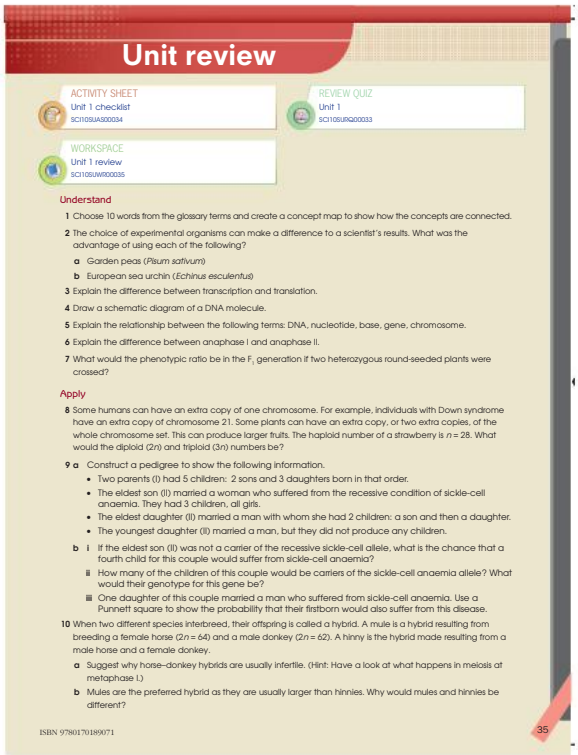
WEB 2.0

To create your report, you can use Animoto, Photostory, a wikispace, blog, poster, pamphlet or slide show.

WEBLINK
Animoto

ACTIVITY SHEET
Using ticker timers
SCI10SIAS00178

ISBN 9780170189071



Unit review

ACTIVITY SHEET
Unit 1 checklist
SCI10SIAS00034

REVIEW QUIZ
Unit 1
SCI10SIRQ00033

WORKSPACE
Unit 1 review
SCI10SIWR00035

Understand

1 Choose 10 words from the glossary terms and create a concept map to show how the concepts are connected.

2 The choice of experimental organisms can make a difference to a scientist's results. What was the advantage of using each of the following?
- a Garden peas (*Pisum sativum*)
- b European sea urchin (*Echinus esculentus*)

3 Explain the difference between transcription and translation.

4 Draw a schematic diagram of a DNA molecule.

5 Explain the relationship between the following terms: DNA, nucleotide, base, gene, chromosome.

6 Explain the difference between anaphase I and anaphase II.

7 What would the phenotypic ratio be in the F_1 generation if two heterozygous round-seeded plants were crossed?

Apply

8 Some humans can have an extra copy of one chromosome. For example, individuals with Down syndrome have an extra copy of chromosome 21. Some plants can have an extra copy, or two extra copies, of the whole chromosome set. This can produce larger fruits. The haploid number of a strawberry is $n = 28$. What would the diploid ($2n$) and triploid ($3n$) numbers be?

9 a Construct a pedigree to show the following information.
- Two parents (I) had 5 children: 2 sons and 3 daughters born in that order.
- The eldest son (II) married a woman who suffered from the recessive condition of sickle-cell anaemia. They had 3 children, all girls.
- The eldest daughter (II) married a man with whom she had 2 children: a son and then a daughter.
- The youngest daughter (II) married a man, but they did not produce any children.

b i If the eldest son (II) was not a carrier of the recessive sickle-cell allele, what is the chance that a fourth child for this couple would suffer from sickle-cell anaemia?

ii How many of the children of this couple would be carriers of the sickle-cell anaemia allele? What would their genotype for this gene be?

iii One daughter of this couple married a man who suffered from sickle-cell anaemia. Use a Punnett square to show the probability that their firstborn would also suffer from this disease.

10 When two different species interbreed, their offspring is called a hybrid. A mule is a hybrid resulting from breeding a female horse ($2n = 64$) and a male donkey ($2n = 62$). A hinny is the hybrid made resulting from a male horse and a female donkey.

a Suggest why horse–donkey hybrids are usually infertile. (Hint: Have a look at what happens in meiosis at metaphase I.)

b Mules are the preferred hybrid as they are usually larger than hinnies. Why would mules and hinnies be different?

ISBN 9780170189071

The **end-of-unit review** consists of an interactive autocorrecting **review quiz**, a **unit checklist** to assist students with revising for a test, and a set of **end-of-unit review questions**. These questions are categorised according to Bloom's taxonomy to extend each student's thinking and understanding.

NelsonNet is your protected portal to the premium digital resources for Nelson textbooks located at www.nelsonnet.com.au. Once your registration is complete, you will have access to exciting and stimulating digital resources that supplement and complement each unit. They include:

Workspaces are provided throughout each unit. These are spaces in which you can complete the work required within the unit. Workspaces can be either printed out or filled in on-screen and submitted electronically to the teacher.

Activity sheets provide extra activities, experiments, literacy exercises, crosswords and more that can be used either within class or as homework and extension material. Activity sheets can be either printed out or filled in on-screen and submitted electronically to the teacher.

Connection sheets provide links to other learning areas such as English, Mathematics and History. Connection sheets can be either printed out or filled in on-screen and submitted electronically to the teacher.

Interactives provide learning objects that you can interact with and use at your own pace to reinforce your learning.

Animations provide you with animated illustrations from the student text.

Weblinks link you to websites on the Internet.

Video links link you to video clips to aid with learning.

Review quizzes appear at the end of each unit. Each quiz contains 10 multiple-choice items and is interactive and autocorrecting.

Nelson iScience NelsonNetBook

NelsonNetBook is a web-based ebook for secondary schools, friendly to interactive whiteboards, computers and iPads. Optional Web 2.0 functionality enables class groups and individuals to add highlights, annotations, audio clips and weblinks. Visit the NelsonNet portal at www.nelsonnet.com.au to find out more, to register or to log in if already registered.

NelsonNetBook allows both teachers and students to personalise the book and for teachers to share their enriched version with groups of students, or a group of teachers, in the school. Alternatively, students can simply use the resource independently without being in a group. The creation and membership of the groups is entirely in the hands of the teacher, and the shared environment is protected through individual access codes and school registration.

The NelsonNetBook becomes central to everything the students do. It loads onto the screen with toolbars down the side and along the bottom (can be interchanged according to the user's preference). The icons on the toolbars correspond to editing features, such as highlighting, note-taking, inserting weblinks, bookmarking, inserting video links and inserting worksheets, as well as for more personalised activities.

Nelson iScience teacher companion site

The teacher will have access to assessment material and detailed curriculum grids that map in detail the units to the science curriculum strands, teaching plans for each unit and a PDF of the student book.

Curriculum grid

Strand	Sub-strands	Content descriptions	Unit coverage
Science Understanding	Biological sciences	The transmission of heritable characteristics from one generation to the next involves DNA and genes.	Unit 1
		The theory of evolution by natural selection explains the diversity of living things and is supported by a range of scientific evidence.	Unit 2
	Chemical sciences	The atomic structure and properties of elements are used to organise them in the periodic table.	Unit 3
		Different types of chemical reactions are used to produce a range of products and can occur at different rates.	Unit 4
	Earth and space sciences	The universe contains features including galaxies, stars and solar systems and the big bang theory can be used to explain the origin of the universe.	Unit 5
		Global systems, including the carbon cycle, rely on interactions involving the biosphere, lithosphere, hydrosphere and atmosphere.	Unit 6
	Physical sciences	Energy conservation in a system can be explained by describing energy transfers and transformations.	Unit 8
		The motion of objects can be described and predicted using the laws of physics.	Unit 7
Science as a Human Endeavour	Nature and development of science	Scientific understanding, including models and theories, are contestable and are refined over time through a process of review by the scientific community.	Units 1, 2, 3, 4, 5, 6, 7
		Advances in scientific understanding often rely on developments in technology and technological advances are often linked to scientific discoveries.	Units 1, 2, 3, 4, 5, 6, 7, 8
	Use and influence of science	People can use scientific knowledge to evaluate whether they should accept claims, explanations or predictions.	Units 1, 2, 4, 5, 6, 7, 8
		Advances in science and emerging sciences and technologies can significantly affect people's lives, including generating new career opportunities.	Units 1, 2, 4, 5, 6, 7, 8
		The values and needs of contemporary society can influence the focus of scientific research.	Units 1, 2, 4, 5, 6, 7, 8
Science Inquiry Skills	Questioning and predicting	Formulate questions or hypotheses that can be investigated scientifically.	Units 2, 3, 4, 6, 7
	Planning and conducting	Plan, select and use appropriate investigation methods, including fieldwork and laboratory experimentation, to collect reliable data; assess risk and address ethical issues associated with these methods.	Units 1, 2, 3, 4, 6, 7, 8
		Select and use appropriate equipment, including digital technologies, to systematically and accurately collect and record data.	Units 2, 3, 4, 6, 7, 8
	Processing and analysing data and information	Analyse patterns and trends in data, including describing relationships between variables and identifying inconsistencies.	Units 1, 2, 3, 4, 5, 7, 8
		Use knowledge of scientific concepts to draw conclusions that are consistent with evidence.	Units 1, 2, 3, 4, 5, 6, 7, 8
	Evaluating	Evaluate conclusions, including identifying sources of uncertainty and possible alternative explanations, and describe specific ways to improve the quality of the data.	Units 2, 3, 4, 5, 6, 7
		Critically analyse the validity of information in secondary sources and evaluate the approaches used to solve problems.	Units 1, 2, 3, 4, 5, 7
	Communicating	Communicate scientific ideas and information for a particular purpose, including constructing evidence-based arguments and using appropriate scientific language, conventions and representations.	Units 1, 2, 3, 4, 5, 6, 7, 8

© Australian Curriculum, Assessment and Reporting Authority 2012.

1

Genetics: chemistry from our ancestors

Do appearances matter?

You may have noticed that many personal features such as height, hair colour, facial shape and athleticism seem to 'run in the family'. These features may be obvious, but family traits can also be hidden and subtle. When visiting doctors, they may ask about family members having had conditions such as asthma, diabetes or cancer. Why? Physical and biological features, as well as medical conditions, can run in the family.

This unit will help you understand what makes you unique and how your parents' and grandparents' physical health can be important for understanding your own.

What do you already know about genetics?

Humans have been practising genetics from at least 15 000 BCE. The first attempts at genetic engineering are evident in the sealed tombs of our ancestors. Ancient pollen from domesticated plants found there have shown that farmers were selecting and breeding plants for desired characteristics. They did not know, however, how these characteristics were passed between generations. Complete Activity 1.1 to find out how much you already know about genetics.

Activity 1.1
What do you already know about genetics?

Work individually to create a list of:

- 10 things that you already know about genetics
- 10 questions that you have about genetics.

Post your questions on the class wallwisher.

INTERACTIVE
Introduction to genes: assessment
SCI10SUIN00001

WEBLINK
Wallwisher

WEB 2.0

1 Build a blog to use throughout Year 10 Science. Send the address of your blog to your teacher so that your work can be viewed.
2 Using Glogster, create a glog called 'Unit 1 Genetics'. This glog will be used to capture your thinking, key ideas, concepts covered and things you consider to be important. It will be a great resource for you when you revise the unit and study the contents. Add to your glog throughout the unit.

WEBLINK
Blogger

WEBLINK
Glogster

Culminating assessment task
Conference of chromosomes and patterns of heredity

Your task is to develop a suite of information about human genetics and conditions, and to present this information in a form of your choice. In this activity, you are asked to:

1 Identify a genetic condition caused by changes in the DNA information on a human chromosome. Use the weblink 'Chromosome viewer' to assist you in your choice.

WEBLINK
Chromosome viewer

2 State on which human chromosome your genetic condition occurs.

3 Determine the change that occurs in the DNA of that chromosome to cause the condition. Identify some of the physical symptoms that people would display if they expressed the condition.

4 Find a pedigree chart showing four generations of a family with the genetic condition. Alternatively, if you know a family with the condition, create your own pedigree using the symbol conventions. Use this pedigree to explain the pattern of inheritance in the condition you researched.

5 Write a response of no more than 800 words (excluding references) describing some of the following issues with the genetic condition you selected.
   - Why patterns seem to emerge in your pedigree chart. For example, does the condition seem to appear in each generation, or does it seem to 'skip' a generation?
   - Whether the disease is serious enough to warrant genetic testing. Are there any preventative actions the person(s) predisposed to the genetic condition can take, or treat it, if it is expressed?
   - Where could a person with the genetic condition find advice, support or others with the same condition?

6 Imagine a day in the life of a person with the genetic condition you have researched. Create a timeline of a whole day for this person. The timeline should outline things that the person either needs to do or finds extremely difficult and therefore needs assistance doing, such as a diabetic's insulin

ISBN 9780170189071

routine and blood checking. A good resource to help you build your timeline is Timetoast.

WEBLINK
Timetoast

7 In what ways is this timeline typical of every other day of the week? What might cause variation in the routine for this person?

8 Imagine that you have the genetic condition you have researched. Write a diary entry about how you feel about the events on your timeline. Alternatively, if you know someone with this condition, interview them about a typical day in their life and how they feel about it.

9 Include references in your presentation to your class.

ACTIVITY SHEET
Rubric: Conference of chromosomes and patterns of heredity
SCI10SUAS00002

Genetics

Genetics is the study of genes and inheritance. It investigates how characteristics are passed from one generation to the next. Knowledge of this is essential in, for example, agriculture to increase crop productivity, biology to identify people at risk of genetic conditions, and police work to solve crimes. As one of the fastest-growing areas of scientific development, genetics also raises different ethical issues about the privacy of a person's own genetic information.

To get a clear picture of why we look the way we do or the way our body works, we must look deep into the body and its cells. In this way we can understand how one molecule controls all of our features. This special molecule is found in the nucleus of most cells and is known as DNA.

DNA: the messenger between generations

Deoxyribonucleic acid (DNA) is a chemical molecule that contains the genetic code, or blueprint, for every organism. In all DNA-containing organisms, including humans, DNA directs the development and functioning of the organism. This molecule is passed on from generation to generation. Approximately 3 m of DNA is in the nucleus of each of our cells.

WEBLINK
The size of DNA

The DNA molecule is structured like a ladder. It has two vertical 'backbones' made of repeating sugars and phosphates. The horizontal 'rungs' are made of units called nitrogenous bases. The DNA molecule is not straight like a real ladder. Rather, imagine holding the top and bottom of a ladder and twisting it around. The resulting shape is known as a double helix (Figures 1.1 below and 1.2 on page 4).

Figure 1.1 DNA – the double-helix molecule

glossary terms

deoxyribonucleic acid (DNA)
the inherited code of genetic information

double helix
the spiral shape of DNA

genetics
the study of genes and inheritance

nitrogenous base
one of the four bases – adenine, cytosine, thymine and guanine – that make up DNA

ISBN 9780170189071

The DNA molecule is made up of many repeating units called nucleotides (Figure 1.3). Each nucleotide consists of a sugar, a phosphate and one of the four different chemical bases: adenine (A), guanine (G), thymine (T) and cytosine (C). The base on one strand of a DNA molecule will always pair with its complementary base on the other strand. For example, A will always pair with T, and G will always pair with C. This is known as the complementary base pairing rule.

ANIMATION
Base pairing
SCI10SUAN00003

ACTIVITY SHEET
Modelling DNA
SCI10SUAS00004

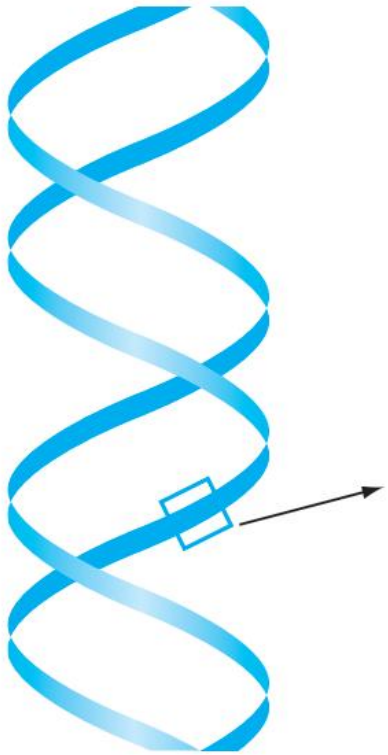


Figure 1.2 The double helix – simplified

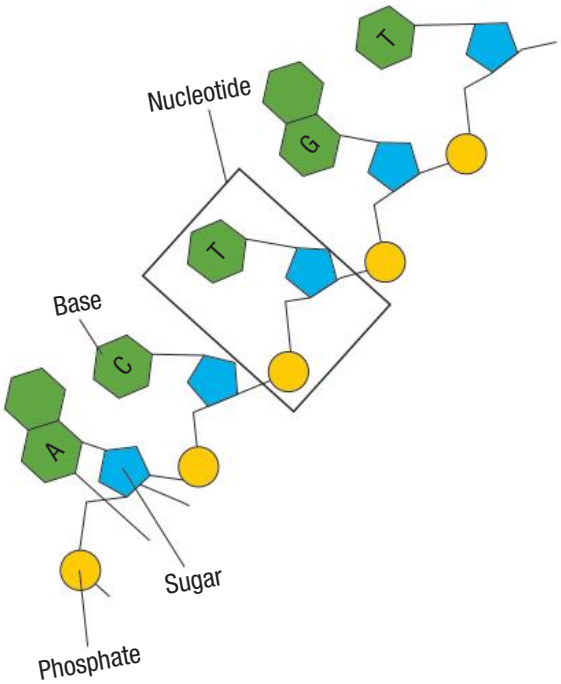


Figure 1.3 A nucleotide unit of DNA contains a sugar, a phosphate and a base.

Activity 1.2
Extracting DNA

WORKSPACE
Extracting DNA
SCI10SIWR00005

What are the risks in doing this activity?	How can you manage these risks to stay safe?
Ethanol or methylated spirits is flammable and toxic.	Avoid handling ethanol or methylated spirits. Use latex gloves and/or a squeeze bottle. Do not use naked flames anywhere around ethanol.

ISBN 9780170189071

DNA is easily extracted from a variety of biological tissues: banana, kiwifruit, onion, liver or wheat germ (a concentrated source).

Materials

- source of DNA: 1 cm^3 of banana, kiwifruit, onion, liver or wheat germ
- mortar and pestle
- salt
- dishwashing detergent
- buffer solution
- 250 mL beaker
- funnel
- filter paper
- meat tenderiser
- ethanol (ice cold) in a squeeze bottle
- hooked Pasteur pipette or paperclip

Method

1. Place your DNA source into a mortar. Using the pestle, grind the material with salt, dishwashing detergent and the buffer solution. Note:
   - The physical grinding increases the contact surface area.
   - The detergent breaks down the oily cell membranes and proteins.
   - The buffer helps the DNA come together.
2. Use the beaker, funnel and filter paper to filter the ground mixture. This removes the cell debris, but the cell nuclei should still pass through.
3. Add 1 tablespoon of meat tenderiser to the filtered material. This breaks down the nuclear membranes.
4. Add the ethanol by running small amounts carefully down the side of the beaker. Water is more dense than alcohol, so the alcohol rests above it. The DNA, which is not soluble in alcohol, will precipitate on the interface of the two mixtures after a few minutes.
5. Lift the DNA out of the beaker using a hooked Pasteur pipette or paperclip.

Results

1. From what material did you extract DNA?
2. Construct a flowchart to show the steps in the method. Include the purpose of each step.
3. Would you expect the same results from different amounts of blending?
4. Why does the detergent affect the cell membranes? (Hint: What are cell membranes mainly made of?)
5. Why does the alcohol remain in a layer on top of the liquid in the beaker?
6. Compare your results with those of another group that used a different DNA source. Would you expect the results from different tissues to be similar? Explain.
7. Compare the volume of strained DNA with the original amount of tissue you ground. Estimate the percentage.

Discussion

8. If the average plant cell contains 3 m of DNA and we consume 50 million cells in an average meal, how many kilometres of DNA do we eat in a week?
9. We cannot isolate and touch most of the other molecules that make up living things as easily as we can DNA. Why do you think this is so?
10. A person cannot see a single cotton thread 30 m away, but if you wound thousands of threads together into a rope, it would be visible from much further away. Explain how this statement is similar to your procedure.

glossary terms

adenine
a base found in DNA and also another nucleic acid called RNA

complementary base pairing
a rule that states the chemical bases are always found in pairs; for example, adenine will always bond with thymine, and guanine will always bond with cytosine

cytosine
a base found in DNA and RNA

guanine
a base found in DNA and RNA

interface
a dividing line or boundary

nucleotide
the subunit that makes up DNA

thymine
a base found in DNA (but not RNA)

ISBN 9780170189071

The structure of DNA

Using X-ray crystallography, accurate images of individual atoms in large molecules can be produced. In the early 1950s British chemist Rosalind Franklin (1920–1958), working with colleague Maurice Wilkins (1916–2004) at King's College, London, prepared several samples of DNA under a variety of conditions, such as using different levels of water (hydration). Franklin's X-ray photograph, which was taken in 1952, clearly showed that DNA had a helical structure and that the two outer strands consisted of sugar and phosphate (Figure 1.5).

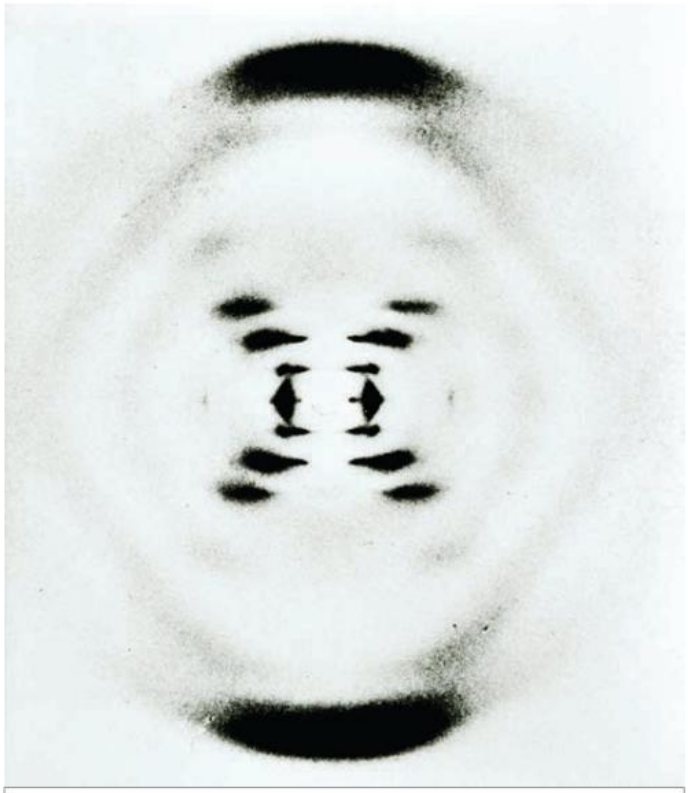


Figure 1.5 Franklin's X-ray photograph looking down the DNA molecule

Figure 1.4 Rosalind Franklin

Franklin's photograph enabled the structure of DNA to be worked out within a year. In 1953, while working together at the University of Cambridge, molecular biologists James Watson (1928–) and Francis Crick (1916–2004) realised the two chains of nucleotides in the helix ran in opposite directions. Using simple materials like retort stands and cardboard, they built a three-dimensional DNA model (Figure 1.6). This is now one of the fundamental ideas in biology. In 1962 Watson and Crick were awarded the Nobel Prize for this discovery, along with Maurice Wilkins.

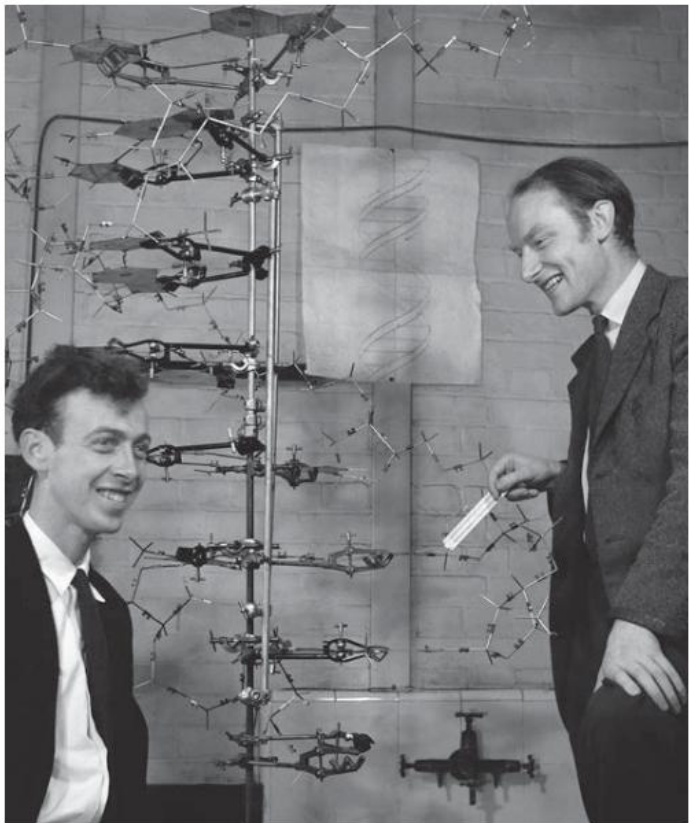


Figure 1.6 American James Watson (right) was only 25 and English Francis Crick a graduate student when they unified the known chemistry of DNA.

WEBLINK
DNA: the greatest discovery in modern science

INTERACTIVE
Genes: what is DNA?
SCI10SUIN00001

ISBN 9780170189071

Questions 1.1
What have you learnt?

WORKSPACE
What have you learnt? 1.1
SCI10SUWR00006

Understand

1 What is genetics?

2 Answer the following questions.
- **a** What does DNA stand for?
- **b** What is the basic subunit of the DNA molecule?
- **c** What does the subunit consist of?
- **d** What is the structural shape of the DNA molecule?

3 What is the complementary base pairing rule?

Apply

4 Below is a template sequence of DNA nucleotides.

ATA TTG GGC GCC AAG ACT

What would be the sequence of nucleotides on the complementary strand?

Reflect

5 Rosalind Franklin died of ovarian cancer, aged 37. Can you suggest any occupational risks (that is, at her workplace) she may have been exposed to?

6 Rosalind Franklin's work was given to Watson without her permission. Without Franklin's photograph, Watson and Crick may not have determined the structure of the DNA molecule for numerous years. Discuss whether you think it was right or wrong for Watson to use the information Franklin discovered without her permission.

7 Rosalind Franklin was not awarded a Nobel Prize for her contribution to the discovery of DNA as Nobel Prizes cannot be awarded posthumously (that is, after a person has died). What are your thoughts about this?

DNA: coding for life

The information in DNA is stored as a code made up of the four chemical bases. It is the order, or sequence, of these bases that determines the code. It is similar to the way in which letters of the alphabet appear in a certain order to form a word. For example, the word 'BUT' has a certain meaning; however, the word 'TUB' has a totally different meaning, even though it contains the same letters. It is the order of the letters that is important.

To maintain this code and pass it on from cell to cell, there must be an orderly process to replicate the DNA during cell division.

DNA replication

In order for cells to divide, they must first copy the DNA so that it can be divided into the daughter cells. DNA replication is a complex process (Figure 1.7 on page 8).

Before the DNA molecule can replicate itself, it is unwound by a special enzyme called DNA helicase. This enzyme separates the DNA molecule, like a zipper being undone, and allows the bases on each strand to be exposed.

Using these exposed bases as a template, another enzyme called DNA polymerase lays down new bases according to the complementary base pairing rule to form a new DNA strand. Each side of the DNA molecule now contains one old strand of DNA and one new strand of DNA. This is called semi-conservative replication. The two molecules are twisted into the familiar double helix shape.

glossary terms

daughter cells
cells produced through mitosis or meiosis (daughter cells created through mitosis are identical to the parent cell; those produced through meiosis are genetically different)

DNA helicase
the enzyme molecule that unzips the DNA

DNA polymerase
the enzyme that lays down new bases on an exposed DNA strand to create a new DNA strand

enzyme
a protein catalyst

replication
the process in which cells copy the DNA prior to cell division (also known as semi-conservative replication)

semi-conservative replication
DNA replication whereby one strand is from the old DNA molecule and one strand is a new DNA molecule

X-ray crystallography
a technique that shines a beam of X-rays through purified materials, revealing the patterns of atoms

ISBN 9780170189071

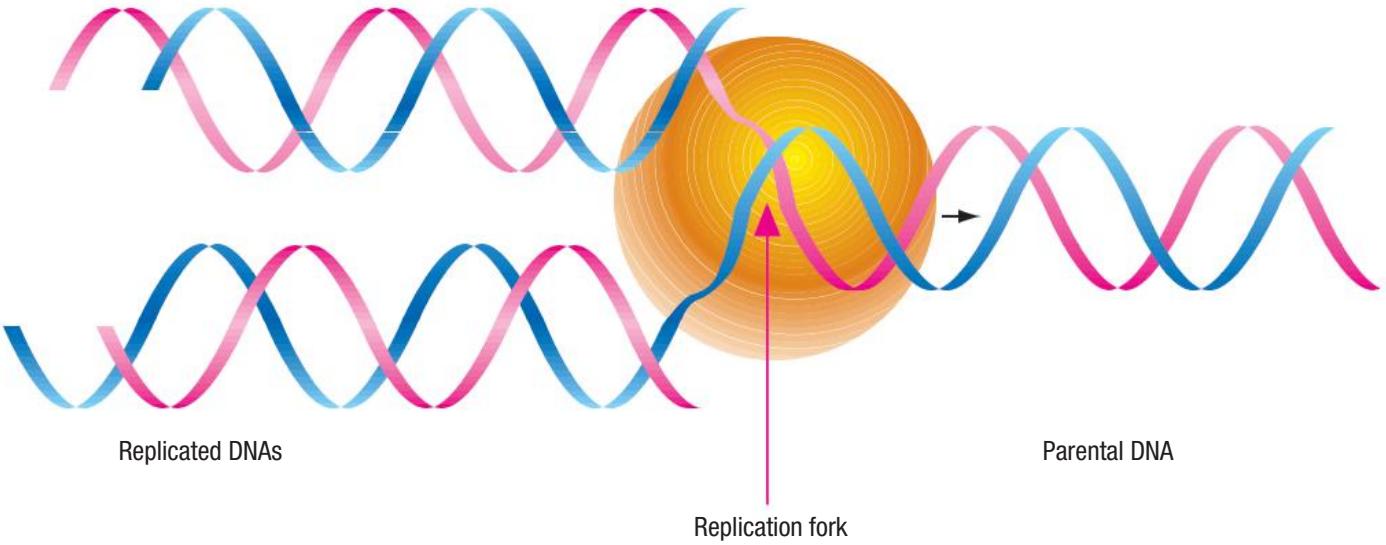


Figure 1.7 DNA replication – the unwinding of DNA strands and the rewinding of newly replicated strands

INTERACTIVE
Genes: DNA replication
SCI10SUIN00001

WEBLINK
DNA replication

Protein synthesis

Once Watson and Crick discovered the structure of DNA, it became clear that there must be a relationship between DNA in the nucleus and the many different proteins found in the cytoplasm. Proteins are polymers of amino acids. Proteins have many functions within a living organism. For example, they can act as enzymes (such as in digestion) or provide structure to cells (the cell membrane contains many different proteins). All proteins are made of many subunits called amino acids. These amino acids differ in their number and order in different proteins.

The DNA somehow provided a plan for the production of all the possible proteins a cell may need. Scientists realised that it was the order of the base pairs in the DNA that coded for the order of the amino acids in a protein. Protein synthesis from the DNA code can be broken down into two parts: transcription and translation. (See Figure 1.8 on page 9.)

Transcription

Each DNA molecule has many genes made up of many bases located along its length. Each gene codes for a particular protein. For the information coded in a gene to be transferred to a protein, the DNA needs to separate into two single strands, just as when the DNA is replicating. This time, however, one of the strands acts as a template for a different molecule to be created called messenger RNA (mRNA). Using the DNA code to produce an mRNA molecule is called transcription. mRNA is a single-stranded molecule and contains the bases A, C and G (similar to DNA) and the base uracil (U), which is used instead of thymine (T).

For example, if the DNA template code was:

ATT CGA ACG TCC GCC

the mRNA code would be complementary but would contain uracil instead of thymine:

UAA GCU UGC AGG CGG

mRNA is a smaller molecule than DNA and is able to pass through the nuclear membrane. Once the gene has been transcribed into mRNA, it leaves the nucleus and moves into the cytoplasm for translation into a protein.

INTERACTIVE
Genes: protein synthesis
SCI10SUIN00001

ISBN 9780170189071

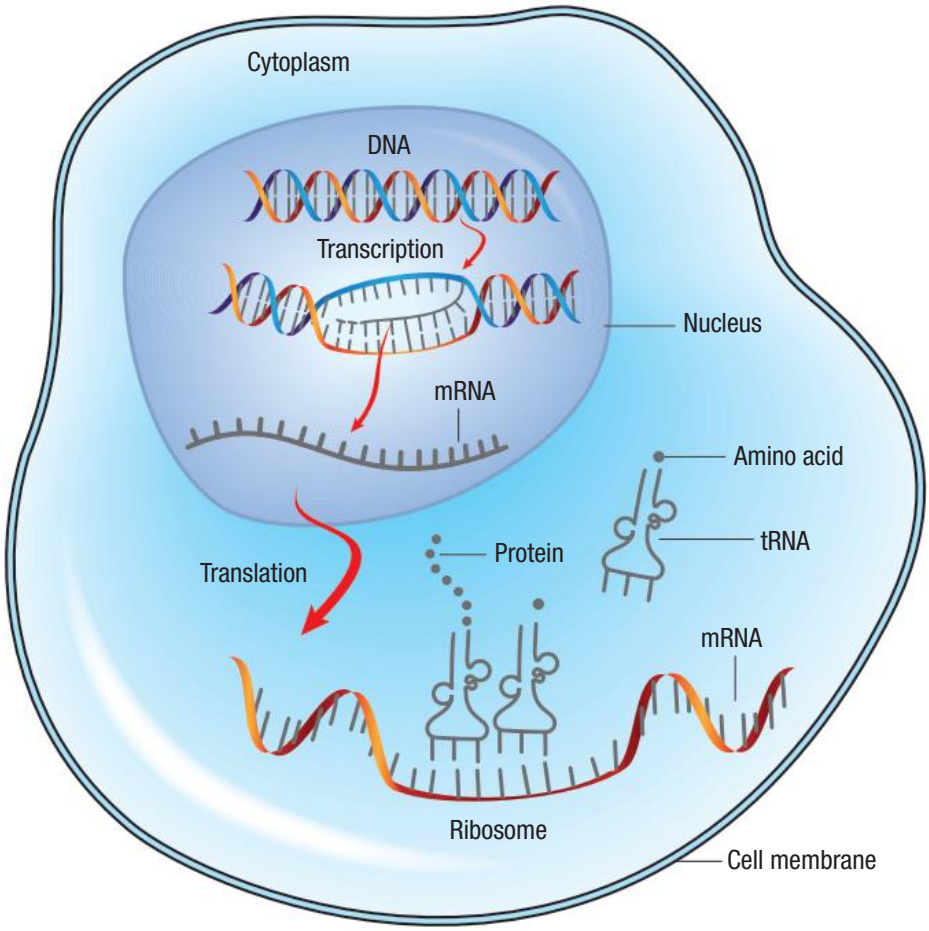


Figure 1.8 Simplified diagrams summarising the process of protein synthesis. Several enzymes assist with each stage.

Translation

Now located in the cytoplasm, the mRNA heads to the site of protein synthesis – the ribosome. Transfer RNA (tRNA) brings the amino acids to the ribosome according to the sequence of the bases within the mRNA. The mRNA bases are read three at a time and amino acids are placed in order to produce the protein. This is called translation. Once the mRNA molecule has been completely read from start to finish, the protein chain detaches from the ribosome.

WEBLINK
Translation

glossary terms

amino acid
the subunit that makes proteins

gene
a section of the genome that provides the code for a particular protein/characteristic

messenger RNA (mRNA)
a type of RNA that moves the information from the DNA template into the cytoplasm

polymer
a large molecule made by linking smaller, similar units together

protein
a large molecule made up of many amino acids

protein synthesis
the process within cells that builds protein molecules

ribosome
the structure in the cytoplasm in which protein synthesis occurs

transcription
the process in which the DNA information is copied, nucleotide by nucleotide, into mRNA

transfer RNA (tRNA)
the molecule that delivers amino acids to ribosomes

translation
the process in which the mRNA information is converted into an amino acid sequence

uracil
a base found in RNA (but not DNA)

ISBN 9780170189071

Activity 1.3

Think, pair, share

Imagine that you have to explain translation and transcription to someone else.

1 **Think**. How would you do this? Plan your thoughts and ideas in detail. Who is your audience?

2 **Pair** up with someone. Share your plans. Create a new plan combining your thoughts for an agreed audience, such as a member of your family.

3 **Share**. Join up with another pair. As a group, combine your ideas and write, draw and/or create how you would explain this for your specific audience.

WEB 2.0

Upload your plans and any resources you have created to your blog.

The genetic code

The genetic code shows the relationship between the information on the mRNA and the amino acids that eventually build a protein. Table 1.1 enables us to interpret this code. For example, let's interpret the three-letter mRNA code CAG. The first letter (down the left-hand side) shows the first base – in this case, C. The top of the table shows the second base, A. The right-hand side of the table shows the third base, G. If we trace to where these three bases intercept, we will end up at CAG, which is the sequence that codes for the amino acid glutamine.

ACTIVITY SHEET

Translating your name into genetic code

SCI10SIAS00007

Table 1.1 The genetic code, showing the amino acids coded for by each mRNA sequence

First letter	Second letter: U		Second letter: C		Second letter: A		Second letter: G		Third letter
U	UUU	Phenylalanine	UCU	Serine	UAU	Tyrosine	UGU	Cysteine	U
	UUC		UCC		UAC		UGC		C
	UUG	Leucine	UCA		UAA	STOP	UGA	STOP	A
	UUA		UCG		UAG		UGG	Tryptophan	G
C	CUU	Leucine	CCU	Proline	CAU	Histidine	CGU	Arginine	U
	CUC		CCC		CAC		CGC		C
	CUA		CCA		CAA	Glutamine	CGA		A
	CUG		CCG		CAG		CGG		G
A	AUU	Isoleucine	ACU	Threonine	AAU	Asparagine	AGU	Serine	U
	AUC		ACC		AAC		AGC		C
	AUA		ACA		AAA	Lysine	AGA	Arginine	A
	AUG	Methionine	ACG		AAG		AGG		G
G	GUU	Valine	GCU	Alanine	GAU	Aspartamine	GGU	Glycine	U
	GUC		GCC		GAC		GGC		C
	GUA		GCA		GAA	Glutamine	GGA		A
	GUG		GCG		GAG		GGG		G

ISBN 9780170189071

Questions 1.2
What have you learnt?

WORKSPACE
What have you learnt? 1.2
SCI10SUWR00008

Understand

1 What is the process and purpose of semi-conservative replication?

2 Complete the following table for different stages in protein synthesis.

Name of the molecule	Where does the activity take place?	What is the name of the process?
	Cytoplasm	
		Protein synthesis

Apply

3 Here is a template sequence of DNA nucleotides.

ATA TTG GGC GCC AAG ACT

a How would this be transcribed as mRNA?
b Use Table 1.1 to determine the sequence of amino acids in the resulting protein.

4 Here is a sequence of amino acids, which is part of a protein.

Leu – Pro – Asn – Asp – Arg

a Suggest an mRNA sequence from which this polymer may have been translated.
b How many different mRNA sequences would give the same sequence?

Analyse

5 Answer the questions using the DNA sequence:

ATG GTC GTA ATA CCG TAC GTA GTA ATT

a What is the mRNA strand?
b What is the amino acid chain that is produced?
c Imagine that one mistake in one base occurred when transcribing the DNA strand to mRNA; for example, CGG instead of CAG.
i How does the mistake change the mRNA strand?
ii What would the new amino acid chain be?
iii What effect would this have on the protein created?

Reflect

6 Do appearances matter? How has this section contributed to your understanding of what you look like? You could record your understandings using a mind map.

Working with genes

How is DNA, and hence genes, passed on from one generation to another? Why do your cells contain genes from your parents? The answer involves a process called meiosis. In meiosis, cells are divided into sex cells or gametes. In humans, this creates the sperm in men and ova in women. Meiosis enables the DNA stored in the nucleus of sperm or ova to be passed on to new generations.

Chromosome stories

If cells were to attempt to divide, with 3 m of one DNA molecule floating in the nucleus, a tangled mess would need to be sorted out. To work around this, the DNA is tightly coiled with proteins to form chromosomes (Figure 1.9 on page 12). In humans, chromosomes organise the DNA information into 46 packages, or 23 pairs of packages. Twenty-two of these pairs are known as autosomes; the remaining pair determines the organism's sex and are known as the sex chromosomes.

glossary terms

autosome
a chromosome that does not determine sex (in humans, pairs 1–22)

chromosome
a densely coiled structure that holds the DNA ready for cell division

gamete
a sex cell – sperm in males and ova in females

meiosis
a type of cell division that halves the number of chromosomes, necessary to produce four haploid sex cells

sex chromosomes
chromosomes (X and Y) that determine the sex of an organism

ISBN 9780170189071

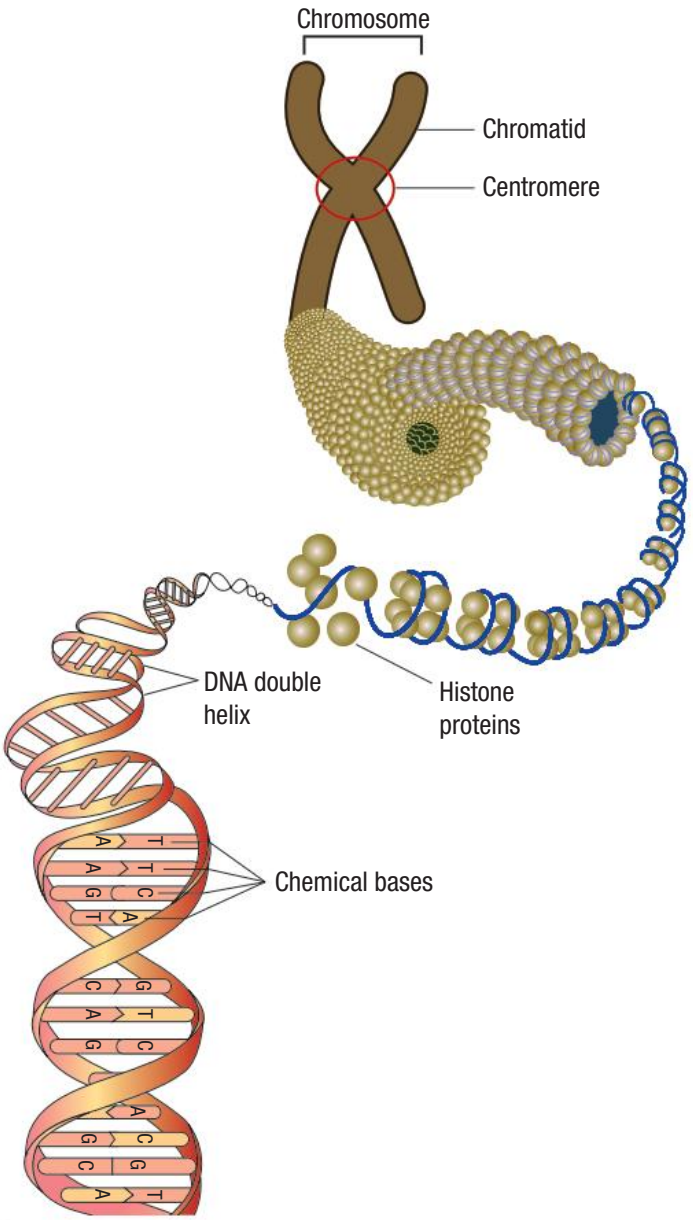


Figure 1.9 DNA is wound tightly around histone proteins to form chromosomes.

ACTIVITY SHEET
Looking at chromosomes
SCI10SIAS00009

WEBLINK
How DNA is packaged

The process of meiosis produces gametes with half the total number of chromosomes – they only have one copy of each chromosome pair in the cell. This is called the haploid (*n*) number. So when two gametes – the sperm and ovum – come together at fertilisation, the total complement of chromosomes for the organism is restored. This is called the diploid (2*n*) number.

It was Belgian embryologist Edouard Van Beneden (1846–1910) who determined that all sex cells had half the number of chromosomes compared with all other cells in the body. He counted exactly eight chromosomes in the body cells of horse roundworm but found only four in its gametes.

Each species, plant and animal, has a different number of chromosomes in their body cells. Table 1.2 shows the different haploid and diploid numbers of some species.

Table 1.2 Chromosome numbers in several species

Species	Chromosome number	
	Body cells (diploid, 2*n*)	Sex cells (haploid, *n*)
Black rhinoceros (*Diceros bicornis*)	84	42
Dog (*Canis lupus familiaris*)	78	39
European sea urchin (*Echinus esculentus*)	38	19
Garden pea (*Pisum sativum*)	14	7
Human (*Homo sapiens*)	46	23
Plains lubber grasshopper (*Brachystola magna*)	24	12
Fire salamander (*Salamandra salamandra*)	24	12

ISBN 9780170189071

WOW!

Adder's tongue

A small, insignificant herb, Adder's tongue (*Ophioglossum reticulatum*), has 1262 chromosomes in each body cell. This is the highest known chromosome count for any living species.

Figure 1.10 Adder's tongue has 1262 chromosomes in each body cell.

Creating sex cells: meiosis

We know that cells have special structures called chromosomes. We know that chromosomes are made up of genes. We also know that genes are lengths of DNA that code for a particular protein. We can now look at how these genes get into gametes to then be passed on to the next generation.

In multicellular organisms, meiosis occurs in the gonads (in humans, these are the ovaries of females and testes of males).

In body cells, or somatic cells, each pair of chromosomes consists of a maternal and a paternal chromosome: the first inherited from the mother and the second from the father. These pairs are called homologous chromosomes.

Meiosis is the division of a cell nucleus and it has two stages: meiosis I and meiosis II. Each stage consists of a number of phases (Figure 1.11 on page 14). Meiosis I includes two crucial events. First, crossing-over (during prophase I) swaps sections of DNA between homologous chromosomes and results in four unique chromatids (Figure 1.13 on page 16). Second, homologous chromosomes are separated (during anaphase I). It is preceded by interphase. Meiosis II divides the sister chromatids of the haploid cells.

Interphase

Most of a cell's life takes place in interphase. During interphase, the cell must replicate the DNA so that it has an extra copy of each chromosome. This replication occurs in the same way as described on page 7. The replicated DNA is now joined together at the centromere (Figure 1.12 on page 15). Each vertical half of the chromosome is known as a chromatid.

Meiosis I: shuffling and mixing DN

Prophase I

During prophase I, a new structure called a spindle starts to form. This is a network of thin protein fibres that stretches across the cell, attaches to the centromere and is used to move chromosomes. The spindle moves the homologous structures towards one another and later moves them to the equator. This is when crossing-over occurs, resulting in

glossary terms

centromere
the part of a chromosome that joins sister chromatids and where the spindle fibres attach

chromatid
each vertical strand of a chromosome

crossing-over
an exchange of genetic material in maternal and paternal homologues

diploid (2*n*)
the total number of chromosomes in a body cell

equator
the centre of a cell where the chromosomes line up during metaphase and anaphase

gonad
an organ that produces sex cells; in humans, ovaries in females and testes in males

haploid (*n*)
a cell with half the number of chromosomes (one from each pair); a sex cell

homologous
relating to a pair of chromosomes with matching genes

interphase
the period in which a cell is not dividing, and the cytoplasm is active

maternal
coming from the mother

paternal
coming from the father

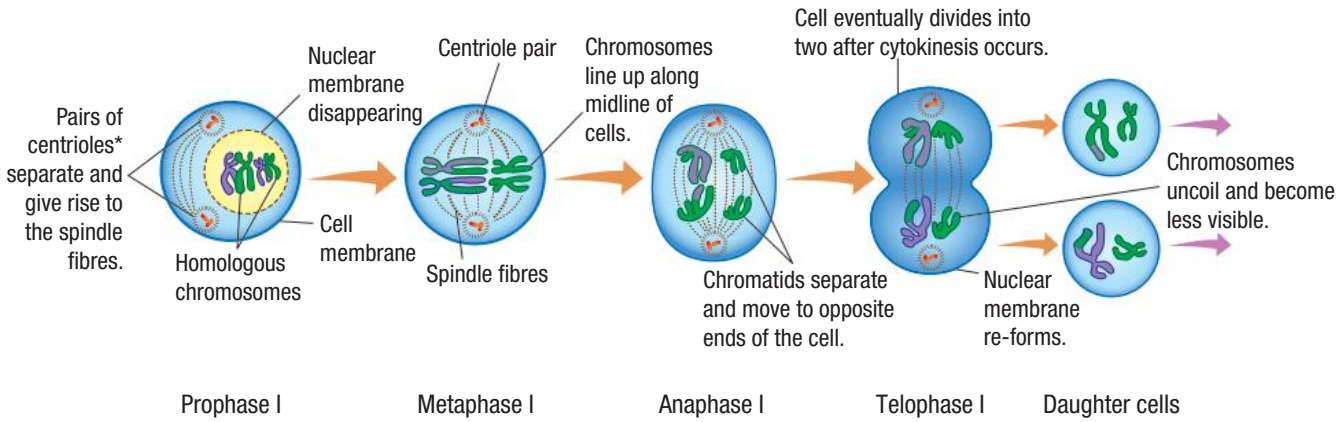
prophase
the first stage of cell division

somatic cell
a body cell (not gamete) that contains a diploid number of chromosomes

spindle (fibres)
protein fibres in the cytoplasm that attach to the centromere and control chromosome movement

ISBN 9780170189071

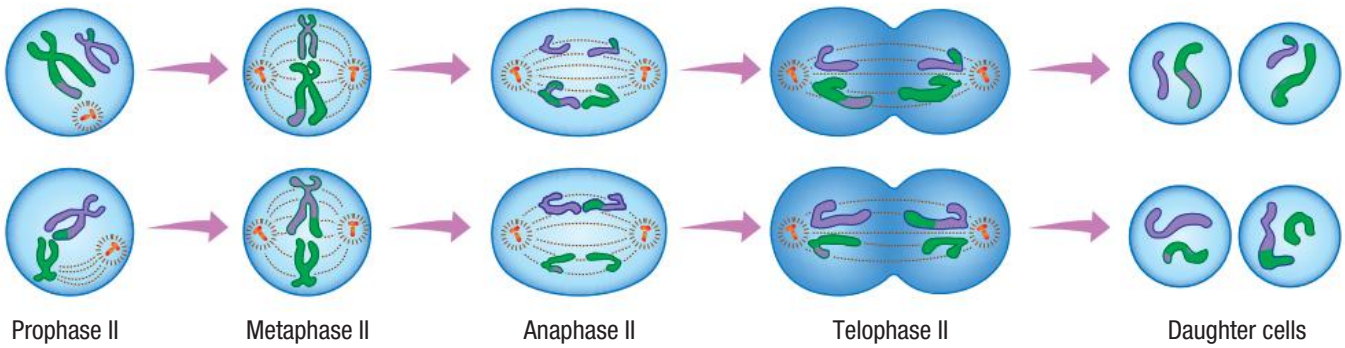
MEIOSIS I



Prophase 1	Metaphase 1	Anaphase 1	Telophase 1	Daughter cells
• Chromosomes coil and become visible. • Nuclear membrane disappears. • Spindle forms and attaches to the centromere. • Homologous chromosomes move towards one another. • Crossing-over occurs.	• Homologous chromosomes align in the middle of the cell.	• Homologous chromosomes move apart. The side to which the maternal and paternal chromosomes go is random. • Note that, in each chromosome, sister chromatids are still attached.	• One chromosome of each pair reaches the opposite poles of the cell. • In some organisms the nuclear membrane may re-form, and the chromosomes become less visible.	• The two daughter cells are haploid. • Note that each sister chromatid is unique.

*Centrioles are minute rod-like structures that form the poles of the spindle.

MEIOSIS II



Prophase II	Metaphase II	Anaphase II	Telophase II	Daughter cells
• Chromosomes condense. • Spindle forms and attaches to the centromere. • Nuclear membrane disappears.	• Chromosomes align in the middle of the cell.	• Sister chromatids separate at the centromere and move to opposite poles of the cell.	• Chromatids reach the opposite poles of the cell. • Cytokinesis begins.	• After the second division there are four genetically unique daughter cells.

Figure 1.11 The stages of meiosis

a unique combination of DNA information in the four sister chromatids (Figure 1.13 on page 16). Most homologues will cross over at least once. This is an important source of variation in sexually reproducing organisms.

Metaphase I

During metaphase I, the homologues line up along the equator of the cell in their pairs. The spindle fibres are still attached to the centromere of each chromosome. The homologues are arranged so that they face opposite sides of the cell.

Anaphase I

During anaphase I, the spindle fibres contract and pull one chromosome of each homologous pair to either pole of the cell. Each pole receives a mixture of maternal and paternal chromosomes. It is this division that actually halves the number of chromosomes.

ISBN 9780170189071

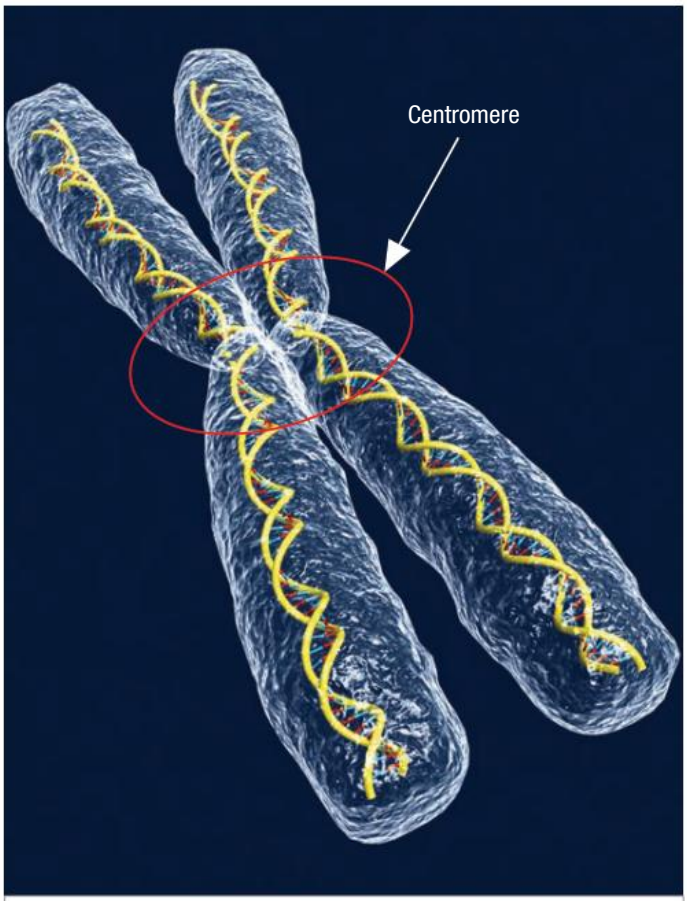


Figure 1.12 A model of a replicated chromosome. The section where the two sister chromatids join is called the centromere.

Telophase I

During telophase I, nuclear membranes may form and cytokinesis occurs. Cytokinesis is the pinching of the cell membrane and the separation of organelles into the two cells.

Meiosis II: separating sister chromatids

The two cells formed during meiosis I contain one chromosome from each homologous pair. Meiosis II is when each chromosome splits at the centromere, forming two chromatids that move into separate cells.

Prophase II

During prophase II, the chromosomes are still condensed following the first division, but they start moving towards the centre of the cell.

Metaphase II

During metaphase II, the chromosomes line up with the spindle fibres attached to the centromere joining the sister chromatids.

Anaphase II

During anaphase II, the spindle fibres contract and the chromatids are separated at the centromere and dragged to either pole of each cell.

Telophase II

During telophase II, the nucleus re-forms and cytokinesis occurs, now creating four haploid sex cells. Each cell contains different combinations of genes.

This overall process and order of the phases can be remembered by a simple acronym: IPMAT PMAT.

WEBLINK
Meiosis

Activity 1.4
Meiosis

1 Visually represent the overall process of meiosis. You might like to do this using either a flowchart or a morphing diagram, or creating a comic or animation.

2 Develop a way to remember this process.

WEB 2.0

Upload your work to the class wiki. Have a look at what others in your class have as suggestions for remembering. Which of these do you like and why? Record your thoughts on your blog.

glossary terms

anaphase
the stage in which homologous chromosomes or sister chromatids are separated and pulled to either pole of the cell

cytokinesis
the process of dividing a cell in two, at the end of the division of DNA

homologue
a pair of chromosomes with matching genes

metaphase
the stage of cell division when the chromosomes are arranged around the equator of the cell

organelle
a small structure inside the cell that helps maintain its function

pole
the top or bottom end of a dividing cell

sister chromatids
two identical chromosomes joined together, after the chromosome has replicated and before it divides

telophase
the final stage of cell division, just before cytokinesis

ISBN 9780170189071

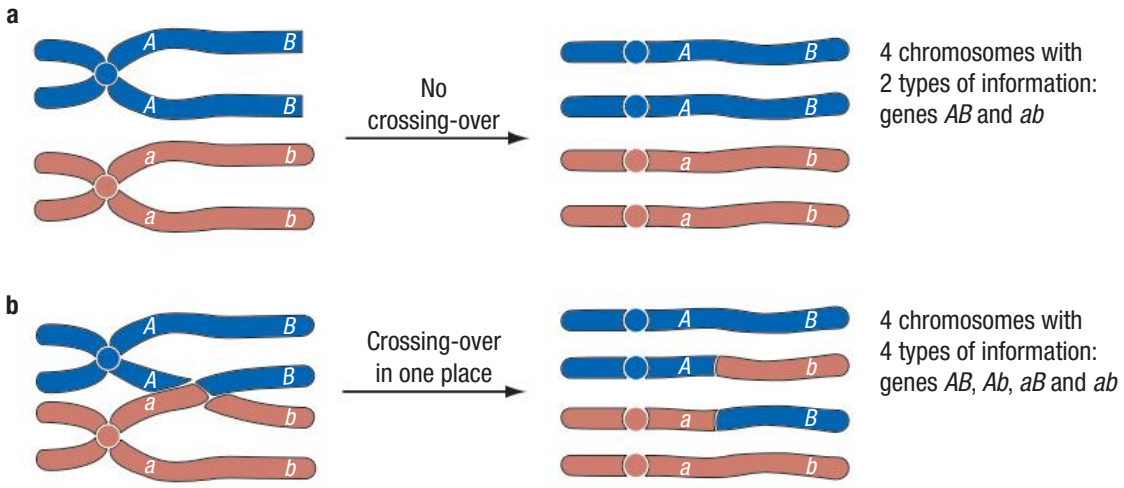


Figure 1.13 A schematic diagram explaining why crossing-over during prophase I results in four unique chromatids.

Chromosome facts

German evolutionary biologist August Weismann (1834–1914) showed that halving the number of chromosomes into the sex cells needed two cell divisions, and produced four sex cells from one parent cell. He called the process meiosis (the Greek word *meiosis* means 'reduction'). German zoologist Oscar Hertwig (1849–1922) used the transparent eggs of sea urchins to see how the genetic material inside two sex cells combined to restore chromosome numbers when the eggs were fertilised.

WEBLINK
Fertilisation in sea urchins

A different take on hotting things up?

In some reptilian species, sex is determined by environmental temperature. In some turtle species, cooler temperatures during a critical stage of egg development will produce all male offspring. Warmer nest conditions will produce all female offspring. In crocodiles, low and high temperatures result in female offspring, whereas intermediate temperatures result in males. What effect will global warming have on the number of males and females in these species?

ACTIVITY SHEET
Sex as a game of 'chance'
SCI10SIAS00010

Sex determination

In many organisms, the sex chromosomes control the sex of the organism. For example, humans and grasshoppers each have a system in which females have two identical sex chromosomes (XX) and males have two differently sized ones (XY). American geneticist Walter Sutton (1877–1916) was a biology research student at the University of Kansas between 1897 and 1901. His research led him to the discovery that grasshopper chromosomes nearly always came in pairs. However, male grasshoppers appeared to have one large extra chromosome. Sutton thought this chromosome was responsible for the organism's gender because it would go into only half the sperm. It was Sutton's work on grasshoppers that explained that the male determined the sex of the offspring. This is because after meiosis, there will be an X or a Y chromosome in each of the sperm. A female is XX, so the ovum can only contain an X chromosome.

Vanishing Y chromosomes

Human females have two copies of X chromosomes, each with about 1100 genes; however, males have only one X chromosome, as well as a Y chromosome that carries fewer than 200 genes. These surviving Y chromosome genes are vital for 'maleness', such as controlling sperm formation.

Damaged Y chromosome genes cannot be repaired. As the Y chromosome gradually disappears, other genes on non-sex chromosomes start to contribute to 'maleness'. This then becomes the first step towards the development of new sex chromosomes.

ISBN 9780170189071

CONNECTION
English: Values and issues
SCI10SHCN00011

When fertilisation occurs, what happens next?

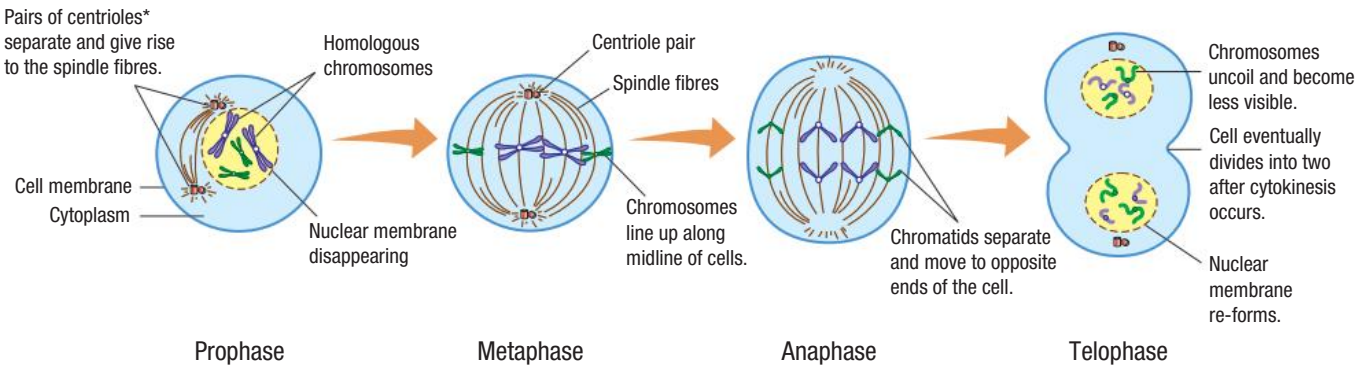
Humans carry out sexual reproduction. At the moment of fertilisation the haploid sperm and ovum fuse, pairing 23 chromosomes from the father and 23 chromosomes from the mother. There are now 46 chromosomes in the new cell or zygote. This zygote grows and divides by the process of mitosis. Two identical daughter cells result. Each daughter cell has the same number and type of chromosomes as the initial cell (also called the parent cell).

ACTIVITY SHEET
Modelling mitosis
SCI10SIAS00012

WOW!

Did you know?

German biologist Walther Flemming (1843–1905) stained cells taken from the gills of a salamander, an amphibian related to the Mexican walking fish or axolotl. In the nuclei of these dividing cells, he saw thread-like structures he called chromosomes (from the Greek word *chroma*, meaning 'colour'). The chromosomes divided lengthwise and separated equally between the two daughter cells. Flemming named this process mitosis (the Greek *mitos* means 'thread'), and showed how the cell nuclei of the two daughter cells would be exact copies of the original nucleus (Figure 1.14).



*Centrioles are minute rod-like structures that form the poles of the spindle.

Prophase (Greek *pro* meaning 'beginning')	Metaphase (Greek *meta* meaning 'after')	Anaphase	Telophase (Greek *telos* meaning 'end')
• Chromosomes coil and become shorter and visible. • The nuclear membrane disappears. • A network of spindle fibres forms. • Spindle fibres attach to the centromere of each chromosome.	• Chromosomes are positioned around the equator, forming a circle.	• The spindle fibres contract towards the poles of the cell. • The centromeres divide – the chromosomes are now two sister chromatids. • Sister chromatids move apart.	• The chromosomes reach the opposite poles of the cell. • The nuclear membrane re-forms, and the chromosomes become less visible. • Cytokinesis begins – animal cells 'pinch in' and plant cells grow new cell membranes and cell walls between the two nuclei.

Figure 1.14 The stages of mitosis were first described in detail by Walther Flemming in 1882. By the end of this cell division, the two daughter cells have the same number of chromosomes as the original parent cell.

glossary terms

mitosis
a type of cell division that reproduces the DNA information exactly; it is used in body cells

zygote
the diploid cell produced by the fusion of a sperm and ovum

ISBN 9780170189071

Questions 1.3

What have you learnt?

WORKSPACE

What have you learnt? 1.3

SCI10SUWR00013

Understand

1 Where are the genes located in a cell?

2 Where did the chromosomes in our own cells come from?

3 A kangaroo has 12 paired chromosomes.
- **a** What is the diploid number of chromosomes?
- **b** How many autosomes are in each cell?
- **c** If this kangaroo is male, how many sex chromosomes are in each sperm?
- **d** What number is *n* in a kangaroo?

4 A platypus has 52 chromosomes.
- **a** How many chromosomes came from its mother?
- **b** What is the diploid number?
- **c** How many homologous pairs are present?
- **d** If a platypus cell reproduced by mitosis, how many chromosomes would be in the daughter cells?

Apply

5 A man and a woman plan to have a family.
- **a** What is the probability their first child will be a son?
- **b** What is the probability their second child will be a son?
- **c** What is the probability they will have a daughter, a son and then another daughter?
- **d** If they have two children, what is the probability they will be a boy and a girl?

6 The diploid number of a rabbit is 44.
- **a** When one of its body cells undergoes mitosis, how many chromosomes will be present in each of its daughter cells?
- **b** What will be the genetic difference, if any, between these daughter cells?
- **c** State the number of chromosomes that will be present in the sperm of a male rabbit.
- **d** Explain why the sperm must have this number of chromosomes.
- **e** Will all the sperm of a particular rabbit be identical in their genetic make-up? Explain.

Analyse

7 Figure 1.15 shows a cell that is dividing. Suggest what type of division it is and what is happening. Describe your evidence for this.

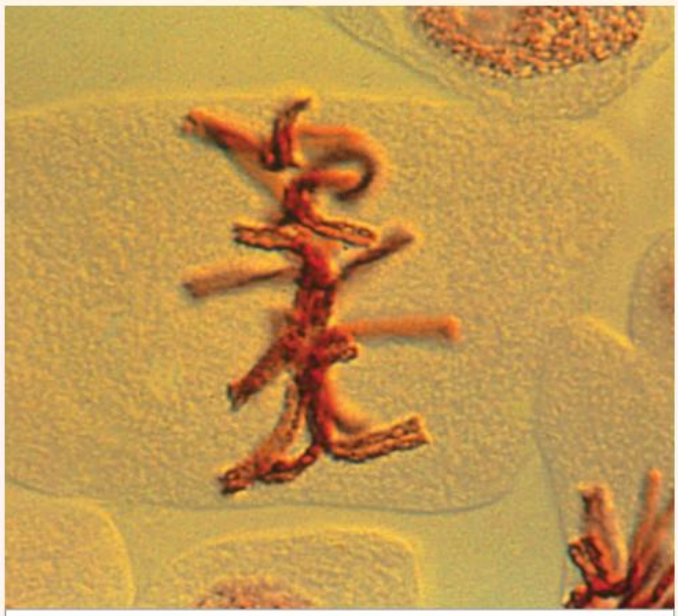


Figure 1.15 A dividing cell

8 Compare the two types of cell division by completing the table below.

	Mitosis	Meiosis
a What happens to the number of chromosomes?		
b How many cell divisions are involved?		
c How many daughter cells are produced?		
d What is the purpose of this kind of division?		

Reflect

Identical twins are created when the newly formed zygote splits in two.

9 Why do identical twins look alike?

10 Explain whether it is possible to have identical twins that are a boy and a girl.

11 In ancient Egypt, royal siblings sometimes reproduced. What are some possible genetic consequences of this?

ISBN 9780170189071

Sexual reproduction: a source of variation

Activity 1.5
PMI: sexual reproduction

WORKSPACE
PMI: sexual reproduction
SCI10SUWR00014

Complete a PMI for sexual reproduction for a species.

Meiosis shuffles and rearranges genes. The fertilisation of cells from two parents further shuffles genes. Together, both produce variation that shows up in the offspring and contributes to the biodiversity that we see on Earth. Some of these offspring are likely to have gene combinations that result in them being less well adapted than their parents to the current environment. For example, they may be smaller or larger, slower or faster growing or more sensitive to disease. Other offspring may have gene combinations that give them an advantage. For a species, this diversity is essential because some individuals may be able to survive if the environment changes.

Figure 1.16 Offspring in the same litter can display a large range of genetic variation.

ACTIVITY SHEET
Hypotheses for the origins of sex
SCI10SIAS00016

Activity 1.6
Variable offspring – 'If ... then' statements

WORKSPACE
Variable offspring – 'If ... then' statements
SCI10SIWR00015

1 Working in a group, brainstorm at least five ideas for each of the following 'If … then' statements.
   - If only poorly adapted organisms were produced, then …
   - If only well-adapted organisms were produced, then ...

2 Using your brainstormed points for the 'If ... then' statements, justify or refute the following statement: 'Variation in offspring is vital for the survival of a species.'

Mutation: another source of variation

Mistakes or mutations can happen during the processes of protein synthesis, mitosis and meiosis. Mutations are an important source of variation within a species. There are many kinds of mutations. Some are 'silent' and do not produce a noticeable effect in the organism. For example, when a nucleotide is replaced in DNA, the amino acid that it translates to remains unchanged.

Sometimes mutations have no effect on the organism, but would not be considered silent. For example, the brown 'age spots' on the skin of elderly people are caused by mutations in skin cells undergoing mitosis. They are not life-threatening and so persist. Occasionally mutations are very harmful. Changes to amino acid order can impede or stop cell function. Damage to the cell division processes can cause tumours and cancer.

Mutations can also occur during the lifetime of an organism through a variety of environmental factors. Exposure to excessive ultraviolet (UV) rays can cause mutations in dividing skin cells. Exposure to cigarette smoke, which contains harmful chemicals, can cause mutations in dividing lung cells. Excessive exposure to X-rays can also result in mutations.

glossary term

mutation
a change in the cell DNA code or chromosome number

ISBN 9780170189071

WEBLINK
Inside cancer

WEBLINK
Gene mutation

Questions 1.4
What have you learnt?

WORKSPACE
What have you learnt? 1.4
SCI10SUWR00017

Understand

1 What is a mutation?

2 During what processes could mutations occur?

3 What are some of the changes that can result because of mutations in DNA?

4 Why are some mutations 'silent'?

5 What are some factors that can increase the rate of mutations?

Apply

6 The answer is 'mutation'. What are 10 possible questions? List these on your blog.

Reflect

7 Do appearances matter? How has this section contributed to your understanding of what you look like? Add any new information to your mind map.

Mendel: the father of genetics

Our understanding of genetics increased dramatically in the 20th century, once the structure of DNA was discovered. We can now use this knowledge to predict the likelihood of an individual passing on certain inherited conditions to the next generation. The path for this understanding was first laid in the 19th century by Austrian Augustinian monk Gregor Mendel (1822–1884).

WOW!

The Habsburg chin

The imperial House of Habsburg is nearly as well known for its chin as its important political connections across Europe over six centuries. Famous Habsburgs include Queen Marie-Antoinette (1755–1793), who died during the French revolution, and Spain's King Charles II (1661–1700), whose prominent jaw prevented him from chewing.

Figure 1.17 The Habsburg chin: **a** Queen Marie-Antoinette and **b** King Charles II

ISBN 9780170189071

Mendel was trained in physics and mathematics, first at the University of Olmütz from 1840 and then at the University of Vienna from 1850. While other natural scientists were investigating biodiversity by describing variations of species, Mendel looked for numerical patterns when performing breeding experiments with a species of self-fertilising garden peas, *Pisum sativum* (Figure 1.18). He noticed in some plants that certain varieties with the same characteristics appeared generation after generation. Mendel considered these plants to be pure-breeding.

Figure 1.18 Mendel used *Pisum sativum* for his experiments.

Mendel pondered what would happen if two different pure-breeding varieties of peas were crossed. For example, what would happen if a round-seeded pea plant was crossed with a wrinkled-seeded pea plant? Mendel was able to control plant crosses. He removed the anthers of unopened flowers of a round-seeded pure-breeding plant and brushed its pollen onto the stigma of a wrinkled-seeded pure-breeding plant. These first two plants became known as the parental generation (P).

VIDEO

Mendel's experiments on inheritance

SCI10SUVD00018

In these experiments Mendel observed that the resulting offspring plants, or first filial (F_1) generation, always resembled only one of the parent plants – they had round seeds. He therefore called this feature the dominant trait.

However, when the F_1 plants self-fertilised, the next generation, or second filial (F_2) generation, always had some plants resembling the dominant parent (round seeds) and some resembling the non-dominant parent (wrinkled seeds). Mendel inferred the non-dominant trait must have been carried, but hidden, within the F_1 generation plants. He called this a recessive trait.

Mendel investigated seven pea plant features in P, F_1 and thousands of F_2 plants. Table 1.3 on page 22 looks at some of his original data.

Activity 1.7

Mendel's results

Use the data from Table 1.3 to answer these questions.

1 Why did Mendel cross so many plants in the F_1 generation?

2 Using the F_2 results, calculate the ratio of each pair of features (round your results to the nearest whole number). What do you notice?

Mendel recognised that each F_2 plant showed the P features in an approximate 3:1 ratio (see column 4 of Table 1.3 on page 22). This is now known as the Mendelian ratio. From his results, Mendel concluded that the information for traits was carried in pairs. Only half of the information was passed on from each parent; fertilisation combined the halves back into a pair, just as described on page 17. The appearance of the offspring depended only on the information that was paired together. These are amazing conclusions since Mendel had no knowledge of the structure of DNA, the process of meiosis or fertilisation.

glossary terms

dominant trait
a trait that masks the other trait of a pair, if present

first filial (F_1) generation
the generation that results after breeding parent organisms

Mendelian ratio
the 3:1 pattern of the second filial (F_2) generation

parental generation (P)
the parents

pure-breeding
relating to offspring of every generation who are the same for a particular trait; this indicates the organism is homozygous

recessive
a trait that is only visible if no dominant trait is present

second filial (F_2) generation
the generation produced from breeding the first filial (F_1) generation

ISBN 9780170189071

Table 1.3 Mendel's original data from his experiments on pea plants

Feature	P Original parental characteristics	F_1 The dominant trait revealed, and number of plants crossed	F_2 Number of plants showing each parental trait
1 Form of ripe seeds	Round	Round	5474 round
	Wrinkled	60 fertilisations on 15 plants	1850 wrinkled
2 Colour of the seed	Yellow/orange	Yellow/orange colour	6022 yellow/orange
	Bright green	58 fertilisations on 10 plants	2001 bright green
3 Colour of the seed coat	Brown	Brown	705 brown
	White	35 fertilisations on 10 plants	224 white
4 Form of the ripe pods	Inflated	Inflated	882 inflated
	Constricted	40 fertilisations on 10 plants	299 constricted
5 Colour of the unripe pods	Dark green	Dark green	428 dark green
	Yellow	23 fertilisations on 5 plants	152 yellow
6 Position of the flowers	Along stem	Along the stem	651 along stem
	Top of stem	34 fertilisations on 10 plants	207 top of stem
7 Length of the stem	Tall	Tall (even taller than parent)	787 tall
	Short	37 fertilisations on 10 plants	277 short

With your understanding of chromosomes, genes and meiosis, you can see how Mendel's logical thinking was correct. For every gene (such as the one controlling seed shape) on one chromosome, there is a corresponding gene on the homologous chromosome. However, as Mendel discovered with his pea plant experiments, there are alternative forms of these genes (such as round or wrinkled seeds) called alleles. This means there is the dominant form and the recessive form.

Mendel predicted and confirmed that the F_2 plants showing the dominant trait were not all the same. He suggested that some of the F_2 plants expressing the dominant trait had two forms of the same allele on the homologous chromosomes – that is, they had the allele for roundness on each chromosome. He named these types of plants homozygous, and they produce sex cells that all carry the same type of allele. He then suggested that the other two-thirds of the F_2 plants expressing the dominant trait would be carrying two alternative forms of the gene: one dominant allele (roundness) on one chromosome and one recessive allele (wrinkled) on the other. He named these types of plants heterozygous, and they produce sex cells that carry either the dominant trait or the recessive trait. Finally, he determined that plants that express the recessive trait (wrinkled) only produce offspring with the recessive trait. Mendel concluded that in order for a recessive trait to be expressed, the individual requires two copies of the recessive allele. As the alleles are the same, these plants are also homozygous.

ISBN 9780170189071

Activity 1.8
Careers with plants and flowers

Today, many careers that involve plants and flowers use genetics. List five possible careers. Select one from your list. Create an xtranormal that explains the career, the science involved, where people in this field work and anything else of interest. Provide a weblink that people can go to get more information about this career.

WEBLINK
Xtranormal

WEB 2.0

Upload the weblink to your xtranormal to the class wiki.

CONNECTION
Maths: Chance
SCI10SICN00019

Explaining and predicting the Mendelian ratio

The set of rules Mendel devised to explain his observations are still used. They are:

1. Genes can come in a variety of forms. For example, different forms of a gene for flower colour can cause red or white. Different forms of a gene for length of stem can cause long or short stems.
2. Different forms of the same gene are called alleles. Alleles occur in pairs – that is, one allele occurs on the maternal chromosome and the other occurs on the paternal chromosome in a homologous pair.
3. Alleles that provide dominant features are given a capital letter. The allele for round seeds is dominant and hence is given the letter *R*. Pure-breeding (homozygous) peas that carry the allele for round seeds on both chromosomes will be represented as *RR*. This means that on each chromatid in the homologous pair the *R* allele occurs. In these plants, gametes will contain only one chromatid with the *R* allele.
4. Alleles that provide the recessive feature are given the same letter but in lower case. The allele for wrinkled seeds is recessive and hence is given the letter *r*. Pure-breeding (homozygous) peas with wrinkled seeds will be represented as *rr*. In these plants, gametes will contain only one chromatid with the *r* allele.

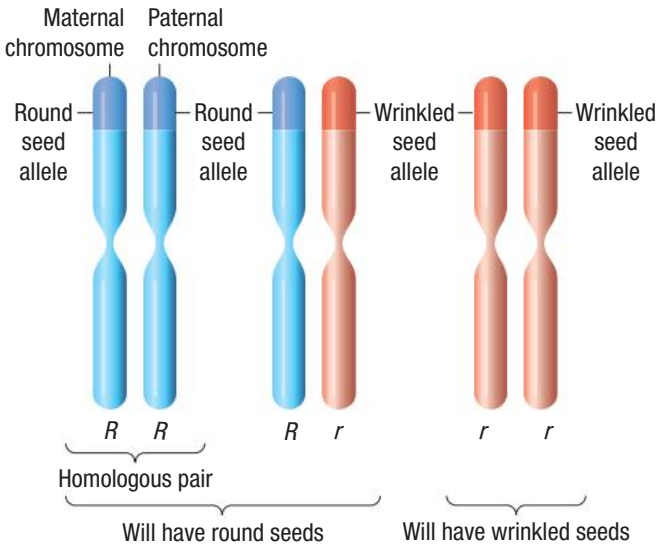


Figure 1.19 How Mendel's ideas match our knowledge of modern genetics – three possible combinations for the seed shape gene.

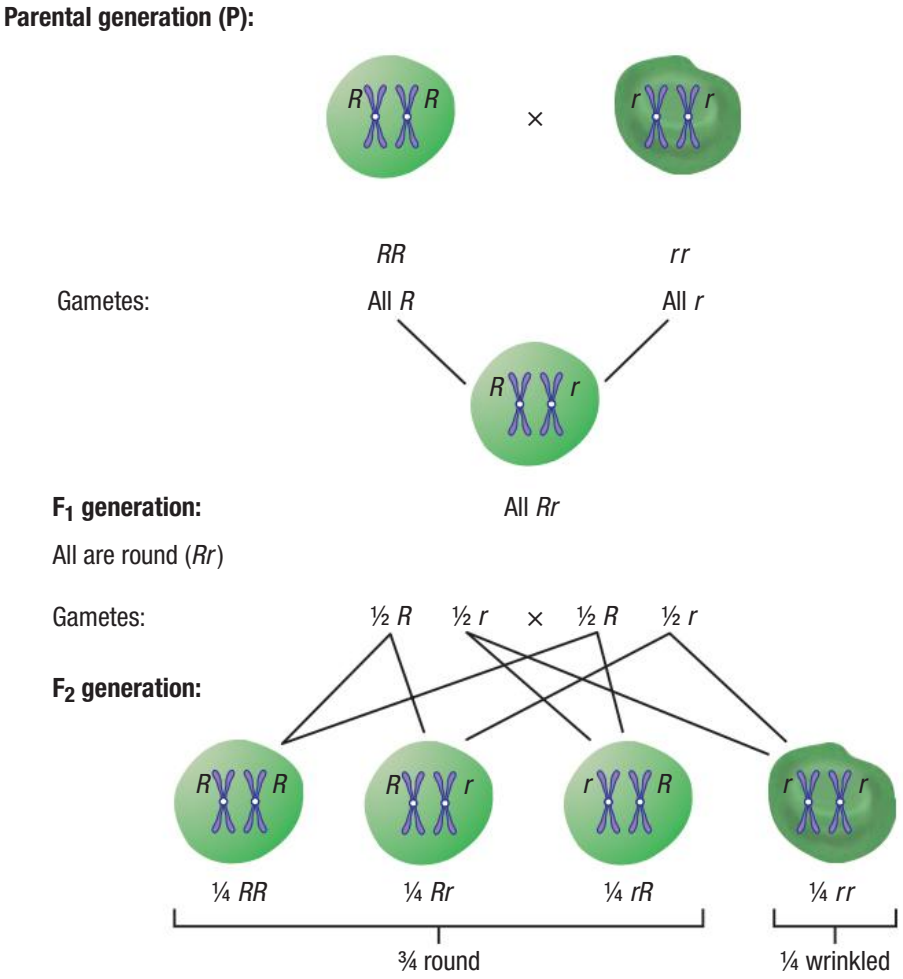
5. Fertilisation combines two gametes. By convention, the capital letter for the dominant feature is shown first. Therefore, if the homozygous parents *RR* and *rr* were crossed, all F_1 plants will be heterozygous *Rr*. These plants have round seeds because they have the dominant trait *R*.
6. F_1 plants can produce gametes containing *R* or *r*. Crossing F_1 plants produces F_2 plants in approximately equal numbers (see page 24). These can be:
   - *RR* homozygous
   - *Rr*, *rR* heterozygous
   - (all these have round seeds, generally expressed as *R_*)
   - *rr* homozygous for wrinkled seeds.

glossary terms

allele
an alternative form of a particular gene
heterozygous
when an individual has two different forms of a gene, such as *Rr*
homozygous
when an individual has two identical versions of a gene, such as *RR* or *rr*

ISBN 9780170189071

Crossing the F_1 generation



¾ are round (*RR* or *Rr*) and ¼ are wrinkled (*rr*) or ¾ : ¼ or 3 : 1

Figure 1.20 Crossing F_1 pure-breeding round- and wrinkled-seeded plants results in a 3:1 ratio in the F_2.

From crossing the F_1 to produce the F_2 you can see:

- The proportion of plants with round seeds to the total is ¾ or 75%.
- The proportion of plants with round seeds that will be pure-breeding (*RR*) is ¼ or 25%.
- The proportion of plants with round seeds that will be heterozygous (*Rr*) is ½ or 50%.
- The proportion of plants with wrinkled seeds (*rr*) compared with the total is ¼ or 25%.

This information can also be expressed in terms of the genetic appearance, the genotype, and the physical appearance, the phenotype. The genotypic ratio in this case is the ratio of *RR*:*Rr*:*rr* or 1:2:1; the phenotypic ratio of round seeds:wrinkled seeds is 3:1.

ACTIVITY SHEET
The Mendelian ratio
SCI10SIAS00020

The Punnett square

English geneticist Reginald Punnett (1875–1967), shown in Figure 1.21 on page 25, is best known for his creation of the Punnett square. This allows geneticists to easily predict the probability of offspring characteristics of a genetic cross between two parents.

ISBN 9780170189071

Figure 1.21 Reginald Punnett devised what is known as the Punnett square for summarising the fusion of gametes in genetic crosses. His work helped to confirm and extend Mendel's ideas.

For example, consider one of Mendel's pure-breeding plants with the characteristic for seed colour. The parents are homozygous for each trait and, according to Table 1.3 on page 22, yellow/orange seed colour is dominant. Denote the dominant trait with *Y* and the bright-green recessive seed colour with *y*. Therefore the parents of this cross will be:

$$YY \times yy$$

During meiosis the chromosomes containing these alleles are split into gametes. One parent will produce only gametes containing the *Y* allele. The other parent will produce only gametes containing the *y* allele. If we show this as a Punnett square, we get the following.

		Male gametes
		All *Y*
Female gametes	**All *y***	All *Yy*

The possible F_1 genotypes are shown in the blue square. All of the F_1 will be *Yy*.

If we then cross the F_1 generation, we can predict the probability of obtaining a plant with bright-green seeds in the F_2. We can use a Punnett square to predict the outcome. Therefore, the cross of the F_1 is:

$$Yy \times Yy$$

Each parent can produce two types of gametes: half the gametes will contain Y and the other half will contain *y*.

Using the Punnett square, divide the gametes from both parents and predict the probability of getting a plant expressing the recessive allele.

		Male parent	
		$\frac{1}{2}Y$	**$\frac{1}{2}y$**
Female parent	**$\frac{1}{2}Y$**	$\frac{1}{4}YY$	$\frac{1}{4}Yy$
	$\frac{1}{2}y$	$\frac{1}{4}Yy$	$\frac{1}{4}yy$

We can see from the above Punnett square that there is a one-in-four, or 25%, chance that the cross between *Yy* and *Yy* will produce a plant with bright-green seeds or *yy*. What is the probability that they would produce a plant with yellow/orange seeds?

ACTIVITY SHEET
Punnett squares
SCI10SIAS00021

CONNECTION
English: Dissecting scientific language
SCI10SHCN00022

VIDEO
Punnett squares
SCI10SIVD00023

glossary terms

genotype
the pair of alleles controlling a trait, such as *Rr*

phenotype
a trait that is physically visible, such as round seeds

Punnett square
a table that is used to determine the probability of offspring characteristics of a genetic cross between two parents

ISBN 9780170189071

Questions 1.5

What have you learnt?

WORKSPACE

What have you learnt? 1.5

SCI10SUWR00024

Understand

1 Define the following terms.
   - **a** Allele
   - **b** Homozygous
   - **c** Heterozygous
   - **d** Pure-breeding
   - **e** Phenotype
   - **f** Genotype

2 Name three dominant traits that Mendel investigated. Explain how he determined whether a trait was dominant or recessive.

3 Who is Reginald Punnett and what is his contribution to genetics?

Apply

4 The widow's peak (a hairline shape) dominates over the recessive form: a straight hair line. A woman who is homozygous for widow's peak has a child with a heterozygous father. What is the probability that the child will carry the recessive allele?

5 The neurodegenerative condition Huntington's disease has an onset at around the age of 40. It is an autosomal dominant condition.
   - **a** What does the term 'autosomal dominant condition' refer to?
   - **b** If a heterozygous individual had a child with an unaffected individual, use a Punnett square to determine the probability that the child will inherit Huntington's.

6 Extension: The gene for hair curliness has two alleles: *C* and *c*. Explain how two parents with wavy hair (*Cc*) are able to have children with three different genotypes.

Analyse

7 Why did Mendel only look at one trait at a time in his experiments?

8 Extension: The four alleles in rabbit coat colour have a range of dominance relationships. The order of dominance, from most to least, is:
   - agouti (C^+): brown- and black-flecked fur
   - chinchilla (c^{ch}): silver- and grey-flecked fur
   - Himalayan (c^h): the cooler extremities like ears and feet have dark fur
   - albino (c): completely lack pigment and even have red eyes.

   a Suggest phenotypes for rabbits with the following genotypes.
      - **i** C^+c
      - **ii** C^+C^+
      - **iii** c^hc
      - **iv** $c^{ch}c$

   b List all the genotypes possible for rabbits with the following phenotypes.
      - **i** Agouti
      - **ii** Chinchilla
      - **iii** Himalayan
      - **iv** Albino

Reflect

9 The genes for the seven traits investigated by Mendel occur on six of the seven *Pisum sativum* chromosomes. The two genes that occur on the same chromosome are physically a long way apart. How might Mendel's results have been different if all the genes existed on the same chromosome?

10 How has this section contributed to your understanding of what you look like? Add any new information to your mind map.

ISBN 9780170189071

How genes influence one another

As discussed earlier on page 22, dominant and recessive traits are caused by different alleles of the same gene. Some genes are identical in all organisms in a species. These often control important cellular and physiological processes. As only one allele exists for these genes, all of us are homozygous for these traits. Other genes can be very variable, with several alleles. For example, rabbits have four alleles for coat colour: agouti, chinchilla, Himalayan and albino. No matter how many alleles exist, no individual organism can have more than two of these alleles because each gene has a physical location on a chromosome, and chromosomes come in pairs.

WOW!

Blue people!

Methaemoglobinaemia is a rare genetic condition caused by a recessive allele. People who express the condition have an enzyme deficiency that increases the amount of the blood protein methaemoglobin. Instead of being bright red, their oxygenated blood is brown. Light-skinned people with the condition look noticeably blue!

Fortunately, a dye you may have used for staining cells can cure this condition in minutes. As methylene blue is transfused into the blood, it reacts with the faulty proteins and the skin turns a healthy pink.

Sex-linkage

In mammals, males carry an X and a Y chromosome. X and Y chromosomes carry different genes; therefore, the genes on the X and Y chromosomes do not match, as in homologous pairs (Figure 1.22). Genes carried on either the X or Y chromosome are known as sex-linked (sometimes referred to as 'X-linked' or 'Y-linked'). If a recessive gene is carried on the X or Y chromosome in males, it will be expressed in the phenotype. This is not the case in female mammals because they will carry two alleles for a trait, one of which may be recessive. Sex-linkage should be suspected whenever a trait is found only in one sex.

A range of sex-linked conditions run through families, such as red–green colour blindness and haemophilia. Both of these conditions are recessive; however,

Figure 1.22 The X and Y chromosomes in humans are different sizes and carry different genes.

because they are linked to the X chromosome, they are expressed differently in girls and boys. As girls have two X chromosomes, they require two recessive alleles to express the condition. If they carry one dominant allele and one recessive allele, they will not express the condition. They are known as a carrier as they are able to pass the condition on to the next generation. In males, they only have one X chromosome, so they only require one recessive allele to express the condition. There is no corresponding allele on the Y chromosome. Thus sex-linked recessive disorders are more common in men than in women.

ACTIVITY SHEET

Australian cattle dogs – a genetic case study

SCI10SUAS00025

glossary terms

carrier
a heterozygous individual who carries the recessive allele

sex-linked
relating to a gene found on one of the sex chromosomes

ISBN 9780170189071

Pedigrees: another way to visualise inheritance

Pedigrees are charts that organise information within a family and represent the family tree using conventional symbols. They are an excellent way to determine either the mode of inheritance of certain genetic conditions, or the genotype of particular individuals.

Symbols

There are a few standard symbols that we need to know to be able to construct a pedigree. Some of the more common symbols are shown in Figure 1.23.

Looking at Figure 1.24 on page 29, we can tell there are three generations in the pedigree. This is shown by the Roman numerals on the left-hand side. Each individual is labelled from left to right; this is shown by the number given to each individual. This pedigree shows that the grandparents (I1 and I2) had four children: two girls (II2 and II3), a boy (II5) and another girl (II7). The eldest daughter married individual II1, the second daughter married individual II4 and the son married individual II6. Together, these three couples had nine children in the third generation (III1–9).

The condition shown in the pedigree in Figure 1.24 – that is, albinism – skips a generation. No individuals in generation II show the condition. From this we can assume that the mode of inheritance is recessive. As albinism affects the males and females in similar frequency, we can also assume the gene is not carried on the X chromosome. Therefore, it is carried on an autosomal chromosome and is recessive. It is therefore known as an autosomal recessive condition.

The genotype of each individual can also be determined. We can use the letter *A* to represent an individual with melanin (the dominant condition) and *a* to represent an individual with albinism (the recessive condition). Individual II2 mates with an individual heterozygous for this condition (II1) and produces an albino son (III2). This means that individual II1 must be heterozygous. Individuals III1 and 3 can be either homozygous dominant or heterozygous – there is no way of telling which. Their genotypes are written as *A*_ as the missing allele could be *A* or *a*.

ACTIVITY SHEET
Pedigrees
SCI10SIAS00026

ANIMATION
Pedigrees
SCI10SUAN00027

VIDEO
Inheritance
SCI10SUVD00028

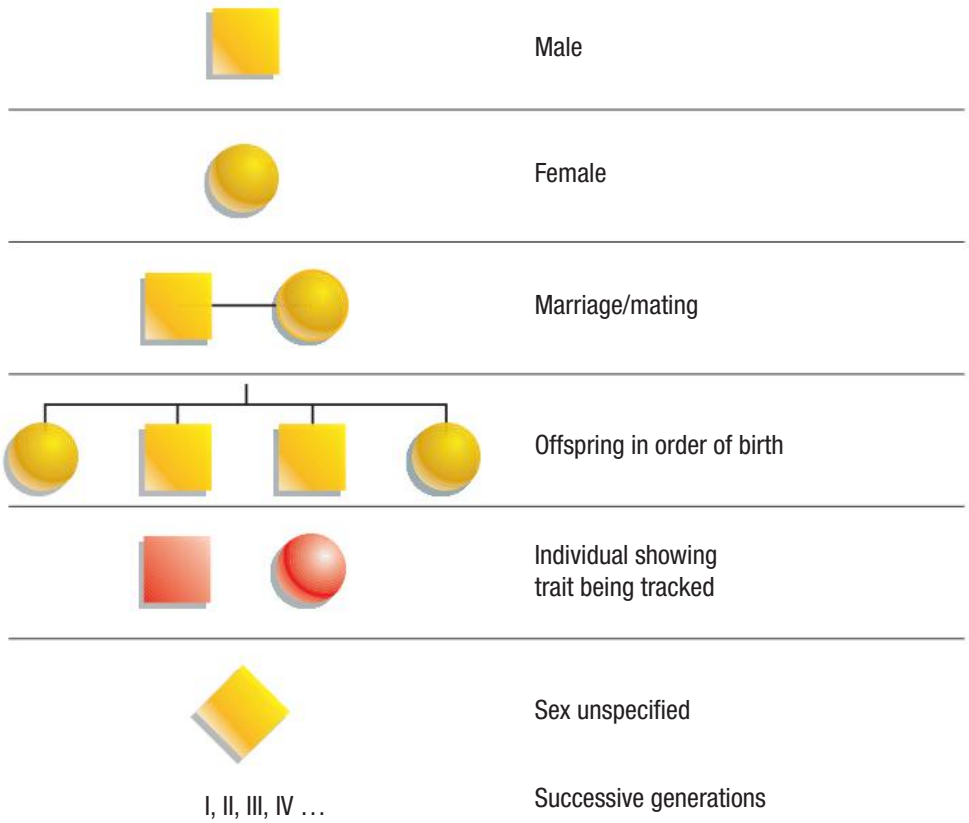


Figure 1.23 Symbols used in creating pedigrees

ISBN 9780170189071

A = normal melanin (pigment) produced
a = albinism (melanin production blocked)

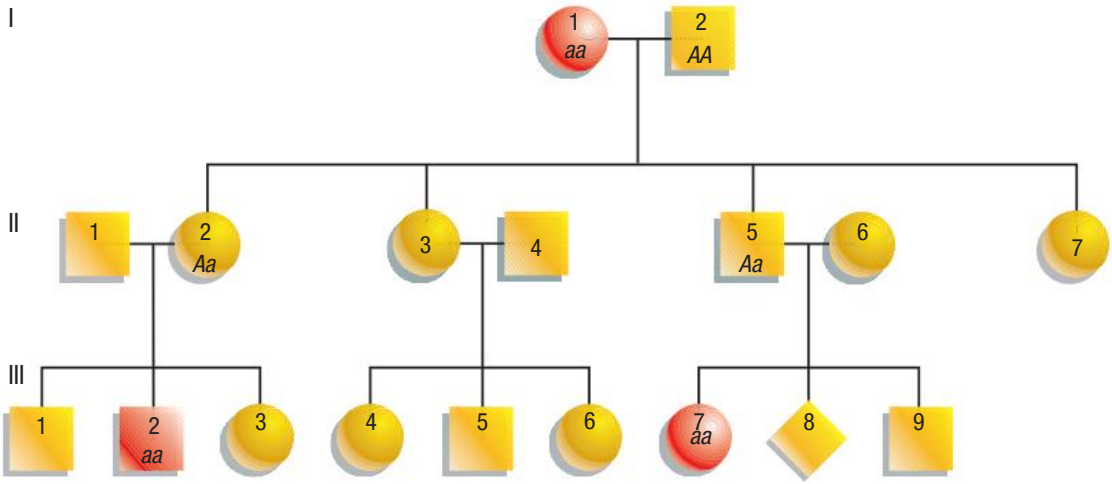


Figure 1.24 A family pedigree for albinism

Karyograms: a snapshot of chromosomal health

The number and appearance of chromosomes in a species is called its karyotype (see Figure 1.26 on page 30 for an example). To determine the karyotype accurately, images of homologous pairs are listed from largest to smallest; the sex chromosomes are shown last. This arrangement is called a karyogram.

Very rarely chromosomes do not separate correctly during meiosis. In humans, children born with chromosomal abnormalities usually have a characteristic set of traits, which is known medically as a syndrome. For example, small chins, round faces, a single crease across their palms and below-average cognitive ability typically occur together in people born with an additional copy of chromosome 21, which is called trisomy 21 or Down syndrome (Figure 1.25). A karyogram (Figure 1.26 on page 30) confirming Down syndrome will alert doctors to other treatable but less obvious symptoms, such as heart disease.

Sometimes karyograms reveal other types of chromosomal abnormalities. Females have two X chromosomes. Sometimes, an X chromosome is absent and the karyogram reveals that the individual has 22 pairs of chromosomes, plus a single X chromosome. This is

Figure 1.25 A person with Down syndrome has distinct features.

glossary terms

karyotype
the chromosome set typical for a species

karyogram
an arrangement of homologous chromosomes in order of size

pedigree
a chart showing family relationships over several generations

trisomy
an extra copy of one chromosome

ISBN 9780170189071

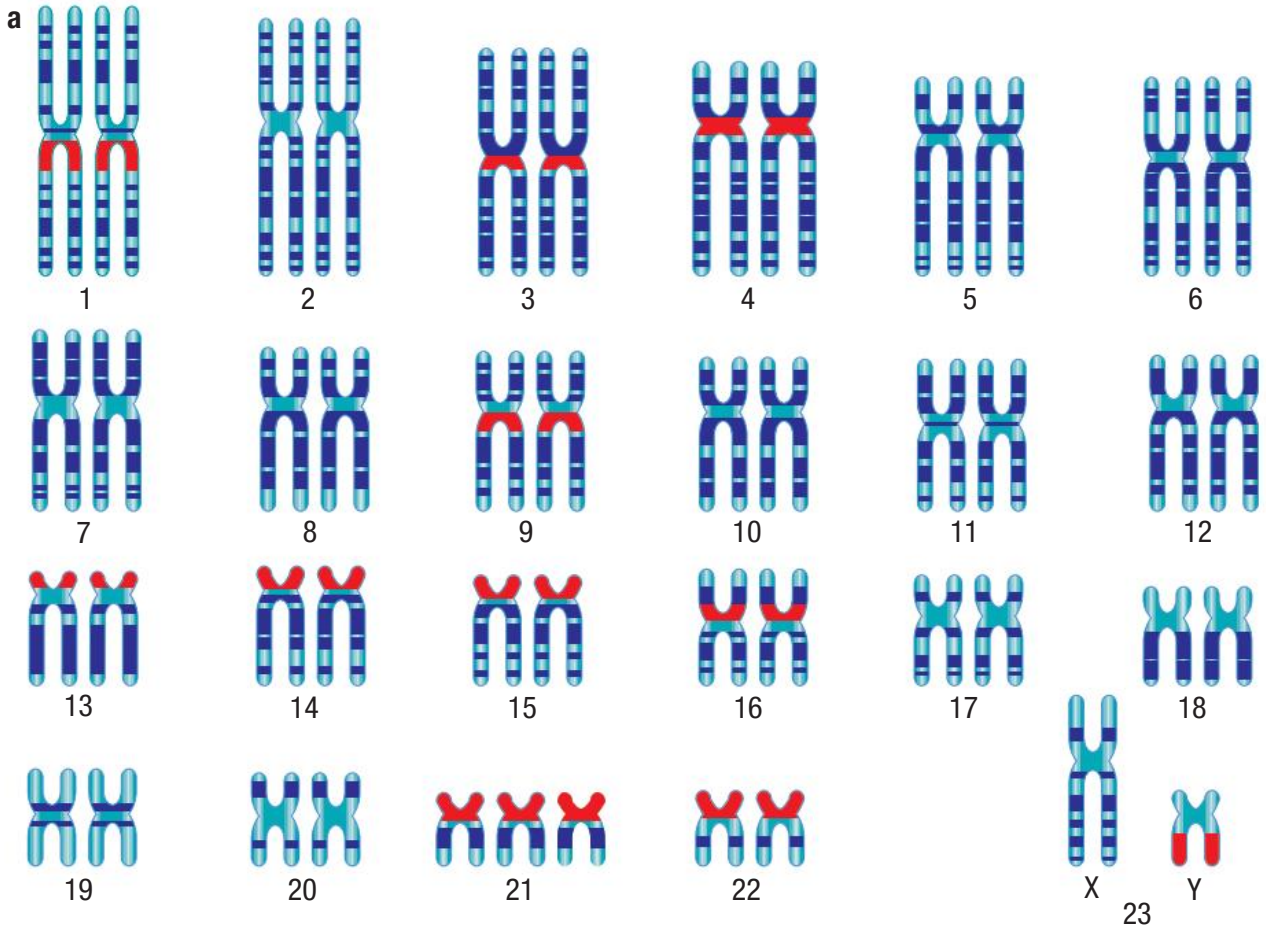


Figure 1.26 A karyogram with trisomy 21

known as Turner syndrome, a condition that occurs in 1 in 2000 females. The syndrome manifests itself in short stature, low hairline, low-set ears, wide and webbed necks and infertility.

Males normally have an X and a Y chromosome. Sometimes, an extra X chromosome is present and the karyogram reveals that the individual has 22 pairs of chromosomes, plus XXY. This abnormality occurs in 1 in 1000 boys and results in long legs compared with a short body trunk and infertility. It is known as Klinefelter syndrome, whose characteristics can be treated with testosterone therapy. Sometimes males with Down syndrome can also have Klinefelter syndrome.

It is also possible for some males to have 23 pairs of chromosomes, plus an extra Y chromosome (that is, XYY). These 'super males' are usually tall, slender and poorly coordinated. Most go on to lead normal lives – many do not even know they have a chromosomal abnormality.

INTERACTIVE

Cell division and DNA: assessment

SCI10SUIN00001

ACTIVITY SHEET

Karyogram

SCI10SIAS00029

Activity 1.9

Science career – genetics

Research a career that is involved in genetics, genetics counselling or genetic engineering.

1 Write five interesting facts about your chosen career.

2 Where are five places that a person with this career might work?

WEB 2.0

Upload what you discover about this career to your blog and the class wiki.

ISBN 9780170189071

Genetic research

Humans have been manipulating chromosomes for thousands of years by selectively breeding domestic plants and animals. For example, modern wheat originates from the natural hybridisation of several grass species to a wild crop grown around 9000 BCE in the western Asian area of the Fertile Crescent and the Nile Delta in northern Egypt (Figure 1.27). From here it spread to Africa, Europe and Asia. Wheat is now a major food worldwide.

With our improved understanding of DNA, genetics and inheritance, we are able to manipulate genes for our own purposes. We can take genes from one species and insert them into the DNA of another species. This is called genetic engineering.

Activity 1.10
GM foods

Watch the video and then answer the questions that follow.

VIDEO
Genetically modified crops
SCI10SHVD00030

1 What are three reasons why foods are genetically modified?
2 From where do scientists get the genes to insert into other organisms?
3 Is it wrong to interfere with nature? What do you think?
4 How is genetic modification different from conventional breeding through hybridisation and selection?

Figure 1.27 **a** Wild wheat and **b** modern wheat

glossary term

genetic engineering
the technique of manipulating the genetic make-up of an organism

ISBN 9780170189071

The Human Genome Project

The Human Genome Project (HGP) was an international scientific project whose objective was to map the bases of the entire human genome and hence the sequence of genes on each chromosome. It was started in 1990 and completed in 2003, two years earlier than anticipated. Initially funded by the US government's Department of Energy and the National Institutes of Health, additional funding was later received from the governments of, for example, Britain, France, Japan, Australia and New Zealand. A core objective was to share the information freely online, and therefore stimulate and support medical research for all, because the genetic code belonged to everyone.

Publicly or privately funded: which strategy yields the best results?

The US$3 billion Human Genome Project was an international effort funded by 18 governments. At the same time, a privately funded parallel project by the Celera Corporation cost about US$300 million and completed the task first!

However, Craig Venter's company Celera had the benefit of being able to access existing public data and used a different strategy to break down the information into smaller manageable sections. Initially, the company also refused to share its information openly.

Ultimately, which strategy do you consider better?

Activity 1.11
Human Genome Project

Watch the video 'Human Genome Project'. Answer the questions that follow.

VIDEO
Human Genome Project
SCI10SHVD00031

1 How can the data from the HGP be used to benefit humans?

2 What disadvantages might there be in releasing the results of the HGP to everyone?

3 Ellie applies to an insurance company to buy a life insurance policy. The company consults the results of her genetic testing and sees that she has a gene for a disease that could shorten her life. They refuse to sell her the policy. This scenario could easily arise in the future, when commercial companies have access to our genetic data. What are the ethical issues raised by this scenario? What are your thoughts?

4 It is possible to patent genes. More than one-quarter of the genes in the human genome now have patents on them. These patents give exclusive rights to a particular company to work with this DNA sequence for a defined period of time. For example, the mutated gene sequences that control breast and ovarian cancer are patented to an American company.

a What is your opinion about private companies owning the rights to genes (or gene sequences)? Give reasons for your answer.

b Breast cancer gene sequences are patented by biomedical company X. List the benefits of this ownership to company X. List the benefits of this ownership to sufferers of breast cancer.

c Suggest any limitations that the private ownership of genes may have on scientific advancements.

ISBN 9780170189071

Questions 1.6

What have you learnt?

WORKSPACE

What have you learnt? 1.6

SCI10SUWR00032

Understand

1 When Mendel crossed tall (*TT*) and short (*tt*) pea plants, he found the plants in the next generation were marginally taller than the *TT* plants. Is this an example of dominant or recessive inheritance, or could it be due to something else?

2 What is sex-linkage?

3 What information can be collected from a pedigree?

4 Fill in the table with the correct symbol.

Symbol	Meaning
	Unaffected male
	Affected female
	Marriage
	Individual of unknown gender
	Generation

Apply

5 Use the pedigree symbols to create a pedigree of a recessive allele (*a*) being passed through three generations of a family. Write a paragraph that describes what is happening in your pedigree.

Analyse

6 Figure 1.28 on page 34 shows a child's karyogram. What information does it provide?

7 Using the pedigree in Figure 1.29 on page 34, answer the following questions.

- **a** Who are the affected individuals?
- **b** Is the condition dominant or recessive? Provide evidence to justify your answer.
- **c** Is the condition autosomal or sex-linked? Provide evidence to justify your answer.
- **d** Write the genotypes for all of the individuals in the pedigree.
- **e** What pattern do you notice between all affected males and their daughters?
- **f** What do you notice about the numbers of affected males and females in this pedigree? Why might the frequency of the condition be higher in one sex than the other?

Reflect

8 Every baby born in an Australian hospital is blood tested for serious genetic disease in case it needs medical treatment urgently. Justify or refute this statement: 'This droplet of blood should also be used to set up a national genetic database.'

9 How has this section contributed to your understanding of what you look like? Add any new information to your mind map.

glossary terms

genome
the total genetic information within an organism or species

patent
a legal right permitting an inventor to exclude others from making, using or selling an invention for a defined period of time

ISBN 9780170189071

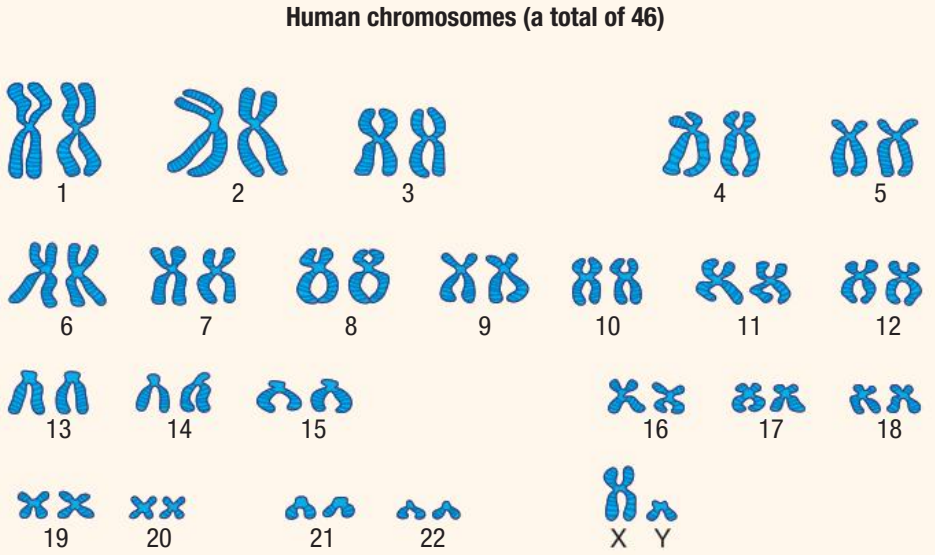


Figure 1.28 A child's karyogram

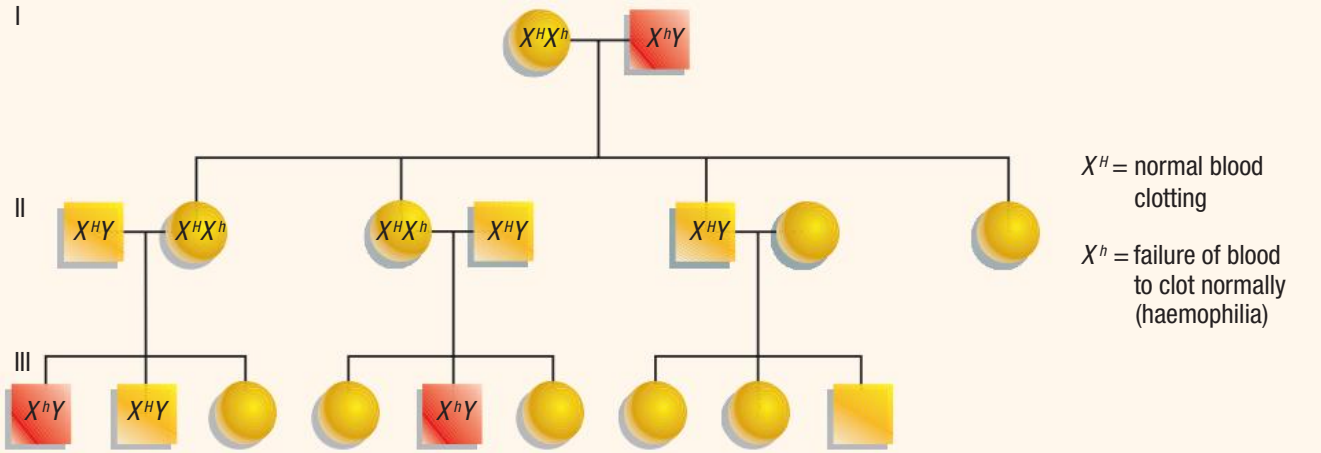


Figure 1.29 A family pedigree

ISBN 9780170189071

Unit review

ACTIVITY SHEET
Unit 1 checklist
SCI10SUAS00034

REVIEW QUIZ
Unit 1
SCI10SURQ00033

WORKSPACE
Unit 1 review
SCI10SUWR00035

Understand

1 Choose 10 words from the glossary terms and create a concept map to show how the concepts are connected.

2 The choice of experimental organisms can make a difference to a scientist's results. What was the advantage of using each of the following?

a Garden peas (*Pisum sativum*)

b European sea urchin (*Echinus esculentus*)

3 Explain the difference between transcription and translation.

4 Draw a schematic diagram of a DNA molecule.

5 Explain the relationship between the following terms: DNA, nucleotide, base, gene, chromosome.

6 Explain the difference between anaphase I and anaphase II.

7 What would the phenotypic ratio be in the F_1 generation if two heterozygous round-seeded plants were crossed?

Apply

8 Some humans can have an extra copy of one chromosome. For example, individuals with Down syndrome have an extra copy of chromosome 21. Some plants can have an extra copy, or two extra copies, of the whole chromosome set. This can produce larger fruits. The haploid number of a strawberry is $n = 28$. What would the diploid ($2n$) and triploid ($3n$) numbers be?

9 **a** Construct a pedigree to show the following information.

- Two parents (I) had 5 children: 2 sons and 3 daughters born in that order.
- The eldest son (II) married a woman who suffered from the recessive condition of sickle-cell anaemia. They had 3 children, all girls.
- The eldest daughter (II) married a man with whom she had 2 children: a son and then a daughter.
- The youngest daughter (II) married a man, but they did not produce any children.

b **i** If the eldest son (II) was not a carrier of the recessive sickle-cell allele, what is the chance that a fourth child for this couple would suffer from sickle-cell anaemia?

ii How many of the children of this couple would be carriers of the sickle-cell anaemia allele? What would their genotype for this gene be?

iii One daughter of this couple married a man who suffered from sickle-cell anaemia. Use a Punnett square to show the probability that their firstborn would also suffer from this disease.

10 When two different species interbreed, their offspring is called a hybrid. A mule is a hybrid resulting from breeding a female horse ($2n = 64$) and a male donkey ($2n = 62$). A hinny is the hybrid made resulting from a male horse and a female donkey.

a Suggest why horse–donkey hybrids are usually infertile. (Hint: Have a look at what happens in meiosis at metaphase I.)

b Mules are the preferred hybrid as they are usually larger than hinnies. Why would mules and hinnies be different?

ISBN 9780170189071

Analyse

11 Sex-linked genetic diseases are much more common in males than in females.

- **a** Suggest an explanation for this.
- **b** Explain whether this is an advantage for an individual organism.
- **c** Use a plus/delta chart to outline the advantages and disadvantages of this.

12 Some species have a mixture of diploid and haploid phenotypes. For example, in some social species of bees and termites, the only individuals in the colony that reproduce are the diploid 'queens' and a small number of haploid 'drones'.

- **a** How might this reproductive mechanism be genetically advantageous to these species?
- **b** In bees, diploid females can be queens or workers, depending on their diet as developing larvae. How can the difference in phenotype be explained?

13 A yellow rat and a black rat mate and produce 12 offspring in the first mating and 9 in the second mating. Of these 21 offspring, 16 are yellow and 5 are black. From this information, determine the genotype of the parents. Explain your logic.

Reflect

14 An objective of genetic engineering is to create crops with larger yields, larger fruits and pest resistance. There are many arguments for and against genetically modifying plants and animals. Go to your blog to provide your opinion on whether scientists should be allowed to modify organisms.

15 Reflect on how your mind map has changed to the unit question 'Do appearances matter?' Record these on your blog.

Self-reflection

16 What are your personal opinions about the genetic engineering of plants and humans? In what ways are your opinions the same or different between plants and humans? Record these on your blog.

17 Compete the following statements.

- **a** When completing this unit I found ... to be the most difficult.
- **b** Things that helped me to learn were ...
- **c** Things that hindered my learning were ...
- **d** This is how I will apply my learning to other things ...

ISBN 9780170189071

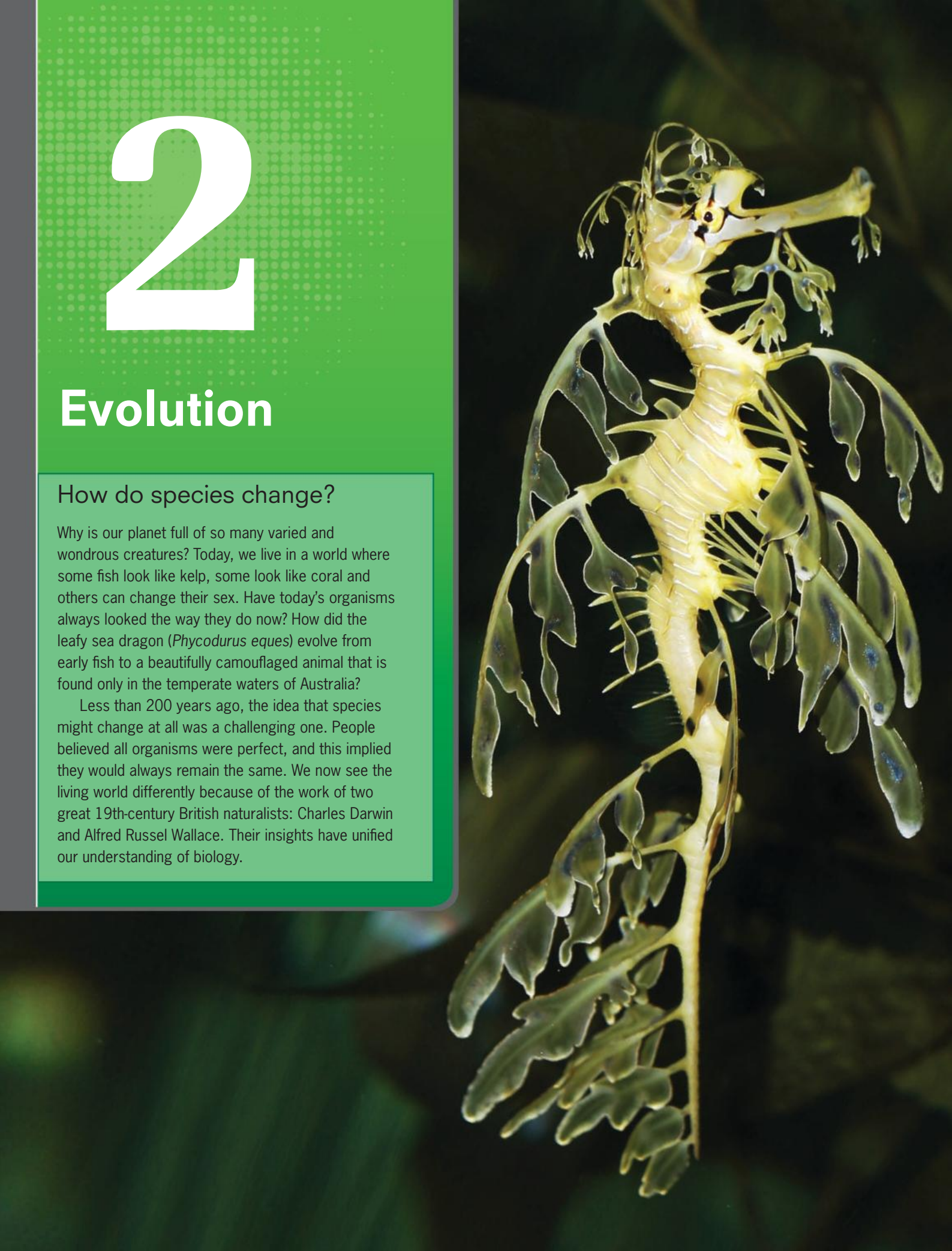
2

Evolution

How do species change?

Why is our planet full of so many varied and wondrous creatures? Today, we live in a world where some fish look like kelp, some look like coral and others can change their sex. Have today's organisms always looked the way they do now? How did the leafy sea dragon (*Phycodurus eques*) evolve from early fish to a beautifully camouflaged animal that is found only in the temperate waters of Australia?

Less than 200 years ago, the idea that species might change at all was a challenging one. People believed all organisms were perfect, and this implied they would always remain the same. We now see the living world differently because of the work of two great 19th-century British naturalists: Charles Darwin and Alfred Russel Wallace. Their insights have unified our understanding of biology.



What do you already know about evolution?

In this unit you will be introduced to the processes that developed the rich biodiversity we are familiar with today. The earliest evidence of life on Earth dates from about 4 billion years ago. Organisms that were large enough to leave distinct evidence of their physical appearance emerged only during the most recent 10% of our planet's history.

In *Nelson iScience 9* you learnt about the relationships organisms have with one another and their environments, and how these can influence or respond to ecosystem change. These interactions are fundamental to understanding how change may occur in species during short time frames, perhaps decades or centuries. The activity below will help you connect your understandings to much longer time periods.

Activity 2.1
What do you already know about evolution?

Conduct a graffiti exercise in your classroom using the following questions to guide your thinking.

- What do you understand by the term 'evolution'?
- What do you understand by the term 'natural selection'?
- What is a theory? What is a fact?
- How do we know evolution is occurring?
- Why do individuals of the same species show variation? (Think about what you have learnt in Unit 1.)
- Why have some species become extinct and others have not?
- Why don't the same species of birds inhabit all the rainforests?
- Do humans share genes with cabbages?
- Is evolution happening today?
- Are new species still evolving?

Discuss the collected ideas with the class. What new questions do you have about evolution now? Write these on a separate page.

WEB 2.0

Save the graffiti pages by photographing them with a digital camera and uploading them to the class wiki. You will be revisiting these ideas at the end of the unit to see how your understanding of evolution has changed.

Culminating assessment task
A creative response to a scientific issue

Choose one 'what if' fictional scenario from the following list, or create your own. (Confirm your created scenario with your teacher before beginning on the task.)

- After reading Alfred Russel Wallace's letter outlining his theory of evolution, Darwin discusses his own theory with Charles Lyell, Joseph Hooker or Thomas Huxley.
- Darwin and Wallace correspond about how their examples support the fact that natural selection is the mechanism for evolution.
- Darwin and Gregor Mendel meet to discuss the possible genetic basis for evolution.
- Darwin gives a short outline of *On the Origin of Species* at the 1859 book launch at Hatchards bookshop in London. He fields and answers questions from the audience.

Choose your presentation format, such as a letter, story or play. If creating a performance-based response, such as a play or video, include a copy of the script. The maximum suggested length for this scenario is 1200 words.

ACTIVITY SHEET

Rubric: A creative response to a scientific issue

SCI10SUAS00037

ISBN 9780170189071

What is biodiversity?

There are many different species of living things on Earth. Scientists estimate there are 3–100 million different species; however, it is more likely to be around 9 million. Only 1.2% of these have been described, classified and named (see Unit 3, *Nelson iScience* 7).

Biodiversity describes the number of different species in a given area. Australian ecosystems are famous for their high biodiversity. For example, the Great Barrier Reef, off the coast of northern Queensland, covers an area five times the size of Tasmania. It is home to more than 1500 species of fish, 411 hard corals, 134 species of sharks and rays, 6 species of marine turtles, 30 species of marine mammals (Figure 2.1), 3000 species of molluscs, 630 species of starfish and sponges, and 215 species of birds – just to name a few. Overall, Australia holds almost 10% of the world's biodiversity. It is also home to a high number of endemic species because it has been isolated from other continents for millions of years. For instance, 80% of our mammals and vascular plants are found only in Australia.

Kakadu National Park, in the Northern Territory, and the Daintree Rainforest, in Queensland, are other areas of immense biodiversity in Australia. In comparison, Antarctica has relatively low species diversity, although the numbers of particular animal species, such as penguins, whales and krill, are high.

Figure 2.1 The dugong, a marine mammal, is one of the vulnerable species living in the Great Barrier Reef Marine Park.

Activity 2.2
Local biodiversity explored

WORKSPACE
Local biodiversity explored
SCI10SUWR00038

Complete one of the activities below.

1. Go into the schoolyard and list (or take a photo of) 10 different living things you can see. Share your list (or photos) with the rest of the class and compile a master list of your schoolyard's biodiversity.
2. Complete a five whys using the following starting question: 'Why is biodiversity important?'
3. Give five reasons for and five reasons against this statement: 'Humans need biodiversity to live.'

The problem of extinction

Extinction is the death of all members of one species. American palaeontologist Stephen Jay Gould (1941–2002) estimated that 99% of all plant and animal species that ever existed on Earth have already become extinct. We have no record of these organisms as most have left no evidence of their existence.

The fact that species became extinct was a problem, or puzzle, for 19th-century scientists since they believed that all species were perfectly formed and adapted for their environments. When fossils of animals that once existed began to be discovered, it made scientists wonder why some species disappear.

There have been five mass extinctions since life began on Earth. Today, we know that a variety of pressures can lead to species extinction. Are human actions responsible for the current rapid rate of extinction? Australia leads the world in mammal extinctions, accounting for 31% of the world total. At least 22 mammals have become extinct in Australia since European settlement in the late 1700s (Figure 2.2 on page 40).

glossary terms

biodiversity
the variety of organisms in an environment

endemic
native (to a particular location)

extinction
the death of all members of a species

palaeontologist
a scientist who studies life in the geological past, especially using fossils

ISBN 9780170189071

Figure 2.2 The extinct eastern hare wallaby *Lagorchestes leporides* was last seen in south-eastern Australia in 1890.

Questions 2.1
What have you learnt?

WORKSPACE
What have you learnt? 2.1
SCI10SUWR00039

Understand

1 Write three questions for which the answer is:
- **a** biodiversity
- **b** extinction.

Synthesise

2 Write a sentence that links the ideas of biodiversity, species and habitat together.

Evaluate

3 Justify or refute this statement: 'Australians have a responsibility to conserve their unique species.'

Reflect

4 What is your response to learning that the Great Barrier Reef is home to so many diverse species?

Evidence from the past

The 19th century was a time in which many famous scientific expeditions were conducted. On 27 December 1831, Charles Darwin (1809–1882) left England on HMS *Beagle* to explore the islands and continents of the world. During an island expedition off the coast of South America in 1835, he was struck by the differences between finches in the Galapagos Archipelago.

The Galapagos Archipelago is made up of 15 main islands, three smaller islands and a number of rocks. It is located on the Nazca tectonic plate, making it very geologically active. The most recent volcanic eruption, for example, was in April 2009.

The main islands have different environments that make them suitable habitats for a variety of species. South Seymour Island is very arid, providing a perfect environment for salt bush and prickly pear cactus. Bartholomew Island is home to penguins and green turtles. Culpepper Island has a maximum altitude of 168 m and is home to fur seals, marine iguanas, swallow-tailed gulls, sea lions, marine turtles and red-footed boobies. Hood Island has a maximum altitude of 206 m and has its own species of lava lizard, mockingbird and tortoise. Weather on the islands changes as the altitude increases. Temperature decreases with an increase in altitude, while the amount of rain increases.

The archipelago is also home to a number of different types of finches. As Darwin travelled from island to island, he noticed that the beaks of these finches varied significantly (Figure 2.3).

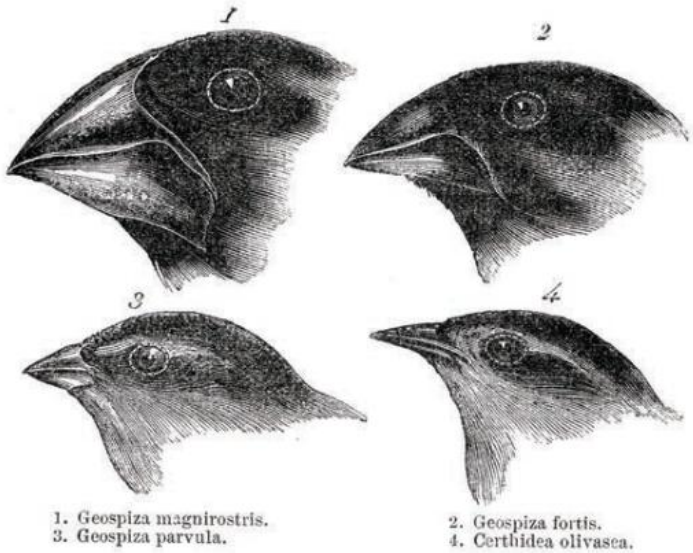


Figure 2.3 The finches of the Galapagos Archipelago

ISBN 9780170189071

Considering the environment of the islands, Darwin concluded that the beaks were adapted for eating different food types; yet the little brown birds were all so similar. He wrote in his travelogue, *Voyage of the Beagle*, that he 'fancied one species had been taken and modified for different ends'. This was the beginning of Darwin's quest to find out why so many different organisms share our planet, and whether similar species could have evolved from common ancestors. Darwin's finches were just one example that he studied to provide evidence for his developing ideas.

To demonstrate that living things can change over time and evolve into new forms, Darwin needed to look for specific types of evidence. He turned to both fossil and anatomical evidence. Darwin insisted that evidence for evolution, or change over time, was all around us if we looked for it.

Fossil evidence

The fossil record provides a very incomplete picture of life in the past. When large organisms die, they are normally dispersed or eaten by scavengers. Plant remains, such as fallen trees, are decomposed by fungi and bacteria. It is extremely rare for any nutrients to escape the recycling of matter in food webs (see Unit 3, *Nelson iScience 9*).

A fossil is any evidence of past life that could only have been made by a living organism (Figure 2.4). Examples include actual remains, traces such as footprints and even chemicals (Table 2.1 on pages 42–43). These scraps of information help palaeontologists deduce how organisms looked, moved, reproduced and ate, and also how they interacted with others that existed when they were alive.

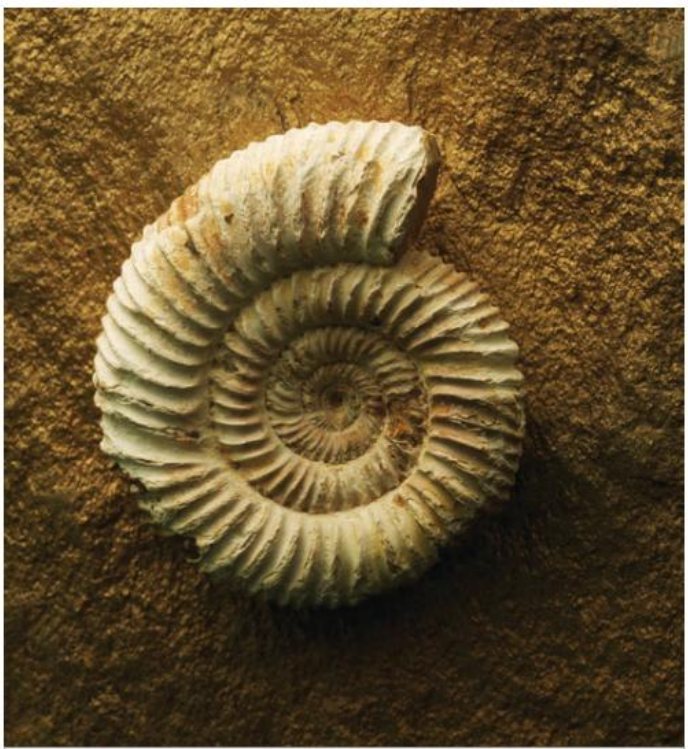


Figure 2.4 A fossilised ammonite shell. Only the hard shell has been preserved. The soft parts have rotted away.

WOW!

The Demon Duck of Doom

The largest bird that ever lived thrived in the central Australian woodlands 6 million years ago. It was long-necked, flightless, at least 3 m tall and weighed about 500 kg. Fossils of its huge beak, adapted for shearing towards the front and crushing at the back, suggest *Bullockornis stirtoni* ate flesh.

The last of the 'Demon Ducks' died 50 000 years ago. Is their memory held in Aboriginal Dreamtime stories about 'emus that ate people'?

Figure 2.5 The Demon Duck of Doom

glossary terms

evolution
any process of formation, growth, change, development or transformation

fossil
any evidence of an organism from a former geological time

fossil record
the history of life on Earth as recorded by fossils

ISBN 9780170189071

Table 2.1 Fossil stories

Type of fossil	Example of fossil type	Information provided
Body fossil – whole organism	Frozen in ice (e.g. in Siberia or Alaska): • woolly mammoths • woolly rhinoceros 	• What the actual organism looked like • Indirectly – behaviour such as movement, diet, and the times of the day it may have been active
	Trapped in amber, petrified tree resin: • invertebrates • small frogs (see Figure 2.6 on page 44) • lizards	
	Trapped in pitch (e.g. in La Brea Tar Pits in California, USA): • sabre-toothed tigers • turtles • bison • wolves 	
	Mummified in deserts and dry caves: • a duck-billed dinosaur (e.g. 'Leonardo', found in Montana, USA) • giant ground sloths (e.g. in South America)	
	Mineralised: • petrified wood • opalised fossils (e.g. 'Eric', an Australian plesiosaur) • coal balls (e.g. plant remains)	
Body fossil – parts	External skeletons: • arthropods (e.g. trilobites that shed their external skeletons as they grew)	• Appearance, particularly if it resembles existing species
	Hard parts: • shells • teeth • claws • skulls and other bones	• Diet • Relative size • Social structure (e.g. if differences between sexes are evident)

ISBN 9780170189071

Table 2.1 Fossil stories (*continued*)

Type of fossil	Example of fossil type	Information provided
Trace fossils – clues about ancient organisms	Imprints – a space that gives an indication of the size or shape of all or part of the original organism: • moulds (negative relief) of shells, and other body fossils • gnaw marks • footprints 	• External features of an organism, e.g. skin, scales and texture • Quality leaf imprints (that show density of stomata) enable atmospheric carbon dioxide concentration to be inferred • Diet, behaviour • Gait • Size of the animal • Speed at which it moved
	Casts – when material fills a mould, replacing the original organism and hardens (positive relief): • shells and other body parts	• External features of an organism, e.g. skin, scales or texture
	Carbonised fossils – when only the carbon of the original organism is left between layers of rock: • plant material • fish	• Outlines of structures, e.g. leaf veins
	Burrows, nests, eggs: • animals	• Size • Behaviour
	• Coprolites – fossilised dung • Gastroliths – stones from gizzards	• Size of the animal and its diet
	Pollen: • plants	• Type and frequency of plants • Climate
Chemofossils – compounds that could only have been made by living organisms	• Petroleum (from dead plankton, mostly algae) • Coal (from leafy plants, including ferns, cycads, horsetails) • Waxes (on leaves)	• Evidence of past climates • Evidence of first appearance of various organisms

ACTIVITY SHEET

Modelling fossilisation processes

SCI10SIAS00042

WEBLINK

How fossils are formed

glossary term

pitch

heavy oil fractions that seep to the surface of the Earth through a fault line

ISBN 9780170189071

Fossils are found only in sedimentary rock, not in igneous or metamorphic rock. The conditions for fossilisation are specific. Organisms must be buried rapidly to prevent any damage from scavengers or degradation from weathering elements, such as wind, water and temperature fluctuations. Once buried, a lack of oxygen is essential to avoid decomposition by bacteria. Examples of ideal environments include within the sediment of stagnant swamps, consistently frozen places such as polar permafrost, or acidic peat bogs. Once buried, the remains may stay undisturbed, although this is extremely rare. More commonly, the original organism will gradually be replaced by minerals.

Sometimes the space once occupied by the organism acts as a mould for a sedimentary rock cast of the organism. Sometimes the mineral replacement of the organism is very gradual and can capture internal features, occasionally even including cellular details.

Body fossils

Body fossils provide direct information about organisms. The rarest examples include whole animals (Figure 2.6) and mineral replacement fossils, which sometimes preserve details of cell structure. More commonly, however, only a few hard parts remain, such as exoskeletons and teeth. If the fossils resemble structures of living organisms, inferences can be made about diet, size and sometimes social behaviour.

Trace fossils

Trace fossils provide clues about how ancient animals lived and were often made during an animal's life. Tracks help deduce the size of an animal and the way it walked or moved. Coprolites can be used to work out the kind of diet eaten by the animal. Casts and moulds can provide good clues about the organism's coat, scales or skin texture.

Chemofossils

Coal and petroleum are fossil fuels because they are remnant chemical mixtures made from ancient swamp plants (Figure 2.7) and ocean plankton. Traces of leaf waxes and degraded cell membranes in sedimentary rocks can be compared with these chemicals in living groups of plants and cells. This comparison provides good evidence of the origins of these living groups.

Figure 2.6 Body fossils, such as this frog embedded in amber, provide direct evidence of past life.

ISBN 9780170189071

Mammoth body temperature was 38°C!

An emerging branch of palaeontology can infer an organism's body temperature by analysing the ratio of 'heavy' isotopes of carbon and oxygen present in fossil bones. Atoms of carbon-13 (^{13}C) and oxygen-18 (^{18}O) have an additional neutron, giving these isotopes extra mass. The probability of both being present in the same carbonate molecule (CO_3^{2-}) increases with temperature. The ratio of these isotopes in bone carbonate ($^{13}C^{18}O^{16}O_2^{2-}$) therefore indicates the temperature at which the carbonate first crystallised in the living organism.

By Jiminy! A cricket chart-topper!

Crickets make their distinctive song by rubbing the ridged edges of their wings together. This is called stridulating. In 2012, Chinese scientists were able to reproduce a 165-million-year-old cricket mating song made by *Archaboilus musicus* by analysing the ridge pattern on the wings of a fossilised cricket. Go to the weblink 'Fossil cricket song' to hear the song.

WEBLINK
Fossil cricket song

Figure 2.7 Fossil fuels are made from the chemicals from ancient swamp plants.

glossary terms

cast
a fossil found in sedimentary rock that fills the space once occupied by a dead organism

coprolite
fossilised dung

exoskeleton
a hard, protective, supportive outer structure, such as the shell of a mollusc or the hard outer surface of an insect or arthropod

mould
a fossil that consists of the space left by a decayed organism

ISBN 9780170189071

Activity 2.3
Australian fossil sites

WORKSPACE
Australian fossil sites
SCI10SUWR00041

Follow the links below of famous Australian fossil sites to get a picture of the ecosystems of our past. Then answer the questions that follow.

WEBLINK
Riversleigh World Heritage Fossil Site

WEBLINK
Dann's Dinosaurs

WEBLINK
Australian Museum

1 Use Google Earth to locate the Riversleigh World Heritage Fossil Site. How does this site contribute to our knowledge of Australian fauna?

2 Select one example of an extinct organism on the 'Dann's dinosaurs' website. Comment on how the actual fossil remains compare with the reconstructions. How do you think scientists know?

3 The Australian Museum provides extensive advice about fossil sites in Australia.
   a Where can you collect fossils legally?
   b How can you collect fossils responsibly?
   c Who owns fossils?
   d Should you collect fossils? What is your opinion?

Dating fossils

The age of fossil remains can be estimated using either absolute dating (also known as radiometric dating) or relative dating.

In absolute dating, the rate of decay (half-life) of radioactive isotopes, such as carbon-14, is measured in the surrounding rocks or remains. This technique can determine the age of fossils thousands of years old. For example, measuring the radioactive uranium remaining in rocks determined that the Earth was approximately 4.6 billion years old. (See Unit 3 for more information.)

Fossils found in sedimentary rocks were deposited at the same time as the sediments. Fossils are therefore the same age as the rocks in which they are found. As dirt fell to the bottom of lakes and seas, horizontal layers or strata built up. Organisms that lived more recently were deposited above earlier organisms. This observation is called the principle of superposition and it forms the basis of relative dating.

Some forms of life, such as stromatolites (Figure 2.8), have survived relatively unchanged for billions of years; others, such as trilobites (Figure 2.9), are found only in certain

Figure 2.8 Stromatolites thrive in the highly saline, shallow, enclosed Hamelin Pool, at Shark Bay, West Australia.

ISBN 9780170189071

Figure 2.9 Trilobites make excellent index fossils because they evolved rapidly, yet all of the thousands of known species were extinct by the end of the Permian period, 225 million years ago. Like other arthropods, they moulted as they grew, leaving a series of exoskeleton traces.

geological periods. This makes these types of fossils useful as indicator or index fossils – they are useful markers for identifying the relative ages of rocks. Index fossils can also indicate whether rocks have been tilted or overturned, or whether layers have been entirely eroded away between periods of deposition.

ACTIVITY SHEET

Investigating the 'gaited' community

SCI10SIAS00043

The fossil story of evolution continues to become more detailed as more extinct species are discovered. However, the general outline was known during the 19th century (Figure 2.10 on page 48). The first, and therefore the oldest, classes were all marine vertebrates: jawless fish, cartilaginous fish (such as sharks and rays) and bony fish. Because of their resilience to dehydration and temperature variation, amphibians, reptiles and mammals appeared on land in that order. Using fossil evidence, it is thought that birds diversified from reptiles during the Jurassic period.

INTERACTIVE

The link between dinosaurs and birds

SCI10SUIN00044

Figure 2.10 shows how biodiversity, or the numbers of different fossil families, increased and decreased with time. Biodiversity declines sharply in all the groups between eras, which is evidence of a mass extinction. When a group becomes extinct, it never reappears in the fossil record. The heavily armoured placoderm is an example of this (Figure 2.11 on page 48).

During the 20th century, several living fossils were discovered. Living fossils are organisms that appear in the fossil record from early geological periods and can be still found today as living specimens. The coelacanth fish and Wollemi pine must have existed continuously but escaped scientific detection (Figure 2.12 on page 48). This demonstrates that these remnant species are extremely rare, and is also further evidence of how unlikely it is for the remains of any organism to become fossilised.

The fossil record helps us understand how our planet has changed over time. Entire ecosystems died during mass extinctions. However, every catastrophe has created new niches and opportunities for the survivors to become established and thrive.

glossary terms

absolute dating
the process of determining the age of a material by looking at its radioactive content

index fossil
a widely distributed fossil, of narrow range in geological time, that can be used as a marker

living fossil
an organism that appears in the fossil record from early geological periods and can be still found today as a living specimen

principle of superposition
a geological observation that, in undisturbed sedimentary rocks, the lowest layer is the oldest

relative dating
the process of determining the order of past events

strata
beds or layers of sedimentary rock; singular 'stratum'

ISBN 9780170189071

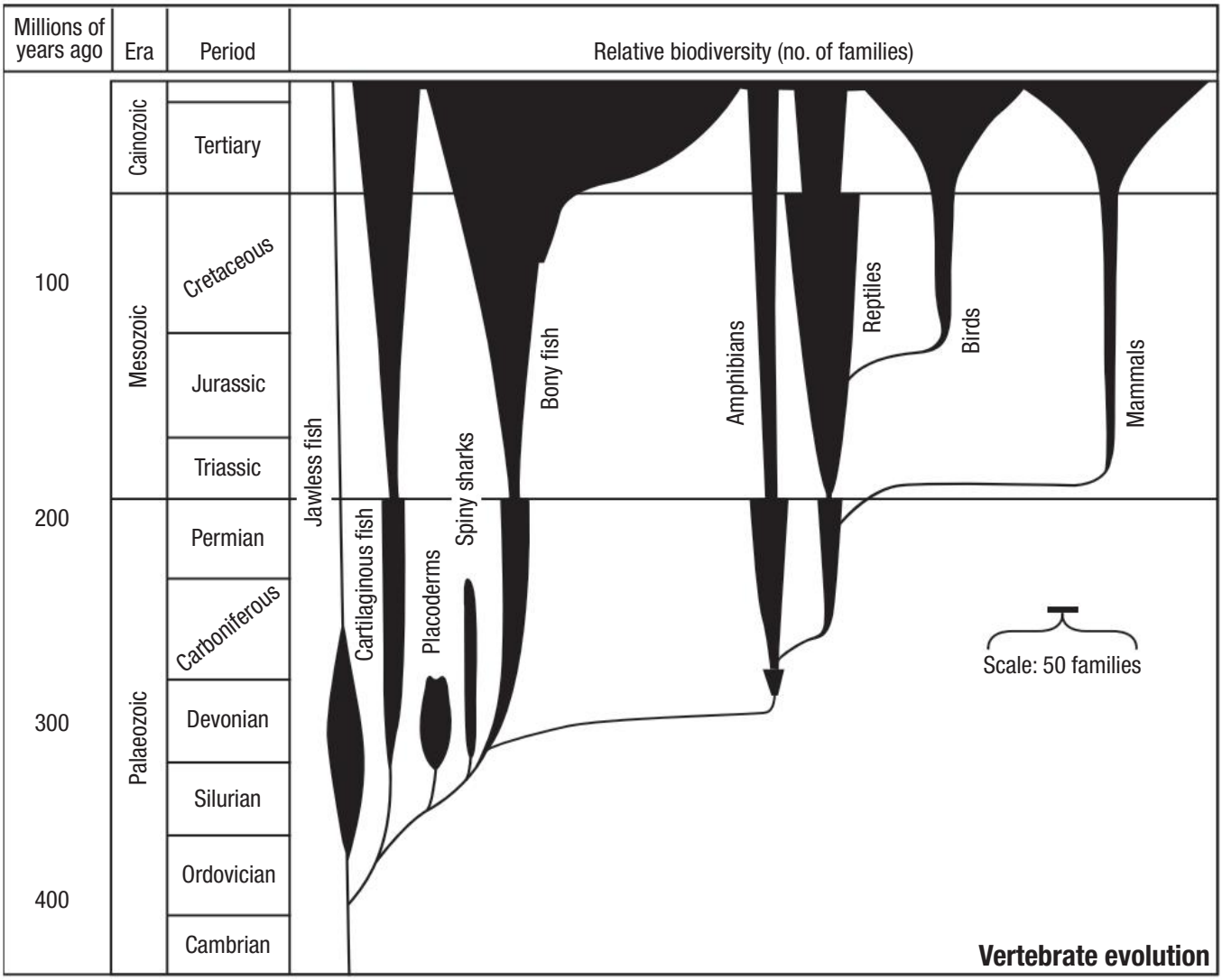


Figure 2.10 Fossil evidence of vertebrate evolution represented as a 'spindle diagram'. The vertical axis shows the geological time (millions of years ago).The horizontal axis represents the biodiversity of each group scaled in numbers of families.

Figure 2.11 The fossil emblem of Western Australia, the Gogo fish, is an example of a placoderm.

Figure 2.12 This 2005 Australian stamp commemorates the discovery of a stand of Wollemi pines in the Blue Mountains, NSW. Prior to 1994, the species had only been known from 150-million-year-old fossils.

ISBN 9780170189071

Questions 2.2

What have you learnt?

WORKSPACE

What have you learnt? 2.2

SCI10SUWR00045

Understand

1 Summarise Darwin's emerging ideas about the diversity of life on Earth under the headings 'Observation', 'Prediction' and 'Evidence'.

2 Why are fossils only found in sedimentary rock types?

Apply

3 Explain why fossils of marine organisms are more common than those of terrestrial species.

4 Explain why fossils of soft organisms, such as jellyfish, are extremely rare.

5 Explain why Darwin needed to study fossil evidence to find support for his ideas.

6 Consider the imprints shown in Figure 2.13. What can you infer about the organism that made them?

Figure 2.13 Imprints

7 Fossils found in alkaline sandy soils typically consist of bones, teeth and occasionally other hard remains. Those found in acidic peat bogs typically have leather-like fleshy remains, but no skeletons.

- **a** Suggest why carbonates, such as bone, are unlikely to be preserved in peat bogs.
- **b** Suggest why Australia is unlikely to have 'bog men', like the prehistoric human remains found in Europe.
- **c** Aboriginal middens (where they used to dispose of their food waste) thousands of years old along Australia's coast are rich in shells. Suggest why this evidence is likely to have been preserved.

Analyse

8 Refer to Figure 2.10 on page 48 to complete the following.

- **a** Name two classes of marine vertebrates that have no modern descendants.
- **b** In order of largest to smallest biodiversity, list the modern classes of vertebrates.
- **c** From which class did mammals evolve?
- **d** During which time period did this occur?
- **e** Which classes had the greatest biodiversity during the Mesozoic era? (Hint: Look at the width of the link.)
- **f** Which classes had the greatest biodiversity during the Palaeozoic era?

9 Compare and contrast the absolute and relative dating of fossils.

Synthesise

10 Create a concept or mind map to organise the evidence for evolution. Add to your concept or mind map as you work through this unit so that, at the end of the unit, it provides a complete summary of evidence.

Reflect

11 Do you think it may be possible for a dinosaur to be found alive today? Suggest reasons for your thinking.

ISBN 9780170189071

Evidence from living species

Darwin began his search for evidence for his ideas by looking at living species in the Galapagos Archipelago. He found further evidence for evolution by studying other living species and comparing them with their distant ancestors preserved in the fossil record.

Anatomical evidence

Anatomical structures – in particular, the skeletal features of vertebrates – have long been studied and compared by curious scientists. The fossil skeletons of extinct species can be compared with living (or extant) species, and their similarities and differences provide evidence for common ancestry and evolution. The forearms of living species can also be compared to study their similarities. Such study is called comparative anatomy.

Comparative anatomy

Your forearm consists of two long bones – the ulna and radius – that can roll over each other as your arm twists from side to side. This bone structure is similar to the front leg of a cat, the flipper of a whale and the wing of a bat (Figure 2.14), and even the front leg of a frog or a lizard and the wing of a bird. These vertebrate forearms are examples of homologous structures. The similarity in structure suggests that they all descended from a common ancestor. In this case, the forearm structure (including the humerus, radius, ulna, carpals and phalanges) can be traced back through the fossil history to the fin of a fish that lived in the late Devonian period (377 million years ago).

Comparative embryology

From the mid-1800s German biologist Ernest Haeckel (1834–1919) studied how closely related vertebrate species go through similar stages in their embryonic development. His research pointed to the fact that pharyngeal gill slits appear at the embryonic stage for fish, salamanders, turtles, chicks, pigs, cows, rabbits and humans (Figure 2.15).

In fish, the pharyngeal gill slits further develop into gills. Mammals no longer have any use for the slits as they exchange gases through their lungs. Instead, the pharyngeal gill slits became the bones of the middle ear. The appearance of pharyngeal gill slits in the embryonic stage of mammals is thought to be evidence of a common ancestor. The feature was never bred out of mammals as it did not provide any disadvantage to survival (Figure 2.16).

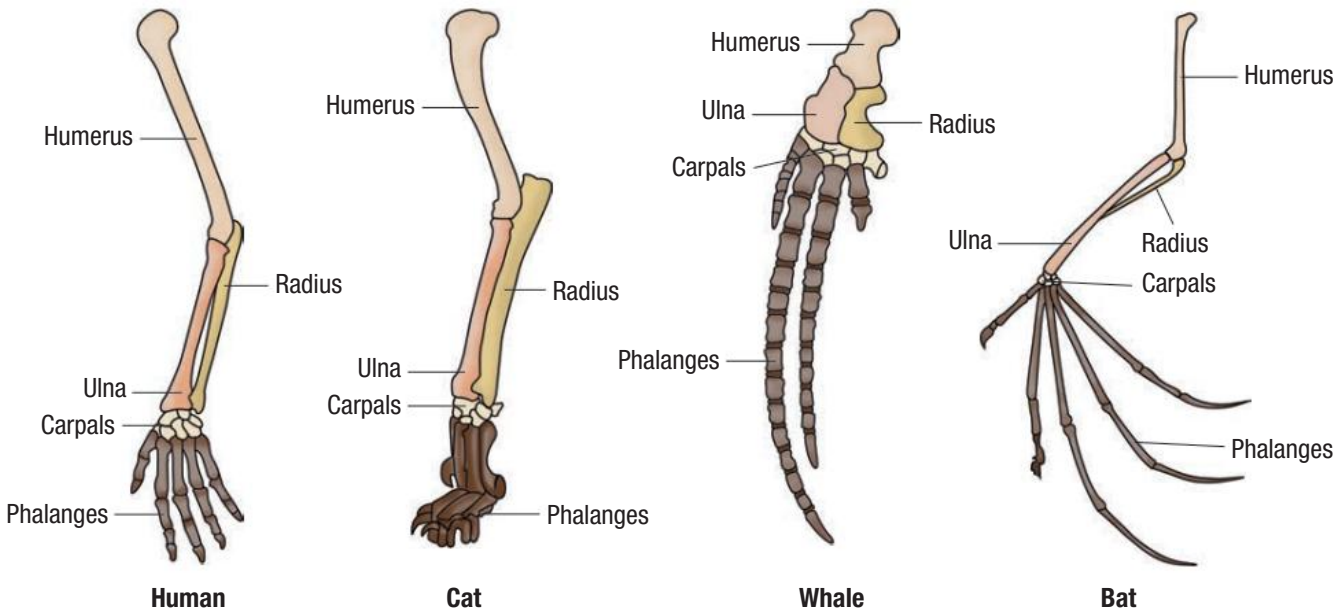


Figure 2.14 Vertebrate forearms are an example of homologous structures.

ISBN 9780170189071

Figure 2.15 Haeckel's 1874 drawings comparing the development of vertebrate embryos

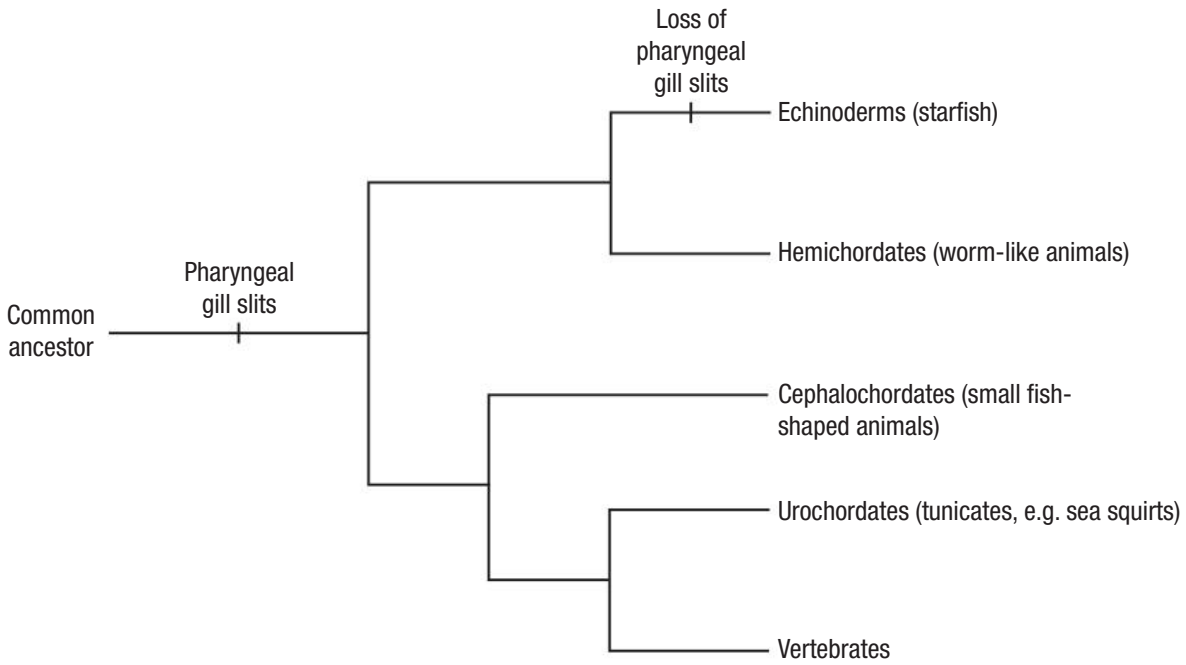


Figure 2.16 The presence of pharyngeal gill slits indicates a common ancestor.

glossary terms

comparative anatomy
the study of similarities and differences in the anatomy of organisms

extant
still in existence

homologous structures
body parts that are similar in different species because the species share a common ancestor

pharyngeal
to do with the throat

ISBN 9780170189071

Evolutionary bioinformatics

Structural and developmental patterns can also be compared at molecular levels. Increasingly, these comparisons use a new tool called evolutionary bioinformatics. Bioinformatics enables the storage of molecular information in huge databases. The information can then be mined and statistically analysed for similarities in things such as nucleotides, amino acid sequences and protein structure between extant and extinct species. This enables scientists to investigate events that happened billions of years ago. Fast computers have made it possible to calculate the likelihood that large biological molecules such as proteins and DNA are related. Bioinformatics was able to demonstrate, for example, a very strong connection between Darwin's Galapagos finches and a South American species. It is this species that is thought to have provided the original population that inhabited the Galapagos Archipelago.

Comparing DNA between species

If DNA nucleotide sequencing information is not available for scientists to analyse, species can be compared using DNA–DNA hybridisation (Figure 2.17). In this procedure, gentle heating separates short sections of the DNA double helix. Complementary strands rejoin almost perfectly as the DNA cools. If this technique combines DNA from two species, some of the cooled DNA will form a mixture. The extent of the matching between DNA from both species indicates the closeness of their relationship. All living things share DNA because all life shares a common ancestor. For example, the DNA of humans only differs from that of chimpanzees by 1.8%.

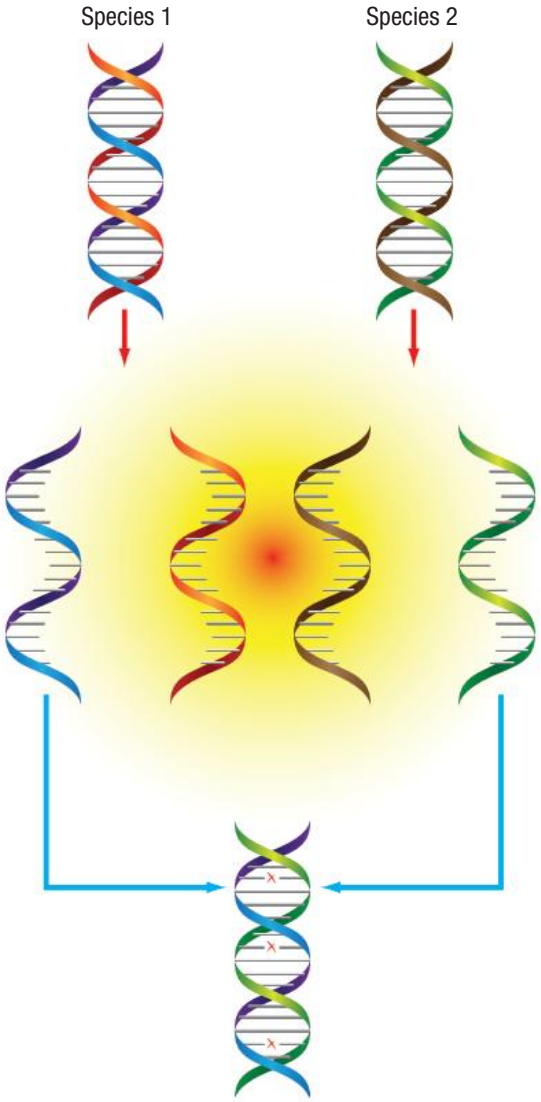


Figure 2.17 DNA–DNA hybridisation

Molecular homology

As discussed in Unit 1, DNA provides the fundamental information for building proteins (see Table 1.3 on page 22).

All cells have homologous structural proteins and enzymes. The most useful comparisons use molecules that are very ancient and have evolved slowly. For example, one-third of the amino acids in cytochrome c, a protein that is used for cellular respiration, are identical in all species.

Activity 2.4
Comparing homologous proteins

WORKSPACE
Comparing homologous proteins
SCI10SIWR00244

Table 2.2 presents the sequence of amino acids in cytochrome c, a protein essential for cellular respiration. Cytochrome c is shown for eight different species, from a human to yeast. Analyse sequences of amino acids in Table 2.2 to infer answers to the following questions.

1. Which species is the most closely related to humans? Explain your reasoning.
2. Which species is the least closely related to humans? Explain your reasoning.
3. Which amino acid position(s) is probably crucial, and which is probably the least crucial? Explain your reasoning.
4. Do you think this evidence supports other knowledge you have of relationships between these species? Explain your reasoning.

ISBN 9780170189071

Table 2.2 Molecular homology of cytochrome c

Amino acid position	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Human	Gly	Asp	Val	Glu	Lys	Gly	Lys	Lys	Ile	Phe	Ile	Met	Lys	Cys	Ser	Gln	Cys	His	Thr	Val	Glu	Lys
Chimpanzee	Gly	Asp	Val	Glu	Lys	Gly	Lys	Lys	Ile	Phe	Ile	Met	Lys	Cys	Ser	Gln	Cys	His	Thr	Val	Glu	Lys
Pig	Gly	Asp	Val	Glu	Lys	Gly	Lys	Lys	Ile	Phe	Val	Gln	Lys	Cys	Ala	Gln	Cys	His	Thr	Val	Glu	Lys
Chicken	Gly	Asp	Ile	Glu	Lys	Gly	Lys	Lys	Ile	Phe	Val	Gln	Lys	Cys	Ser	Gln	Cys	His	Thr	Val	Glu	Lys
Dogfish	Gly	Asp	Val	Glu	Lys	Gly	Lys	Lys	Val	Phe	Val	Gln	Lys	Cys	Ala	Gln	Cys	His	Thr	Val	Glu	Asn
Drosophila	Gly	Asp	Val	Glu	Lys	Gly	Lys	Lys	Leu		Val	Gln	Arg		Ala	Gln	Cys	His	Thr	Val	Glu	Ala
Wheat	Gly	Asn	Pro	Asp	Ala	Gly	Ala	Lys	Ile	Phe	Lys	Thr	Lys	Cys	Ala	Gln	Cys	His	Thr	Val	Asp	Ala
Yeast	Gly	Ser	Ala	Lys	Lys	Gly	Ala	Thr	Leu	Phe	Lys	Thr	Arg	Cys	Glu	Leu	Cys	His	Thr	Val	Glu	Lys

Questions 2.3
What have you learnt?

WORKSPACE
What have you learnt? 2.3
SCI10SUWR00046

Understand

1 What is meant by the term 'homology'? Provide three examples.

2 How does homology support the idea that species have changed over time?

3 How does the following evidence support the idea of common ancestry?
   - **a** Similarity in protein structures between different species
   - **b** DNA–DNA hybridisation

4 Explain why human babies are not born with pharyngeal gill slits.

Evaluate

5 Ernest Haeckel's images of embryos are now considered controversial because they were believed to not be accurate. In your opinion, how important is academic honesty to scientific endeavour?

Reflect

6 What is your reaction to learning that human and chimpanzee DNA differ by only 1.8%?

7 Revisit, add to and edit your concept or mind map.

glossary terms

bioinformatics
the application of computer science to analyse molecules

cellular respiration
a process that requires oxygen to generate high-energy storage chemicals (abbreviated as ATP) and that produces water and carbon dioxide as wastes

DNA–DNA hybridisation
a technique for combining single DNA strands from two species, to compare their similarity

homology
a structural or developmental similarity based on descent from common ancestors

ISBN 9780170189071

Evidence from plate tectonics and biogeography

You may recall that continents have moved across the Earth over time according to the theory of plate tectonics (see Unit 8, *Nelson iScience 9*). This theory suggests that all of the continents on Earth were once joined as one large land mass, known as Pangaea, about 250 million years ago. This land mass split over millions of years into two supercontinents: Laurasia in the northern hemisphere and Gondwana in the southern hemisphere (Figure 2.18). As millions of years passed, the continents continued to drift apart on their plates into their present-day positions. They are still on the move today, with Australia slowly heading north at about 7 cm per year. How long will it be before Australia collides with South–East Asia?

Evidence for biogeography

As a child you may have noticed how the Earth's continents looked like they could fit together, like pieces of a jigsaw puzzle. This physical fit suggests that at one time the continents were joined. At the same time, geological structures, such as rock types at the former interfaces between continents, also suggest that some land forms were previously adjacent. Fossil evidence that occurs only in the southern hemisphere provides good support for the theory, as does the distribution of closely related organisms across the continents.

The scientific study of the geographical distribution of living organisms is known as biogeography. It attempts to explain where species occur with regard to factors such as climate and processes such as continental drift. Have you ever wondered why marsupial mammals are only found in Australia and the Americas? As naturalists sailed around the world in recent centuries, they began to ponder these sorts of questions (as we will see in the next section).

The distribution of living genera in the southern hemisphere of the plant family Protoaceae provides an example of biogeography with respect to ancient continental connections (Figure 2.19). Within the family Protoaceae, the genus *Protea* is native to southern Africa; *Banksia*, *Grevillea* and *Hakea* are largely native to Australia; *Orites* and *Lomatia* are common to Australia and South America; and *Embothrium* is unique to South America.

Alfred Russel Wallace

Alfred Russel Wallace (1823–1913) was a self-taught naturalist and professional collector. He travelled to two of the most biodiverse places in the world: the Amazon region, in Brazil, for four years; and the Malay Archipelago (including Indonesia, Papua New Guinea and the Philippines) for eight years. During that time Wallace collected more than 125 600 specimens, ranging from beetles to mammals.

Wallace first identified the importance of geography in the evolution of species. He was initially puzzled that 'an animal so large, so peculiar and of such a high type of form as the orang-utan' could only be found on two widely separated islands: Sumatra and Borneo. He then realised these apes were small, leftover populations of a species that had once been widely distributed (Figure 2.20).

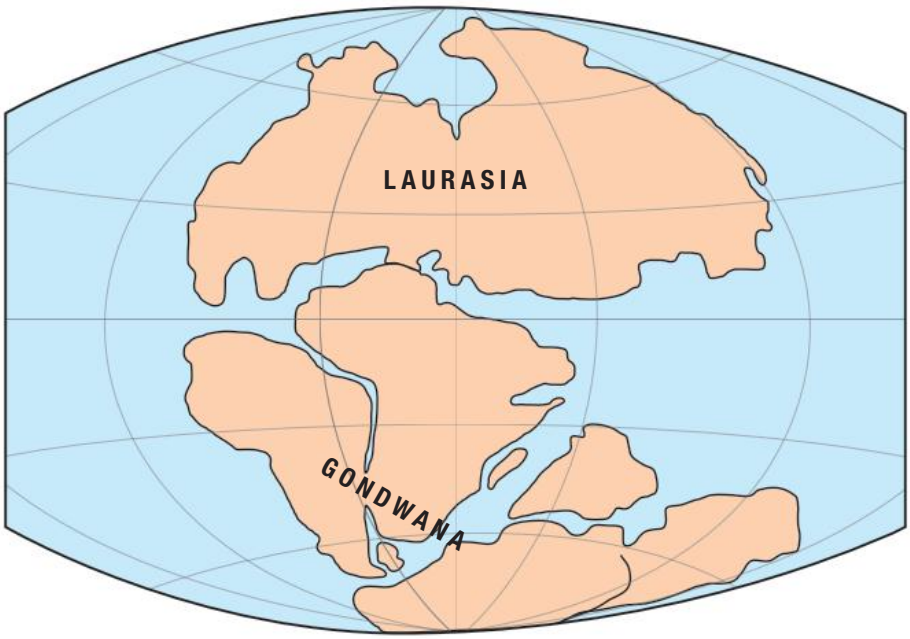


Figure 2.18 Laurasia and Gondwana

ISBN 9780170189071

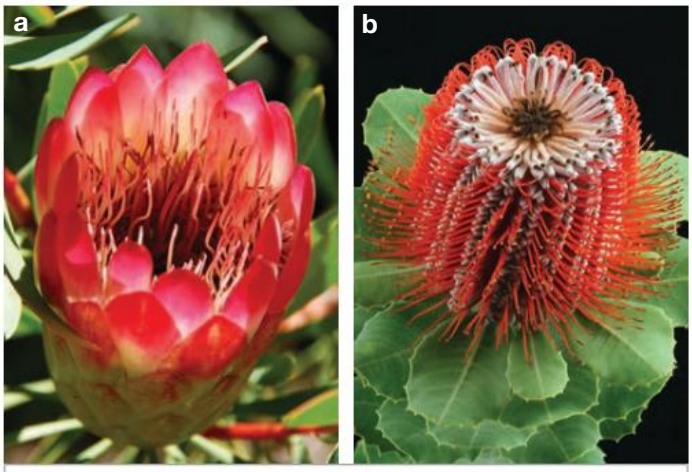


Figure 2.19 Two genera in the widely distributed Protoaceae family: **a** southern African *Protea* and **b** an Australian *Banksia*

Activity 2.5
Moving lands

1 Find out where the continents were when the Protoaceae family first evolved 100 million years ago.

WEBLINK
Gondwana

2 Draw a three-circle Venn diagram to describe the genera of family Protoaceae. What does your diagram suggest about the order in which the continents separated?

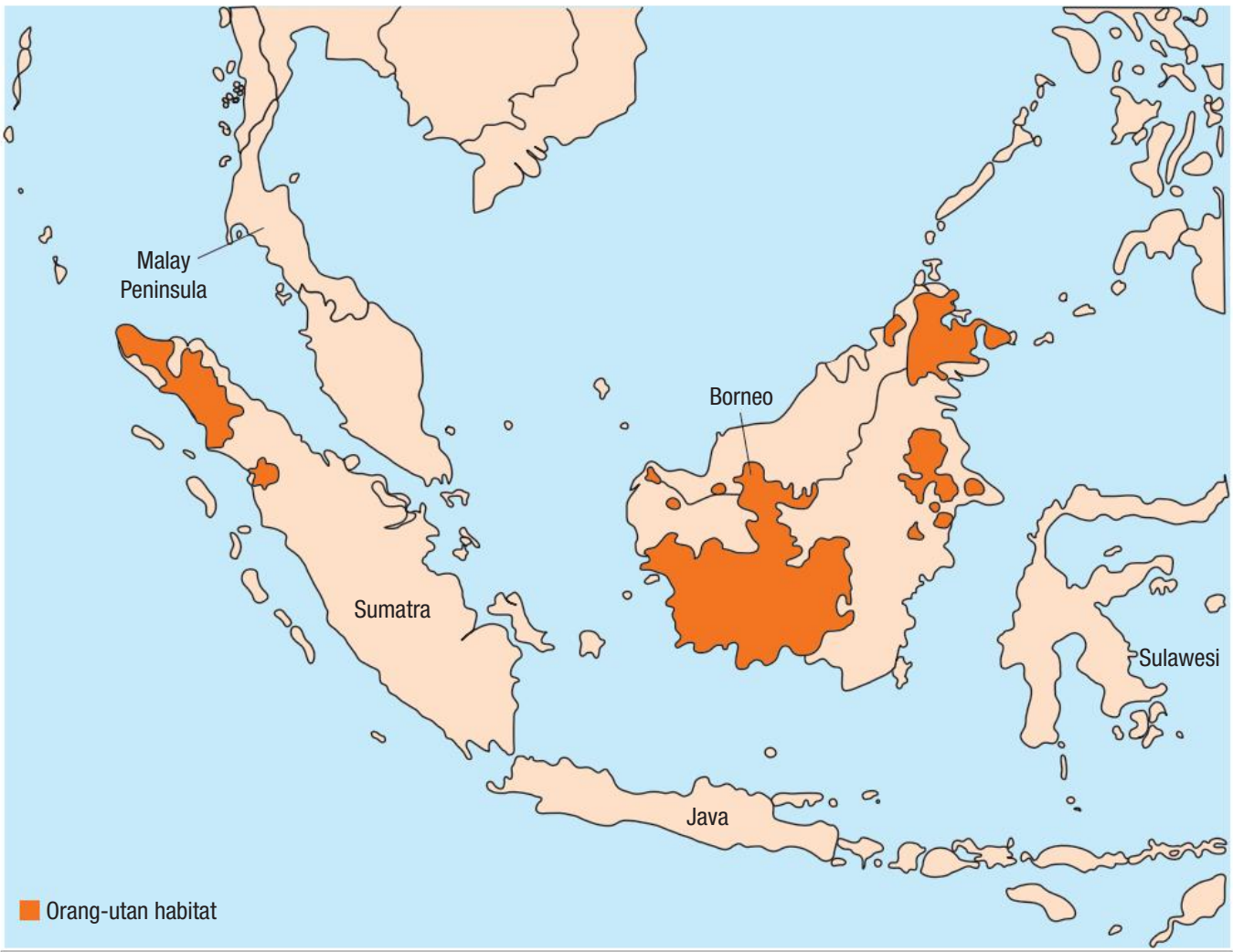


Figure 2.20 A map that shows the distribution of orang-utans

glossary term

biogeography
the study of the geographical distribution of living things

ISBN 9780170189071

Wallace's Line divides Indonesia in a way that reflects his observations about the distribution of regional species (Figure 2.21). He noted that west of this zone, the species are Asiatic; and to the east, they are a mix of Asiatic and Australian species. Because of his extensive work on developing the study of species distribution into a science, Wallace is known as the father of biogeography.

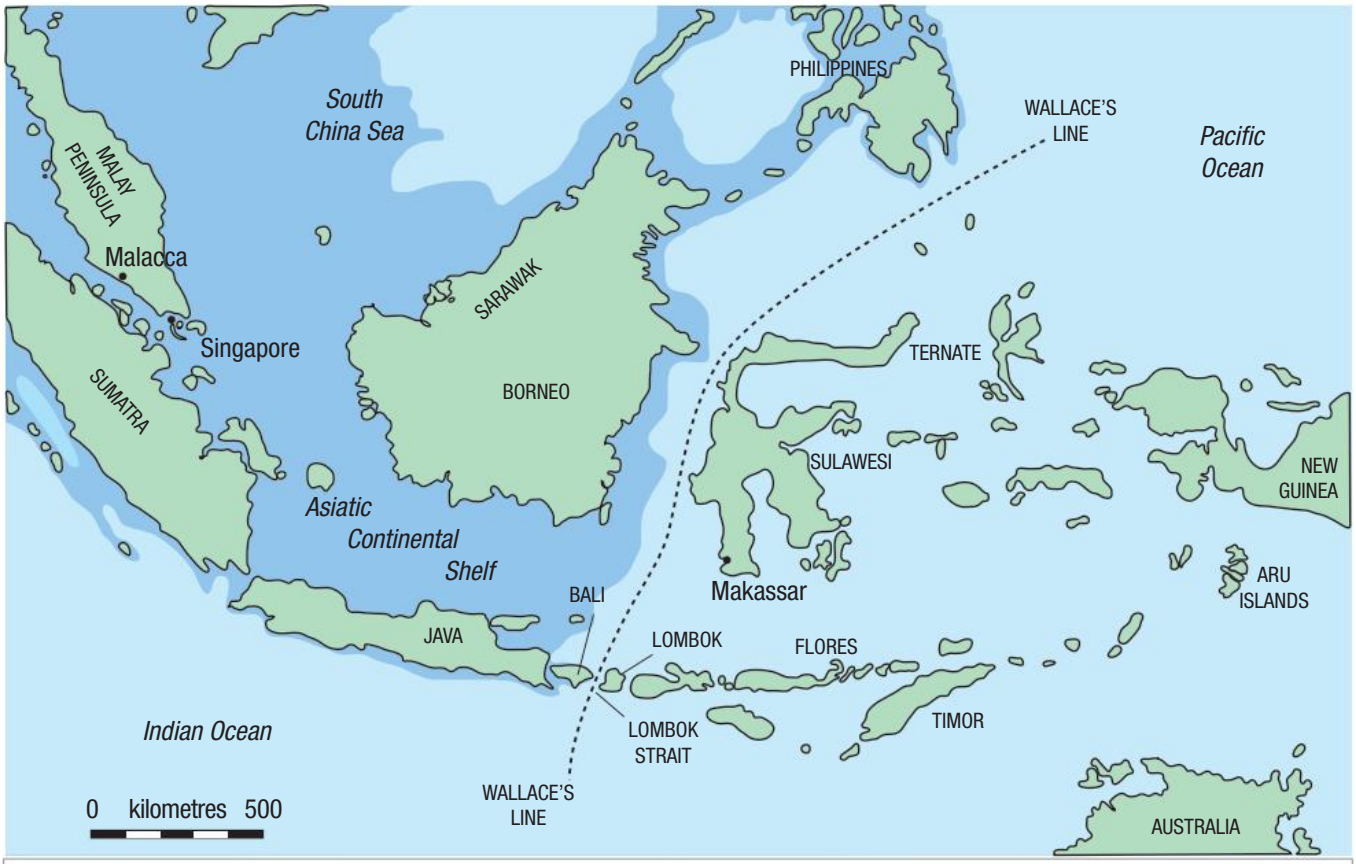


Figure 2.21 Wallace's Line divides Indonesia according to the distribution of regional species.

Questions 2.4
What have you learnt?

WORKSPACE
What have you learnt? 2.4
SCI10SUWR00047

Understand

1 What is biogeography?

2 How does geographical distribution of species support the idea that species shared a common ancestor?

3 How does the theory of plate tectonics provide supporting evidence for the idea that species shared a common ancestor?

Apply

4 How would you explain the location of Wallace's Line?

Analyse

5 Which Habits of Mind did Alfred Russel Wallace display in his quest to find evidence for his ideas?

6 Both the continents of North America and Australia have many families of endemic marsupials, although no families in common. Using your knowledge of the *Protoaceae* family, what does this suggest about the speed of evolution in plants compared with animals? Give reasons for your ideas.

ISBN 9780170189071

Explaining evolution

In 1795 Scottish geologist James Hutton (1727–1797) proposed the theory of gradualism. He said that the Earth's features changed in a slow, gradual, continuous process. In the 1800s, British geologist Charles Lyell (1797–1875) suggested that geological evidence showed the Earth to be millions of years old. Both ideas were revolutionary at the time since most people believed that the Earth was only thousands of years old and had remained unchanged.

In 1794 English physician and naturalist Erasmus Darwin (1731–1802), the grandfather of Charles Darwin, suggested that all living organisms evolved from a single common ancestor and that species could change into new species. He did not, however, propose a mechanism for this change process.

In 1809 French naturalist Jean-Baptiste Lamarck (1744–1829) proposed his theory of evolution by transformation. He believed that the environment affected how organisms used their body parts; and that what was used was passed on to offspring, but what was not used would not be passed on. This was referred to as inheritance of acquired characteristics. The common example he gave was that of a short-necked animal that could acquire a long neck simply by stretching its neck up regularly to eat leaves (Figure 2.22). This acquired trait could then be passed on to produce long-necked offspring. Is this how giraffes evolved? Not quite. Lamarck's claims were mistaken, but can you see any elements of his theory that were good ideas?

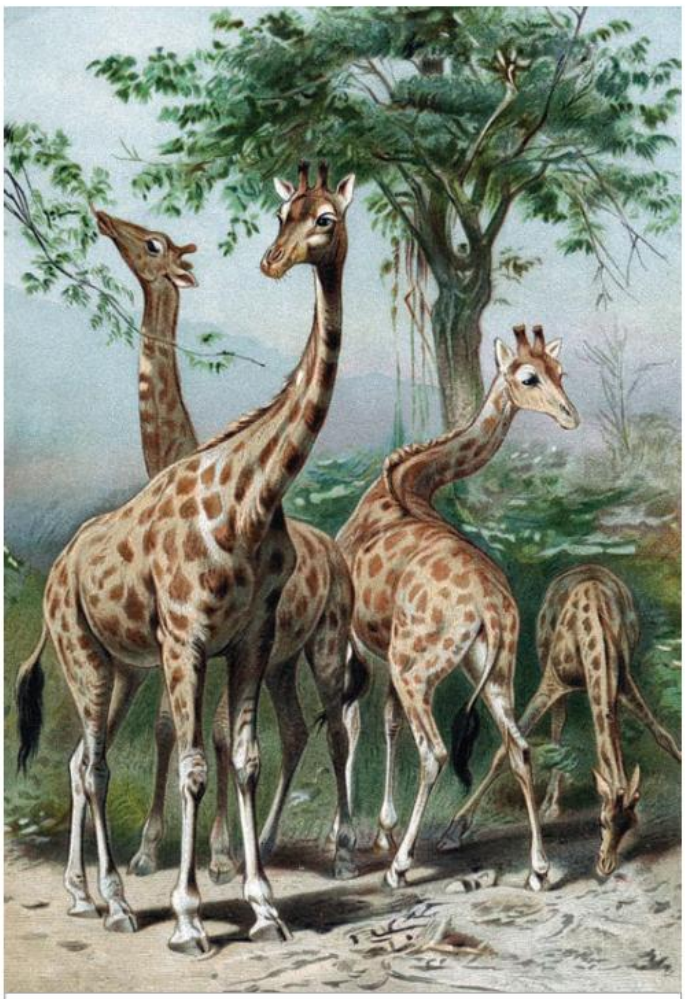


Figure 2.22 Lamarck's theory of inheritance by acquired characteristics said that giraffes could stretch their necks to reach the leaves higher in the trees. These stretched necks could be passed on to offspring.

Natural selection and the process of evolution

Charles Darwin was a keen observer and a meticulous note-taker. He spent almost five years travelling around the world on HMS *Beagle* making observations, taking copious notes and collecting specimens that he would later analyse. These became the basis of his eventual theory about how species evolved or changed over time.

Twelve years after Darwin completed his voyage on HMS *Beagle*, Alfred Russel Wallace (Figure 2.23 on page 58) was in the Amazon pondering why monkey species differed on either side of the river. In the Malay Archipelago, from 1854 to 1862, he continued to note the striking patterns of species distribution and thought about how species evolved. In February 1858, Wallace wrote the paper 'On the Tendency of Varieties to Depart Indefinitely From the Original Type', which proposed that species changed over time by a process now called natural selection. He sent this paper to Charles Darwin for his opinion, who then passed it on to Charles Lyell as Wallace had requested. Coincidentally, Darwin had developed the same idea over the past 20 years but had been reluctant to publish. Lyell and British botanist John Hooker (1817–1911) prepared a joint paper featuring the work of Darwin and Wallace. On 1 July 1858 this paper was presented to the Linnaean Society of London. Both Wallace and Darwin were absent. In November 1859 Darwin published his book *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life*, becoming one of the most highly influential books of all time (Figure 2.24 on page 58).

Darwin's book outlined his theory of evolution by natural selection. This can be briefly defined as the process by which organisms best suited to their environment survive to pass their genes on to their offspring in increasing numbers, in contrast to the less well-adapted organisms in the population who produce fewer organisms or do not breed at all (Figure 2.25 on page 58).

ISBN 9780170189071

Figure 2.23 Alfred Russel Wallace (left) and Charles Darwin

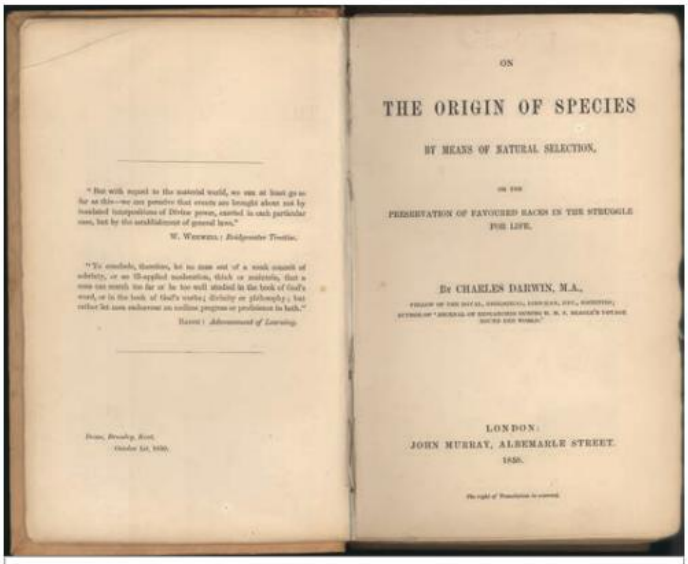


Figure 2.24 Frontispiece (left) and title page (right) of Darwin's *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life*

The theory of evolution is based on the following assumptions.

- Variation exists in populations.
- More offspring are produced than can possibly survive to reproduce in a population.
- In the struggle for survival, those organisms better suited to their environment survive in greater numbers than those less suited.
- Surviving organisms breed and pass on the genes that helped them survive to the next generation.
- Over time, the population is dominated by those organisms with the genes best suited to surviving in the current environment.

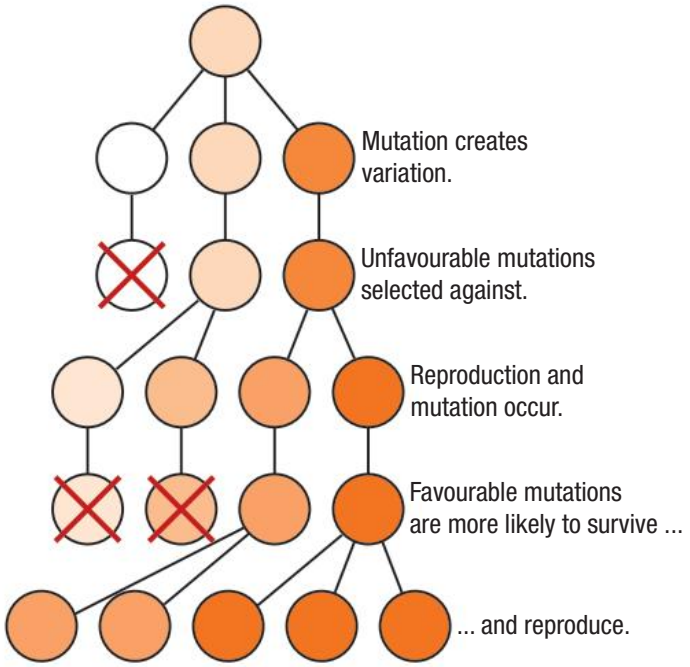


Figure 2.25 A diagrammatic representation of natural selection

ACTIVITY SHEET
Getting the message across
SCI10SIAS00048

New species can arise by this process. In order for this to happen, there needs to be:

1. variation within a species
2. isolation and competition
3. selection and speciation.

Variation within a species

If you look closely at the members of the same species, you will notice differences in their appearance. For example, skin, hair and eye colour, height and foot size are obvious differences in the human species. If you could look inside the human body, you would also see differences. Humans can have different blood types, some suffer from diabetes while others do not and most adults have four wisdom teeth, though it is possible to have less than this. These represent naturally occurring variation among members of the same species (Figure 2.26).

Much more variation exists within sexually reproducing species than those that reproduce asexually. This is because the gametes in sexually reproducing species are produced by meiosis (see Unit 1, pages 13–16). In contrast, the offspring of asexually reproducing species are produced by binary fission or mitosis. Both asexual processes produce offspring genetically identical to their parent.

ISBN 9780170189071

Figure 2.26 Variation in shell pattern within a snail species across Australia

In meiosis, several factors assist to mix up the paternal and maternal DNA within the cell, leading to variation within the offspring:

- During interphase, when the DNA is replicating, mutations occur. These could include point mutations, where just one base pair is replicated incorrectly, or larger mutations that involve parts of chromosomes. This is when pieces of chromosome are deleted, added or swapped around.
- During prophase I, pieces of homologous chromosomes are exchanged during crossing-over and this results in four unique chromatids that will eventually separate into gametes.
- During anaphase I, when the homologous pairs of chromosomes line up along the equator of the cell, maternal and paternal chromosomes are separated into gametes at random.

The result of all this mixing of chromosomes is four haploid gametes, each with a unique set of DNA that will code for a unique set of proteins via transcription and translation (see Unit 1, pages 8–9).

Therefore, in sexually reproducing organisms, two parents contribute gametes to each new offspring. One unique gamete combines with another unique gamete in fertilisation. This produces an individual with DNA that contains a unique set of DNA and codes for a distinctive set of proteins. These proteins could be enzymes that control eye colour, height, skin colour or blood type.

Isolation and competition

Members of the same species can interbreed naturally to produce viable offspring (see Unit 3, *Nelson iScience 7*). As long as a male and a female are brought together and still able to reproduce, they are considered to be the same species.

However, what if two populations of the same species were isolated from each other? This could be physical isolation due to an earthquake (Figure 2.27 on page 60), volcanic eruption, the building up of mountain ranges, a drying river permanently isolating two groups of fish, or continental drift.

WEBLINK
Meiosis – mixing up DNA

glossary terms

binary fission
the asexual division of a prokaryote cell into two

point mutation
the substitution of a single base during DNA replication

variation
differences between things

viable
healthy and able to reproduce

ISBN 9780170189071

Figure 2.27 The isolation of a population can occur by earthquakes, making it physically impossible for individuals to get together to mate.

Each environment provides only a limited number of places in which organisms can live. These places, or niches, include physical resources (such as shelter) and biological resources (for example, food). However, every generation adds new members to the population. All these organisms must compete with one another for the limited number of available niches. How do the number of niches available for a population relate to how species evolve?

Selection and speciation

In science, the accuracy of a theory is tested by the range of observations it explains. Natural selection can explain how the volcanic islands of the Galapagos Archipelago came to have such a variety of finch species.

Originally, a few lost South American finches arrived on one of the remote islands of the Galapagos Archipelago (Figure 2.28). These finches had a variety of naturally

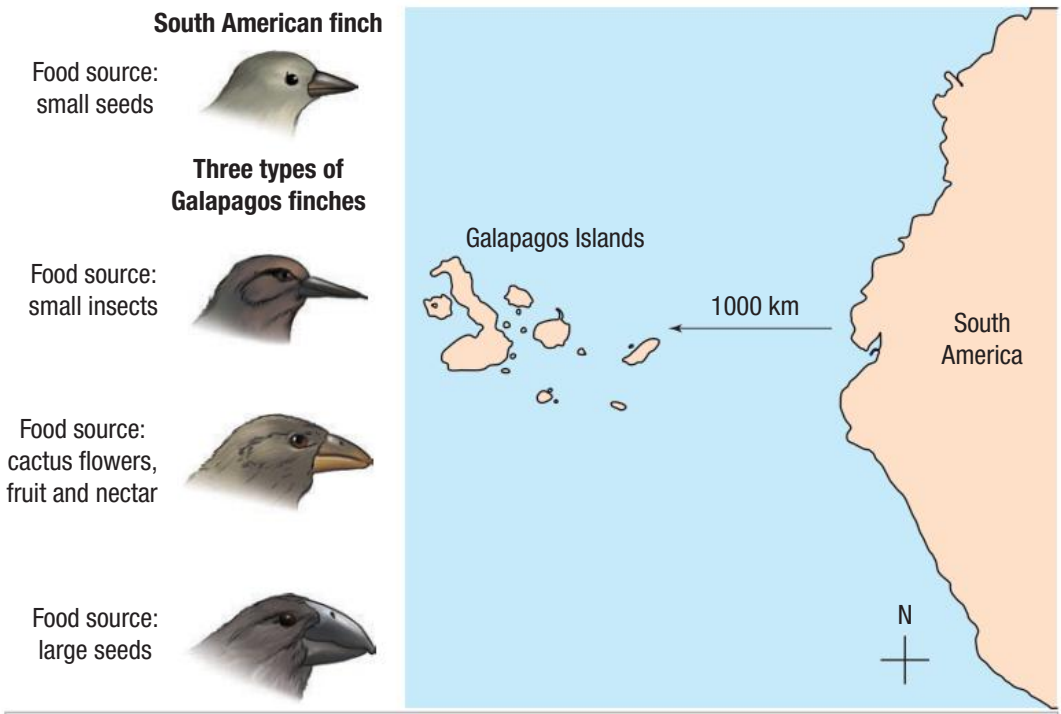


Figure 2.28 A founding population of finches originally came from South America.

ISBN 9780170189071

occurring genetic variations, such as colour, beak size and leg length. The descendants of these birds gradually populated the other islands, each with different environmental conditions (see page 40). Plants growing on the drier islands are more likely to produce seeds with thick coats. This is an adaptation often associated with the survival of seeds in these circumstances. In turn, this seed feature provides a selection pressure on the finches, where natural selection will favour birds with larger, stronger beaks capable of eating these seeds and selects against those birds with smaller, shorter beaks. The larger, stronger-beaked birds are able to survive, breed and pass on the larger, stronger beak genes to their offspring. Over time, the whole population of finches has the larger, stronger beaks. If these finches reunited with the smaller, shorter-beaked finches, could they still interbreed and produce viable offspring? If they could not, they would be considered different species.

Activity 2.6
A species of your own

WORKSPACE
A species of your own
SCI10SUWR00049

Create a species that will survive one million years. Go to the weblink 'Switcheroo Zoo' to create an animal that is very well adapted to a particular environment. Describe the environment.

WEBLINK
Switcheroo Zoo

WEB 2.0

Take a screen grab of your animal and upload it to the class wiki. Other members of the class can describe the environment in which it would be best suited to live.

Questions 2.5
What have you learnt?

WORKSPACE
What have you learnt? 2.5
SCI10SUWR00050

Understand

1 How did Darwin build on the ideas of those who came before him? Do you think he rejected any of their ideas? Explain.

Apply

2 How does genetics contribute to variation within a species?

3 Natural selection is often described as 'survival of the fittest'. Is this an accurate description? Explain.

4 How would you test whether two isolated populations were different species?

5 Why does a population need to be isolated before it can evolve into a new species?

Analyse

6 The answer is selection pressure. What is the question?

7 What personal qualities did Charles Darwin display?

Reflect

8 Revisit, add to and edit your concept or mind map.

glossary terms

adaptation
a genetic trait that is advantageous to survival

niche
a place in which an organism can live

selection pressure
the driving force that favours organisms with a particular characteristic over those without that characteristic

ISBN 9780170189071

Acceptance of the theory of natural selection

The theory of evolution by natural selection is so widely accepted by scientists today that it could be considered scientific fact. Similar to so many other theories in science, it was built on the ideas of all those that came before. Natural selection itself is the proposed mechanism to explain *how* the evolution of species is happening. It has been tested for more than 150 years and has not been disproved. New molecular science advances continue to confirm and expand the theory. It is a unifying theory that forms the basis for all of biology.

More evidence to support natural selection

Finches of Daphne Major

Since 1973 British evolutionary biologists Peter and Rosemary Grant have spent six months of each year measuring and recording the beak length of every finch hatched on Daphne Major, a tiny island in the Galapagos Archipelago (Figure 2.29). Their painstaking field research has involved tens of thousands of birds and uncovered data on environmental factors, such as weather, over the years. They have been able to monitor the effects of several exceptional weather cycles.

The first notable weather event was a severe drought in 1977. Seeds were scarce and consequently many finches starved. As the summer progressed and the drought continued, more and more finches died. By the end of the season, only one finch in seven survived. Significantly, each of the survivors possessed a beak that was slightly longer than the previous average. Although the difference in beak length average was less than 1 mm, this small distinction was enough to help these birds obtain food. Their offspring also had, on average, longer beaks.

The second major weather event occurred in 1983, ten years into the Grants' study. This time, an unusual wet season meant all the birds initially had enough food; however, because large beaks are 'costly' structures to grow, the smaller-beaked finches had a slight advantage in the wet conditions. Compared with larger-beaked finches, the smaller-beaked finches laid slightly more eggs and raised more chicks. A few seasons later, when dead vines from that wet season still smothered many of the large seed-producing plants, the smaller-beaked finches had an even greater advantage.

This story is just one of many important observations emerging from the Grants' long-term study. Their results match the pattern being found in other field studies around the world. Year after year, in every location, the population is different. Species respond quickly to environmental change.

ACTIVITY SHEET
Beak efficiency investigation
SCI10SIAS00051

ACTIVITY SHEET
Modelling selection pressure
SCI10SIAS00052

Mimicry and sexual selection

Poisonous insects or reptiles are often dramatically coloured. This trait was thought to help potential predators learn to avoid eating them. English naturalist Henry Bates (1825–1892), a friend of Alfred Russel Wallace, also

Figure 2.29 Daphne Major in the Galapagos Archipelago

ISBN 9780170189071

Figure 2.30 Spotted tiger moths (left) are harmless Batesian mimics, but their colours resemble dangerous wasps (right).

observed a relationship in South America that could be explained by the theory of natural selection. Bates noticed that, in environments where dangerous animals were common, there were also other, edible and non-poisonous species with the same 'warning' colours as the poisonous species. This type of mimicry protected these harmless species from the same predators (Figure 2.30). This became known as Batesian mimicry.

Natural selection theory explains even more puzzling features. For example, the males in some species use a large amount of their energy input to grow unwieldy structures the females do without. Peacocks have long, colourful tails that could attract predators; and bull elephants have huge, heavy tusks. Darwin proposed that the females of these species selected the flashiest males to mate with. Another hypothesis proposes that the extreme features resulted from male-to-male competition to win the right to mate with the females (Figure 2.31). Either way, large differences between the males and females in a species could be explained by sexual selection.

Figure 2.31 Sexual selection in action. Only male kangaroos 'box'. The winner of this contest earns mating rights with many females. His genes will pass on to the next generation.

glossary terms

mimicry
the ability to physically resemble a different organism to benefit from the mistaken identity

sexual selection
the advantage that certain individuals of the same sex have over other individuals, causing them to be more successful in reproduction

Activity 2.7
Sexual selection in guppies

Female guppies strongly prefer to mate with brightly coloured male guppies. However, the same feature also attracts guppy predators. Visit the guppy sexual selection simulator to investigate how these competing selection 'pressures' affect a population.

WEBLINK
Guppy selection

ISBN 9780170189071

Activity 2.8
Exploring scientific history online

Use information from the weblinks and videos to answer the questions.

WORKSPACE
Exploring scientific history online
SCI10SIWR00053

INTERACTIVE
Charles Darwin on the importance of the *Beagle* voyage
SCI10SUIN00044

WEBLINK
Finches of the Galapagos Islands

WEBLINK
Wallace's collections

WEBLINK
Darwin and Wallace's ideas on evolution

1 What does the excerpt about the voyage of HMS *Beagle* suggest about Darwin's character?

2 What structural and behavioural differences can you observe between the Galapagos finches?

3 Before going on their own collecting expeditions, Wallace and Bates spent many days memorising the detailed scientific descriptions of all the organisms held in the London Museum of Natural History.
   a What methods would you use to remember this knowledge?
   b What does this tell you about the skills of scientists in the past compared with those today?

4 Consider the individual styles of the papers written by Wallace and Darwin. Both were first drafts: Wallace's paper is a discussion intended for Darwin to read privately, and the other is an extract from a letter Darwin addressed to a colleague living in the United States. How is 'precedence' of scientific discovery determined in 21st-century science?

WOW!

The case of the midwife toad

Midwife toads normally mate on land and do not develop scaly 'nuptial pads' during the breeding season, unlike closely related species that mate in water. The experimental results obtained by Austrian biologist Paul Kammerer (1880–1926) could not be explained by natural selection.

Kammerer forced the toads to mate in water. After six generations, his toads developed nuptial pads, a trait their offspring inherited, even if they lived on land!

Kammerer was accused of scientific fraud; he died humiliated, six weeks after this accusation. Recent advances in genetics now suggest his experiment had to do with how the genes were expressed. The genes are a characteristic that the toads had always shared with their relatives.

Questions 2.6
What have you learnt?

WORKSPACE
What have you learnt? 2.6
SCI10SUWR00054

Understand

1 While the Grants were measuring beak length on Daphne Major, they found that beak length changed over time. What were the selection pressures that brought about these changes?

2 Explain why isolation, such as on islands, seems to result in different sets of adaptations than those on large land masses.

Apply

3 Using the assumptions of natural selection listed on page 58, explain how Batesian mimicry could evolve.

4 The answer is sexual selection. What is the question?

ISBN 9780170189071

5 Compared with on large land areas such as continents, animal life on small, remote islands differs in predictable ways. Suggest possible reasons or advantages for the following trends on small islands.
   a Amphibians are absent.
   b Reptiles, such as tortoises and lizards, are often very large.
   c Birds are often flightless.
   d Mammals, like kangaroos, are often small.

6 Picture the following two Batesian mimics: a toxic wasp and a tasty harmless fly. To protect themselves against predation, state how effective the warning colour is:
   a when there are many wasps, but few flies
   b when there are many flies, but few wasps.

7 Suggest an experimental design that would test for female sexual selection (preference) in peacocks.

Analyse

8 Analyse the following statement in terms of the costs and benefits of large tusks: 'Between 1925 and 1968, the average tusk size in Ugandan elephants killed for ivory decreased by nearly 50%.'

Reflect

9 Consider the Grants' long-term experiment on Daphne Major. Suggest some Habits of Mind these scientists show to be able to complete their work.

10 Revisit, add to and edit your concept or mind map.

Artificial selection as evidence for evolution

If two Australian cattle dogs mated (Figure 2.32), their puppies would not be expected to look like poodles. The variation in dog breeds is quite remarkable. The appearance and temperament of most pure-bred dogs are consistent and predictable. However, the majority of dog breeds have arisen in less than 200 years.

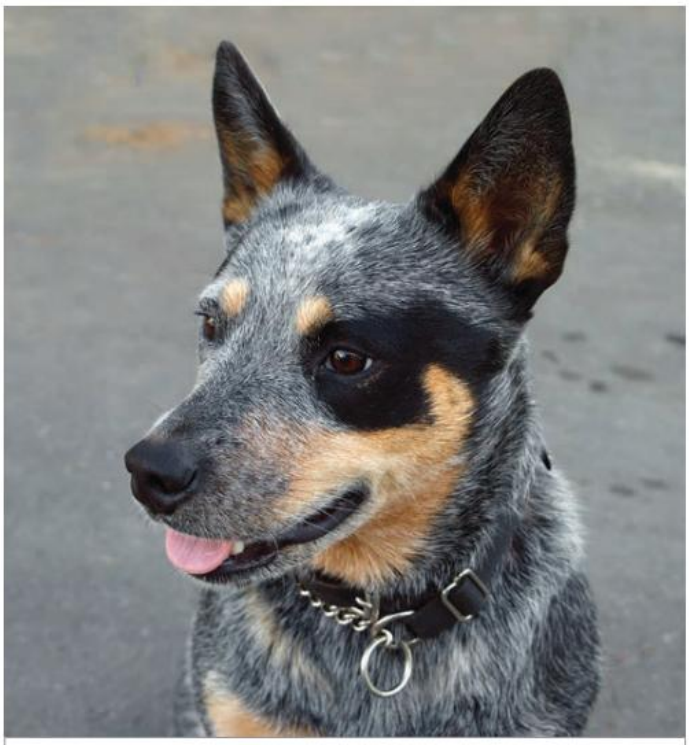


Figure 2.32 The Australian cattle dog has been bred for toughness and hard work.

Every domestic organism – plant and animal – is the result of sustained selection by humans. Artificial selection differs from natural selection in that it is not random. Once humans deliberately began selecting organisms with desirable traits, species of plants and animals changed rapidly, generating new and distinct varieties. In addition to dogs and pigeons, two species that have a huge amount of variation, all domestic animals and plants tend to be more manageable and predictable in their behaviour than their wild ancestors. Some, such as the edible South American guinea pig and corn, have also become much larger.

CONNECTION
History: Artificial selection of wheat in the Fertile Crescent
SCI10SUCN00055

glossary terms

artificial selection
intentional breeding for certain characteristics

variety
a low taxonomic subdivision of a species consisting of naturally occurring or selectively bred populations, like a breed

ISBN 9780170189071

Genetics and evolution

We have seen how the theory of natural selection suggests that advantageous phenotypes are preserved. Sometimes, existing structures were modified for different functions. For instance, the flipper of a whale or dolphin, the wing of a bird and the front leg of a dingo all have structural similarities to the bones of a human arm. This is an example of divergent evolution because the underlying pattern of the structure – in this case, the pentadactyl limb – is consistent. This similarity suggests that a common genetic feature underpins their development. Other examples of divergent evolution include the persistence of vestigial organs in some species, such as the appendix in humans and blind eyes in cave fish. Similar, functional organs are still useful in closely related species. Ernst Haeckel's comparative embryology data suggested that an organism's development from its embryo recaptured stages of evolutionary development of the species. Unfortunately, his beliefs overrode his critical observational skills to the extent that he exaggerated the similarities between the embryos he drew.

Could there be a genetic explanation for these intriguing patterns? In 1984 a very special group of genes was discovered called 'Hox genes', 'homeobox genes' or 'homeotic genes'. This group of genes provides timing signals for other genes to become active during the development of embryos (Figure 2.33). The way these 'supergenes' are placed within the organism's DNA is consistent over a range of phyla, invertebrates and vertebrates included. Although active for different amounts of time, the genes managed by these supergenes are sometimes almost identical from fruit flies to mice!

Supergenes were immediately recognised as powerful tools for investigating relationships between phenotypes and species. They explained the shared developmental and anatomical homologous patterns in different organisms (see Figure 2.14 on page 50).

Supergenes also set theoretical limits for evolutionary change. Structures can be altered or rearranged (Figure 2.34), but the overall pattern cannot be changed (Figure 2.35). Snakes do not grow legs, although they have the genes to do so. When embryo snakes develop, their genes for limb development are never switched on. The gill pouches of fish have been rearranged to become the middle ear bones in mammals. The similar appearance of human and fish embryos occurs before the ear bones change position.

Figure 2.33 The difference in nose length between the Afghan hound (left) and the Pekingese (right) can be explained by groups of genes being activated for different periods of time during each puppy's development; the actual genes might be similar.

ISBN 9780170189071

WOW!

Alexander the Great's horse had toes!

Very rarely, animals are born with features that resemble those of their remote fossil ancestors. This is known as atavism. For example, horses and donkeys sometimes show zebra-like stripes on their hind quarters. In horses, the fused digits that end in hooves are occasionally separate, leading to tiny, extra hooves.

Such unusual features were once thought to inspire dread and were therefore sought after for leaders' warhorses. Bucephalus, ridden by Alexander the Great (356–323 BCE), had toes.

How might this feature be explained by the action of supergenes?

Figure 2.34 In this Hox mutant (right), the fly's balancing organs have been transformed into a second pair of wings.

Figure 2.35 Pegasus is a myth: the addition of a pair of wings is too radical a departure from the typical four-limbed body plan found in vertebrates.

Is evolution still happening?

Scottish bacteriologist Alexander Fleming (1881–1955) and Australian pathologist Howard Florey (1898–1968) discovered in 1928 that penicillin could kill bacteria (see Unit 1, *Nelson iScience 8*). Penicillin has since been widely used to treat bacterial infections in a range of living things. Because of the overuse of antibiotics such as penicillin, bacteria are now becoming resistant. Disease-causing bacteria that are resistant to a broad range of common antibiotics are referred to as 'superbugs'.

The overuse and misuse of antibiotics is a very real health problem in countries with easy access to antibiotics. Since viruses are not living, they cannot be killed with antibiotics; therefore, antibiotics should not be prescribed for viral infections. Antibiotic awareness campaigns – such as Australia's 'Common colds need common sense, they don't need antibiotics' and Europe's 'Antibiotics are wasted on cold and flu' – attempt to combat this misuse that is leading to drug-resistant strains of superbugs.

Staphylococcus aureus (or golden staph) is a notorious superbug found in hospitals. Once a cause of minor skin infections, it is now known to cause death by pneumonia or blood poisoning. Since bacteria have short generation times, their population size grows rapidly and their rate of evolution is extremely fast. In 1961 *S. aureus* was not resistant to the antibiotic methicillin; however, this superbug appeared within one year. Doctors treated a patient suffering from this methicillin-resistant *S. aureus* (MRSA) with the antibiotic vancomycin. During the treatment, the MRSA evolved over 35 mutations to become vancomycin-resistant as well. This is why the overuse of antibiotics should be avoided and the full course of antibiotics must be finished to ensure all bacteria are killed off (Figure 2.36 on page 68). If any bacteria are left in a person's system, those that take longer to be killed by the antibiotic will survive to reproduce. They will pass their 'resistant' genes on to their offspring. Bacteria also have the ability to transfer their antibiotic resistance genes to other species of bacteria, compounding the problem.

glossary terms

divergent evolution
evolutionary change caused by the modification of existing structures

pentadactyl limb
a limb with five digits (or fingers)

phyla
a very large taxonomic group, such as echinoderms, arthropods and chordates

vestigial
reduced, degenerate or non-functional

ISBN 9780170189071

Figure 2.36 Always complete a course of antibiotics to ensure all the bacteria are killed off.

Questions 2.7
What have you learnt?

WORKSPACE
What have you learnt? 2.7
SCI10SUWR00056

Understand

1 What is artificial selection?

2 How is artificial selection different from natural selection?

3 List five species that have been bred through artificial selection. For each, what were the characteristics that were being selected for?

4 Give two examples of vestigial organs. Why haven't they been 'bred out' of the species?

5 What is the significance of supergenes?

Analyse

6 Is the evolution of technology, like computer software, an example of artificial selection? Explain your answer.

Synthesise

7 Develop a slogan that alerts people to the misuse of antibiotics.

8 Use the assumptions of natural selection (see page 58) to explain why bacteria are becoming resistant to antibiotics.

Reflect

9 Revisit and complete your concept or mind map.

ISBN 9780170189071

Unit review

ACTIVITY SHEET
Unit 2 checklist
SCI10SUAS00059

REVIEW QUIZ
Unit 2
SCI10SURQ00058

WORKSPACE
Unit 2 review
SCI10SUWR00060

Understand

1 Explain what is meant by the concept of a species.

2 Why is the fossil record incomplete?

3 Consider all the different types of fossils. Which type do you think is the most unlikely to occur? Use your knowledge of the process of fossilisation to explain your choice.

4 Explain how you can determine the age of a fossil located in rock strata.

5 How does the observation of camouflage in both predators and prey support the idea of natural selection?

6 Use the principle of superposition to explain how the dessert in Figure 2.37 was assembled.

Figure 2.37 Dessert

7 List the three different ways that populations of the same species could be isolated from one another.

Apply

8 Australian flightless birds all have wings. Use your knowledge of genetics and evolution to explain:

- **a** the tiny, useless wings of Australia's emu and cassowary
- **b** the effectiveness of little penguins' flipper-like wings.

9 Could natural selection occur if there was no variation within a species? What would happen if this species' environment suddenly changed?

10 The 1928 discovery of penicillin heralded a new era in medicine. Explain why today's microbes are developing antibiotic resistance.

ISBN 9780170189071

11 One hypothesis for the evolution of human intelligence attributes it to the female sexual selection of males.

- **a** How might you test this hypothesis?
- **b** Sexual selection by peahens for peacocks with long, colourful tails is countered by predator selection against the development of such tails. Can you suggest examples of selection pressures that might counter the development of intelligence?

Analyse

12 How are biodiversity and natural selection linked?

13 Consider the fossil remains shown in Figure 2.38. What can you infer about the organism from these remains?

Figure 2.38 Fossil remains

14 Research one Australian mammal that has recently become extinct. What new selection pressure contributed to its extinction? What features(s) might have helped it counter this pressure?

Synthesise

15 The last line in a student's essay was: `And so only those plants that had large green leaves survived as they could make the most of the small amount of sunlight available to them.' Write the beginning of the essay.

Evaluate

16 Consider all the evidence available to support the theory of evolution by natural selection. Which type of evidence do you think is the most compelling? Give reasons for your opinion.

17 Certain scientists discussed in this unit might have acted unethically when viewed from the values of today's society. Darwin has been accused of plagiarising; and Haeckel, exaggeration. Analyse the pressures, motivations or societal conditions that might have contributed to their actions.

Reflect

18 Major extinctions are a fact of Earth's long geological history. Should we care that the Earth is presently losing biodiversity at unprecedented rates? Give reasons for your opinion.

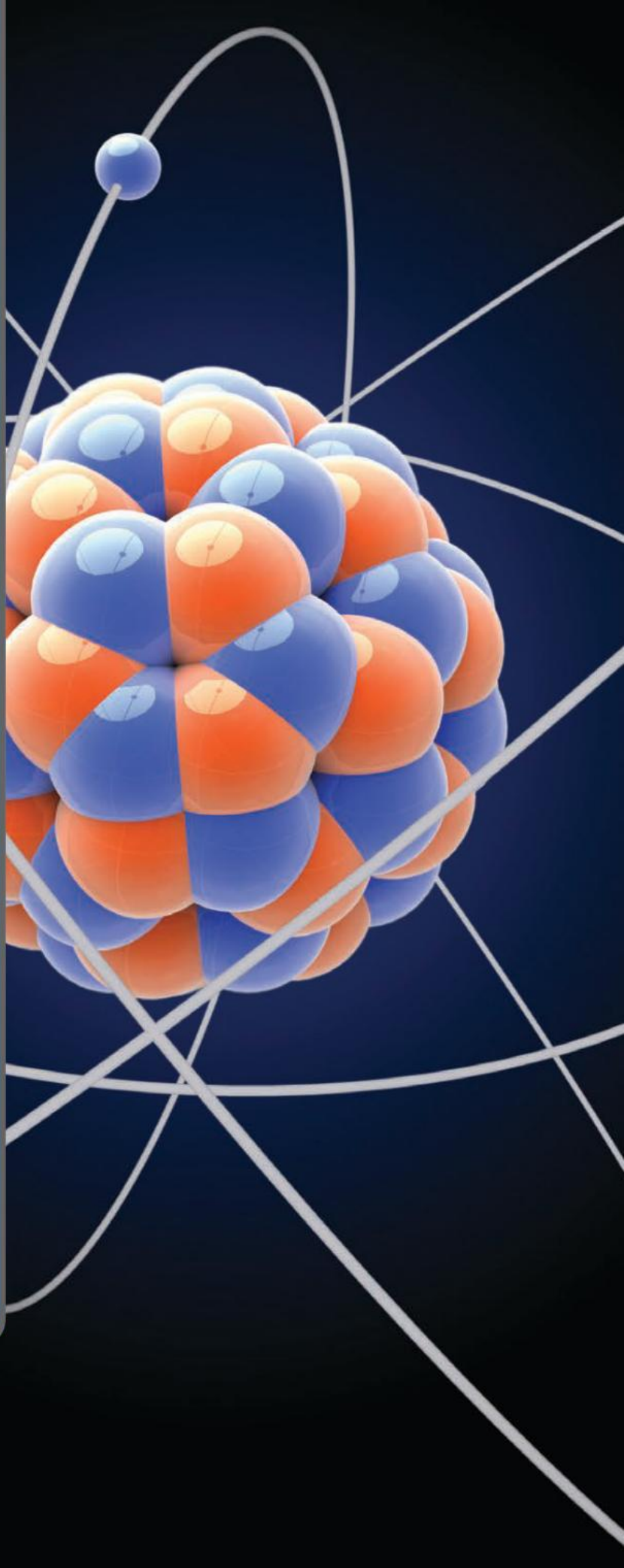
19 Return to your graffiti pages. How have your ideas changed since the start of the unit? Answer the questions that were posed in Activity 2.1.

20 Complete your concept or mind map organising the evidence for evolution. Do you think this evidence is compelling enough to transform the theory of evolution by natural selection into scientific fact? Explain.

ISBN 9780170189071

3

Organising and classifying elements: understanding structure



How are an element's structure and properties related?

Since the earliest days of chemistry, attempts have been made to arrange the known elements in ways that revealed similarities and differences between them. You have discovered the structure of the atom in terms of the subatomic particles of which it is made and also how atoms can rearrange in chemical reactions to form new substances. And just as chemists' understanding of atomic structure continues to develop as new technology reveals more about these particles, so will your understanding grow and change.

What do you already know about atoms?

In this unit you will learn more about the arrangement of the particles within atoms, and how this arrangement relates to an element's properties and its position in the periodic table.

Similar to chemists, you will learn how an understanding of an atom's structure can be used to make predictions about the properties of elements and the reactions they undergo.

In *Nelson iScience 9* you learnt about atoms, isotopes and the periodic table. The quiz in the following activity will give you a chance to find out what you remember.

Figure 3.1 The periodic table

Activity 3.1
Atom and isotope quiz

WORKSPACE
Atom and isotope quiz
SCI10SUWR00061

1 Match each word on the right with a statement on the left.

Positive particle in the nucleus	Neutron
Atom with the same atomic number but different mass number	Mass number
Neutral particle in the nucleus	Marie Curie
Negatively charged particle orbiting the nucleus	Isotope
Scientist who pioneered work on radioactivity	8
Scientist credited with the development of the periodic table	Electron
Represented by the letter 'Z'	6
Represented by the letter 'A'	Proton
Number of neutrons in nitrogen-15	Dmitri Mendeleev
Number of electrons in carbon-12	Atomic number

ISBN 9780170189071

2 Complete the following table of information related to the particles that make up an atom.

Particle	Symbol	Charge	Mass	Where found in the atom
Proton				
Neutron				
Electron				

Culminating assessment task

Investigating a group in the periodic table

Research one group in the periodic table. Compare at least four elements in your chosen group. Compare their properties and structure to justify why they should be in the same group.

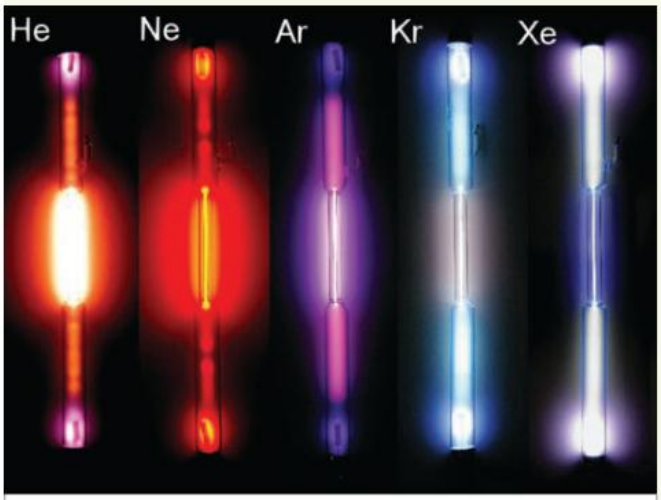


Figure 3.2 Noble gases produce coloured light when their atoms are excited.

1 **a** Name the group.

b Identify at least four elements in this group and represent them using the correct conventions, including name, symbol, atomic number and mass number.

c Draw or find a diagram of the electron arrangement of each atom in the group.

d Provide data in both table and graphic form on three physical properties, such as melting or boiling point.

2 **a** Describe at least two chemical properties of each of the identified elements.

b Describe at least two uses of each element.

3 Evaluation: Compare the properties and structure of the identified elements, highlighting similarities and differences and justifying why they are in the same group.

Figure 3.3 Alkali metals are very reactive.

4 Use technology to present your results to the class at the end of the unit.

WEB 2.0

You could use a presentation tool such as Prezi, Keynote or PowerPoint, or you could present your findings as a movie.

ACTIVITY SHEET

Rubric: Investigating a group in the periodic table

SCI10SUAS00062

ISBN 9780170189071

The atomic story so far

In Year 9 you learnt how scientists developed increasingly sophisticated models of the atom as new evidence emerged. Because atoms are so small, scientists were not able to look at them directly. However, they were able to look at secondary effects caused by atoms and develop hypotheses based on these effects.

Many scientists contributed to the current understanding of the structure of the atom. They built on the understandings of colleagues and predecessors by incorporating new evidence from their own experiments and discoveries.

Major milestones

Although many scientists contributed to the understanding of the atom, there were some major contributions in the timeline of discovery that made significant leaps in understanding.

1803 English meteorologist and chemist John Dalton (1766–1844) proposed the idea of atoms being solid spheres based on measurable properties of mass.

1897 English physicist J. J. Thomson (1856–1940) announced the existence of the electron and, by bending a beam of electrons in a magnetic field, determined that it had a negative charge.

1909 French physicist Jean Perrin (1870–1942) provided definitive evidence of atoms by measuring the motion of microscopic pollen particles suspended in water.

1911 New Zealand-born physicist Ernest Rutherford (1871–1937) established that the atom has a nucleus and that it was very dense, small and positively charged. He did this by firing alpha particles at a thin piece of gold foil and observing that some of them were deflected rather than passed straight through it.

1914 English physicist Henry Moseley (1887–1915) supplied experimental evidence for the existence of protons.

1919 English physicist Francis Aston (1877–1945) discovered the existence of isotopes using an instrument called a mass spectrograph.

1932 English physicist James Chadwick (1891–1974) measured the rebound of certain radiation from nitrogen and helium and found it corresponded to a neutral particle about the same mass as a proton, thus confirming the existence of the neutron.

So by the 1930s all major parts of the atom had been discovered, but there were still many questions about the atom to be answered.

Activity 3.2
Atomic structure timeline

Connect to the website 'Atomic structure timeline' to learn about the contributions of many more scientists to the development of an understanding of the atom. Use key words in your findings to create a wordle. Remember that words that are the most important should be larger.

WEBLINK
Atomic structure timeline

WEBLINK
Wordle

WOW!

The atom is mostly empty space

If you were to remove all the electrons from all the atoms that make up the Sydney Opera House, you would be left with only their nuclei. These would pack together to be about the size of a single die. However, because most of the atom's mass is in the nucleus, the die would weigh as much as the Opera House.

Figure 3.4 A dice of nuclei

ISBN 9780170189071

Where do the elements come from?

The periodic table of the elements provides a list of all the known elements in order of atomic number. But where did these elements come from in the first place? So far you have learnt that atoms are composed of protons, neutrons and electrons. There is one exception to this: hydrogen.

Hydrogen – the most abundant element in the universe – has 99% of its atoms made up of one proton and one electron. Most hydrogen atoms don't contain any neutrons. There are, however, two isotopes of hydrogen with neutrons: deuterium, which has one proton, one neutron and one electron; and tritium, which has one proton, two neutrons and one electron.

So why is the simplest element the most abundant? Where does it come from?

Activity 3.3

The answer is ...

WORKSPACE

The answer is ...

SCI10SUWR00064

1 The answer is proton. What are five possible questions?

2 The answer is neutron. What are five possible questions?

3 The answer is electron. What are five possible questions?

WEB 2.0

Record your answers to these questions on your blog.

Formation of elements

Most scientists believe that the universe began as a massive, unbelievably dense ball of matter that suddenly exploded about 1.37 billion years ago. This theory is known as the big bang theory (see Unit 5).

During this mighty and brief explosion, hydrogen – which makes up 90% of the universe – and a small amount of helium were formed. Eventually, hydrogen atoms clumped together into stars. The extreme gravitational pressure inside a star causes hydrogen atoms to begin fusing together to form helium, releasing the energy that powers the star.

Figure 3.5 The Orion Nebula, in the handle of the Saucepan, is a place where new stars are formed.

Stellar ovens

When a star begins to run out of hydrogen fuel, things start to get more interesting. Stars lacking hydrogen begin to fuse helium in their cores. Sometimes the helium atoms fuse together to form even-numbered elements, and sometimes protons and neutrons are ejected so that odd-numbered elements are made. Soon there are appreciable amounts of lithium, boron, beryllium and carbon inside the star.

At this point, small stars may 'die' creating a white dwarf, which is primarily carbon.

glossary terms

alpha particle
a helium nucleus emitted when an unstable larger nucleus decays

deuterium
an isotope of hydrogen with one proton, one neutron and one electron

tritium
an isotope of hydrogen with one proton, two neutrons and one electron

ISBN 9780170189071

WOW!

A diamond in the sky

A white dwarf star nicknamed Lucy, approximately 50 light years away in the constellation Centaurus, has been found to have the biggest diamond in the universe at its core. Scientists were able to verify the presence of the diamond using modern analysis technologies. Lucy's diamond has been estimated to be 4000 km in diameter.

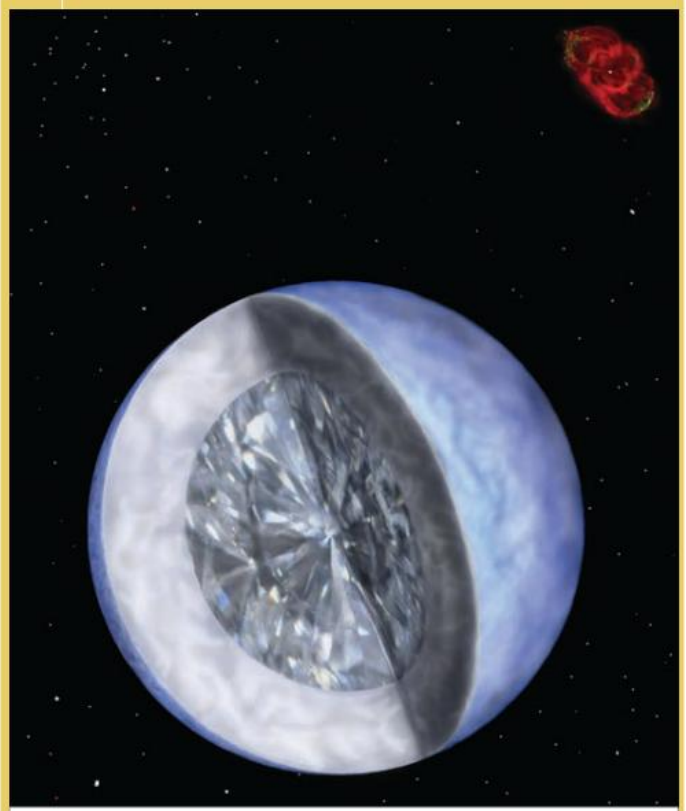


Figure 3.6 Lucy's diamond

Activity 3.4

A diamond in the sky

Read the WOW box 'A diamond in the sky'. What would you do with a diamond this size? Itemise what you would do and justify why you would do it. Upload your response to the class wiki.

Heavier stars – those at least eight times more massive than the Sun – continue to produce new elements up to magnesium. Some of the stars then perish; however, the biggest, hottest ones continue on, producing all the elements up to iron (atomic number 26). The iron nucleus is the most stable nucleus in nature: it resists fusing into any heavier nuclei.

So where do elements 27 to 92 come from?

Supernova

When an extremely massive star explodes into a supernova (Figure 3.7), it produces a huge amount of light and releases an extremely large number of neutrons. The neutrons are rapidly captured by the various nuclei released by the exploding star, leading to the formation of elements up to uranium (atomic number 92).

So what about the rest of the elements in the periodic table – numbers 93 to 112? These elements are not found naturally. They have been synthesised by scientists using very specialised equipment. Later in this unit, you will learn more about how this happens.

Figure 3.7 Six light years wide, the Crab Nebula is an expanding remnant of a star's supernova explosion.

VIDEO

Origin of the Earth's elements

SCI10SUVD00065

ISBN 9780170189071

Questions 3.1

What have you learnt?

WORKSPACE

What have you learnt? 3.1

SCI10SUWR00066

Understand

1 What major discovery did Ernest Rutherford make about the atom?

2 What contribution to an understanding of the atom did Henry Moseley make?

3 Why is hydrogen the most abundant element in the universe?

4 Name the theory that describes the beginning of the universe.

5 Which element has the most stable nucleus?

6 Helium is an even-numbered element. How are the odd-numbered elements formed?

7 Why aren't elements beyond uranium found in stars?

8 Explain why the heavier stars only produce elements up to iron.

Analyse

9 Using your knowledge of the structure of the atom, propose why the electron was the first subatomic particle discovered.

10 Suggest why the discovery of the neutron occurred so much later than that of the proton and electron.

11 Refer to the major milestones in our understanding of the structure of the atom on page 74. How did each of these discoveries contribute to our combined knowledge of the atom?

Development of the periodic table

As you have learnt in Years 8 and 9, Russian chemist Dmitri Mendeleev (1834–1907) is credited with creating the periodic table of the elements. Many scientists developed tables to demonstrate relationships between elements. What set Mendeleev's table apart from the others?

To organise the elements, Mendeleev wrote down their chief properties on cards and arranged the cards into groups with similar properties. He then organised the groups, and the elements within the groups, according to their characteristic mass. Other scientists had arranged the elements into groups according to mass; however, Mendeleev took three bold steps in his arrangement:

1 He left gaps in the table for missing elements, and was so sure of himself that he predicted both chemical and physical properties of the missing elements.
2 When experimental evidence was contradictory, he was prepared to place elements in a different group.
3 Mendeleev was prepared to place the elements in his table in the wrong order of atomic mass if the common properties supported his theory about groups.

The genius of Mendeleev's insight was revealed when other scientists found the missing elements and their properties matched those predicted by Mendeleev. The discovery of isotopes supported his decision to consider properties before mass in his arrangement.

Remember that, when Mendeleev developed his table, he did so using the experimental evidence of observed properties – electrons, protons and neutrons were unknown at that time.

WEBLINK

Mendeleev activity

INTERACTIVE

The elements

SCI10SUIN00068

INTERACTIVE

The elements: classify elements

SCI10SUIN00068

ISBN 9780170189071

Activity 3.5

Comparing properties

WORKSPACE

Comparing properties

SCI10SIWR00067

What are the risks in doing this activity?	How can you manage these risks to stay safe?
Copper sulfate solution is toxic.	Be extremely careful when using this chemical. Wear safety goggles. If spilt on skin, wash with plenty of water. Dispose of in waste jar provided. **Do not** pour it down the sink.
Sodium hydroxide solution is caustic and can burn the skin.	Be extremely careful when using this chemical. Wear safety goggles. If spilt on skin, wash it with plenty of water.

Background

The original designers of the periodic table used experimental evidence of the properties of the elements to make decisions about their placement in the table. In this investigation you will compare the properties of two metals used as electrical conductors and two metals used in nails.

Materials

- 1 × 2.5 cm piece of aluminium wire
- 1 × 2.5 cm piece of copper wire
- 1 steel nail
- 1 galvanised nail (steel nail coated with zinc)
- 2 test tubes
- 100 mL beaker
- test-tube rack
- measuring cylinder
- 25 mL 1 mol/L sodium hydroxide solution
- 25 mL 1 mol/L copper sulfate solution
- safety goggles
- digital video camera (optional)

Method

1 Examine the aluminium and copper wires and record as many of their physical properties as you can.

2 Place the aluminium wire in one test tube and the copper wire in the other.

3 Measure out 5 mL of the sodium hydroxide solution and pour it into the test tube containing the aluminium wire.

4 Predict what you think is going to happen now.

5 Measure out 5 mL of the sodium hydroxide solution and pour it into the test tube containing the copper wire.

6 Observe the test tubes for a few minutes and then record your observations.

7 Examine the steel and galvanised nails and record as many of their physical properties as you can.

8 Lay both nails in the bottom of the beaker, making sure they do not touch.

9 Predict what you think is going to happen now.

10 Measure 20 mL of the copper sulfate solution and carefully pour into the beaker.

11 Observe for a few minutes and then record your observations.

Results

1 Write down all of your observations.

2 How did your observations compare with your predictions?

Discussion

3 How are aluminium and copper the same? How are they different?

4 The steel nail is mostly iron, while the galvanised nail is a steel nail coated with zinc. Both nails perform the same function. How are they different? Why are they different?

5 If you were developing the periodic table based on the properties you examined, would you put these elements in the same group or different groups? Justify your decision.

WEB 2.0

You could record this activity using a digital video, and create a podcast to convey your observations.

ISBN 9780170189071

The periodic table today

The periodic table we use today looks quite different from Mendeleev's table. One reason for this is that the elements are now placed in order of atomic number, not atomic mass. Another reason is that many new elements have been discovered – when Mendeleev created his table, there were only 63 known elements; today there are 114 elements, with more pending.

The most familiar format of the periodic table is the one found in most chemistry laboratories, classrooms and textbooks (see Figure 3.1 on page 72). More than 700 versions of the periodic table have been produced since Mendeleev first presented his in 1869. Scientists have developed alternative formats of these versions in an attempt to illustrate different patterns and relationships between elements. For example, Figure 3.8 shows a spiral periodic table, and Figure 3.9 on page 80 shows a layered periodic table.

New elements

In May 2012, the naming of elements 114 and 116 was confirmed. The scientists who discovered these were invited to propose names for them. The proposed name for element 114 was flerovium; and for element 116, it was livermorium. These names went through a review process by the International Union of Pure and Applied Chemistry (IUPAC) before being adopted. It is IUPAC that gives official recognition to any new element.

Figure 3.8 The spiral periodic table

ISBN 9780170189071

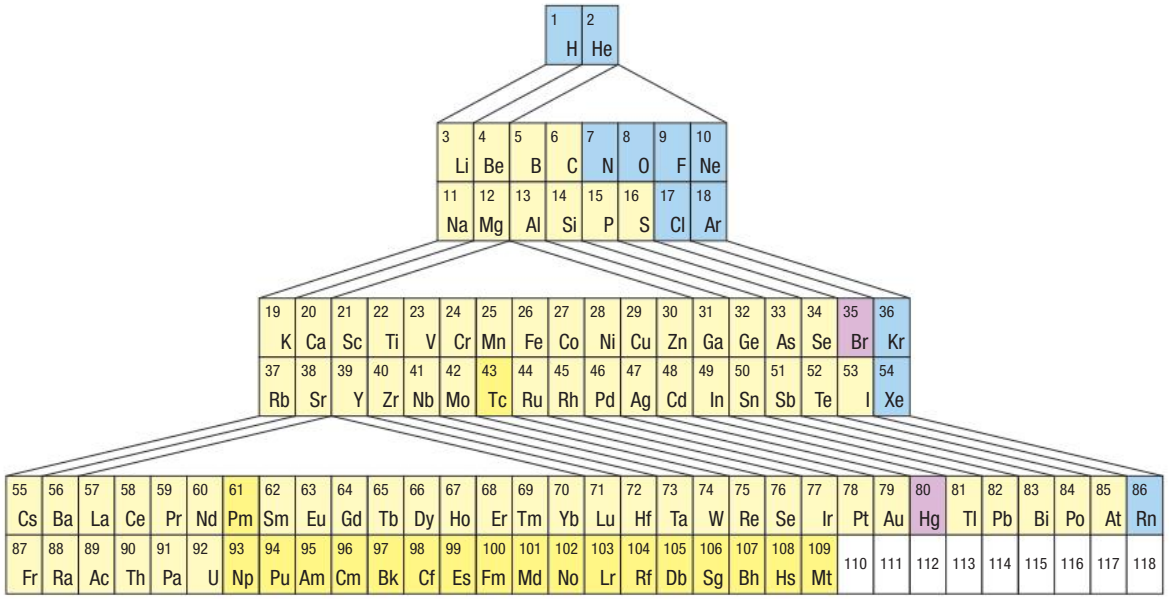


Figure 3.9 Layered periodic table

Identifying patterns

The periodic table has been specifically designed to provide order to the elements. If you look at the blank table in Figure 3.10, you will see it consists of 18 jagged columns (groups) and seven horizontal rows (periods), with two extra rows hanging below. Each of the blank boxes represents an element, and each element has a specific position. The position of an element determines nearly everything scientifically interesting about it.

Changing groups

If you look at a pre-1990s version of the periodic table, you will see the groups numbered with Roman numerals. For example, group 8 was once called group VIII. The convention was changed by IUPAC to the simpler convention used today.

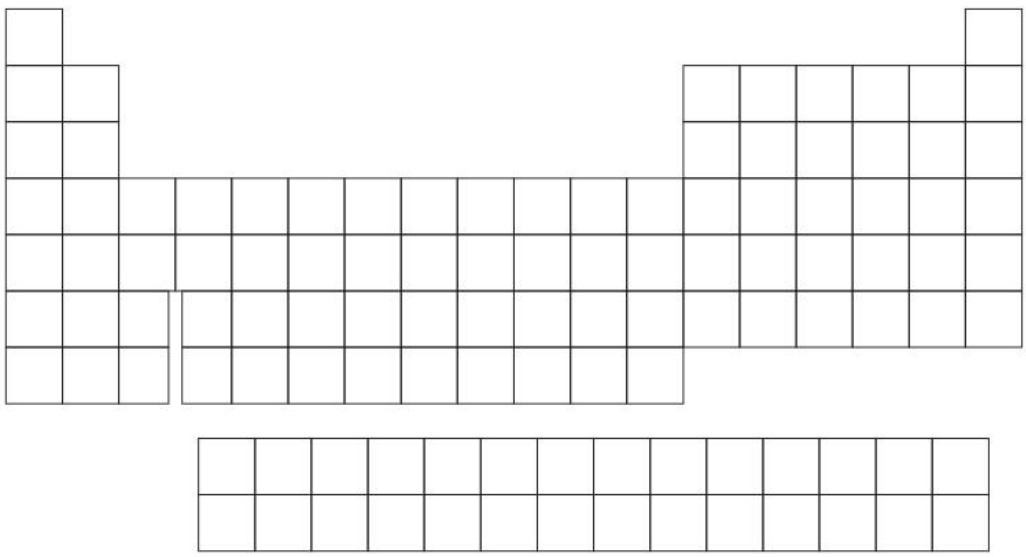


Figure 3.10 Blank periodic table

ISBN 9780170189071

Most of the elements are solids at room temperature (25°C); two, mercury and bromine, are liquids and 10 are gases. Metals make up 75% of the elements, while the remainder are either non-metals or metalloids (sometimes referred to as semimetals). Metalloids are elements that have properties somewhere between metals and non-metals. Each of the three groupings has distinct physical properties by which it can be classified.

Some sets of elements have particular names. These are listed in Table 3.1.

Table 3.1 Special sets of elements of the periodic table

Set of elements	Name
Group 1 (except hydrogen)	Alkali metals
Group 2	Alkali earth metals
Groups 3–12 (except those in the separate rows below the table)	Transition metals
Group 17 non-metals	Halogens
Group 18	Noble gases
Elements 57–71	Lanthanoids, or the lanthanoid series
Elements 89–103	Actinoids, or the actinoid series
Elements from 93 onwards	Transuranium elements

Table 3.2 The physical properties of metals

Property	Description
Metallic lustre	Mirror-like shininess (see Figure 3.11 on page 82)
Good conductor of heat	Allows heat to travel from one end to the other
Good conductor of electricity	Allows an electric current to travel from one end to the other
Malleable	Able to be beaten into another shape without breaking
Ductile	Able to be drawn out into a wire

Activity 3.6
My own periodic table

Part A

The weblink 'Periodic table quizzes' has information about the periodic table and the properties of the groups. There are activities and quizzes to check your understanding. Click the link to start and then choose 'The periodic table'. Once you have completed this one, you could also try 'Groups in the periodic table'.

WEBLINK
Periodic table quizzes

Part B

Complete the following.

1. Create a new way to present the periodic table.
2. Explain why you have presented it the way you have.
3. Upload this to the class wiki.
4. Look at the way others have presented the information. Which way do you prefer and why?

VIDEO
The noble gases
SCI10SUVD00069

Comparing the physical properties of metals, non-metals and metalloids

While elements are grouped on the basis of common properties, this does not mean that every element in this grouping has all the common properties. In the case of metals, all metals have the physical properties listed in Table 3.2 in common. However, a number of other properties do vary from metal to metal, as shown in Table 3.3 on page 82.

glossary terms

group
a vertical column in the periodic table; elements in the same group have similar properties

metalloids
nine elements whose properties are between metals and non-metals; they are found between metals and non-metals in the periodic table

period
a horizontal row in the periodic table; elements in the same period have similar size

ISBN 9780170189071

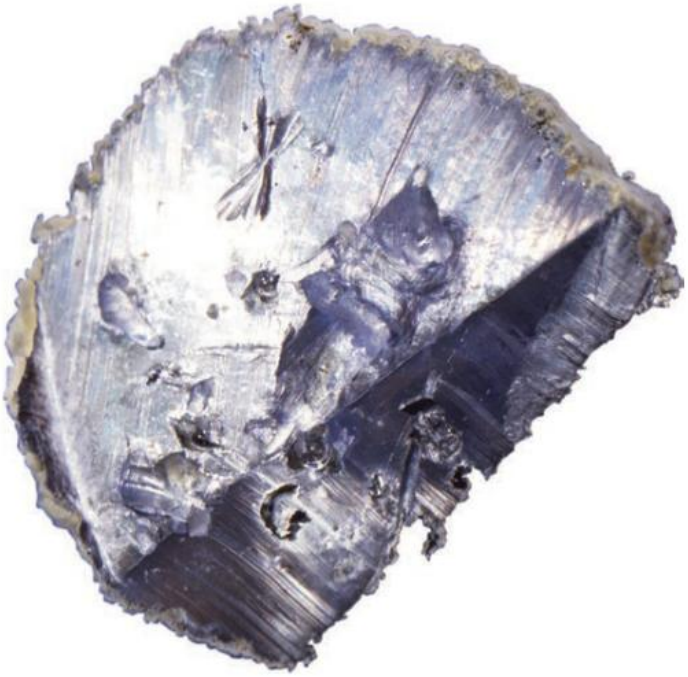


Figure 3.11 Freshly cut potassium metal shows typical metallic lustre.

Activity 3.7
Five whys

WORKSPACE
Five whys
SCI10SIWR00070

Complete a five whys on the question: 'Why is it important to know about the properties of metal?'

WEB 2.0

Upload your final answer to the class wiki.

Table 3.3 Some of the properties that vary from metal to metal

Property	Meaning	Comment
Hardness	• The material is scratch-resistant. • The hardest substance cannot be scratched by any other material.	• Most metals are fairly hard to scratch. • Gold, lead and calcium are examples of soft metals – that is, they are easily scratched.
Density	• This refers to the number of grams in each cubic centimetre of a material. • If a material is denser than water, it will usually sink in water.	• Density varies from metal to metal. • For example, 1 cm^3 of gold weighs 19.3 g, but the same volume of aluminium weighs only 2.7 g. Gold is described as a very dense metal, whereas aluminium is considered to be a 'light' (not very dense) metal.
Tensile strength	• The material has the ability to withstand a stretching force. • For example, the material in cables suspended between poles must have high tensile strength.	• Tensile strength varies considerably from metal to metal. • For example, steel (which is mostly iron) has greater tensile strength than aluminium.
Melting point (MP)	• The temperature at which the material melts – that is, it turns from a solid to a liquid.	• The MP varies considerably from metal to metal. • For example, mercury is already a liquid at room temperature (its MP is −39°C), but a large number of metals require temperatures in excess of 1000°C to melt them.

ISBN 9780170189071

Unlike metals, non-metals show a lot of variation in their properties. Ten are gases at room temperature, one is a liquid and the remainder are solids. The solid non-metals, such as carbon and sulfur, are brittle and have a dull appearance. In fact, non-metals tend to be classified by what they cannot do, such as conduct heat and electricity.

All the metalloids are solids, except hydrogen. These elements have some similarity to metals and some to non-metals, depending on the particular element. For example, silicon and germanium are shiny like metals, but brittle like non-metals. They may also conduct electricity, but only under certain conditions. For this reason they are called semiconductors.

Activity 3.8
Properties crossword

Create a crossword on metals, non-metals and metalloids. Use information about hardness, density, tensile strength and melting point from Table 3.3 when developing the clues.

WEBLINK
Crossword maker

Activity 3.9
Investigating the physical properties of metals and non-metals

WORKSPACE
Investigating the physical properties of metals and non-metals
SCI10SIWR00071

What are the risks in doing this activity?	How can you manage these risks to stay safe?
When hammering, any solid material can fly up into your eyes.	Safety goggles and protective clothing must be worn at all times. Also take care that you do not hit your hand!
Some metals and non-metals are toxic.	Wash your hands with soap and water after the investigation, before you leave the room. Do not touch your face – especially eyes, nose and mouth – before washing your hands.

Aim

To test and compare malleability, hardness and electrical conductivity of some metals and non-metals.

Materials

- samples of non-metals, such as carbon and sulfur
- samples of metals, such as zinc, iron, aluminium, copper and tin
- hammer and board
- iron nail
- quartz crystal
- 3 electrical wires
- 2 alligator clips
- power pack
- ammeter
- stereomicroscope
- Petri dish
- safety goggles, lab coat and gloves

Method

1 Examine the metals and non-metals first with your naked eye and then under the stereomicroscope (on the Petri dish). Note any similarities and differences in their appearances. Record your observations.

glossary term

semiconductor
a substance that can weakly pass heat or electricity from one end to the other

ISBN 9780170189071

2 Prior to performing each test below, predict what you think is going to happen.

3 Place a small piece of each substance you are testing, in turn, on the board and hit it with the hammer. Does it bend or shatter? Record your observations.

4 Try scratching each substance first with the sharp point of an iron nail and then with the quartz crystal. Which substances did the iron nail scratch? Which did the quartz crystal scratch? Record your observations.

5 Set up the electric circuit shown in Figure 3.12. Check if the circuit is working by placing a copper wire in the circuit – the ammeter should produce a reading.

6 Replace the copper wire with each metal and then each non-metal in turn. Does the ammeter produce a reading for each? Record your observations.

7 Place all the metals and non-metals in the containers provided by your teacher and pack up.

Results

Record all of your observations in a table similar to Table 3.4 or on a spreadsheet.

Table 3.4 A comparison of metals and non-metals

Property	Metals	Non-metals
Appearance		
Malleability		
Hardness		
Electrical conductivity		

Discussion

1 What did you find about the electrical conductivity of metals compared with non-metals?

2 Can you think of a property exhibited by some metals but not others? Discuss, using examples to support your answer.

3 Which substances were hard? Which were not?

4 State one everyday application of each of the following properties.

a Good electrical conductor

b Non-conductor of electricity

c Malleable

d Hard

5 Is it reasonable to draw general conclusions about properties from the number of samples you examined? Discuss.

6 How did your observations compare with your predictions?

7 What questions do you have about this activity?

Conclusion

8 How do the metals that you tested compare with non-metals? Are there any generalisations that you can make based on your results?

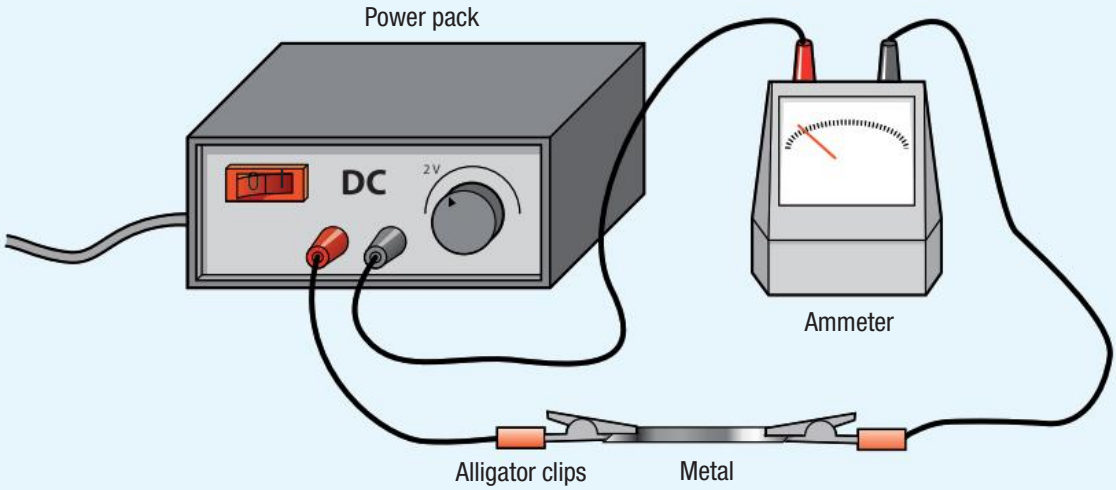


Figure 3.12 Testing electrical conductivity

ISBN 9780170189071

Activity 3.10
Identifying patterns in the periodic table

In this activity you will label and classify groupings of the elements using either an electronic version of the periodic table or your own paper copy.

Materials

- a paper printout of a blank periodic table (see Figure 3.10 on page 80), or a blank electronic version (see weblink below)
- different-coloured highlighters
- pencil
- pen
- access to a computer

WEBLINK
Blank periodic table

Method

1 Go to the weblink 'Interactive periodic table'. Use the drop-down menus in the bottom left-hand corner to change the category. Make sure you have the heading just above the menus set to 'Classification'.

WEBLINK
Interactive periodic table

2 Number the groups and periods of the periodic table on your own copy.

3 Use three different-coloured highlighters to colour in the elements classified into the following categories.

- Metals (using just the 'Properties' drop-down menu)
- Metalloids (using just the 'Classification' drop-down menu in the second column)
- Non-metals (these are the elements remaining)

Include a key at the bottom of your periodic table. Make sure you set the drop-down menus back to their original positions before you move on to the next category.

4 Reset the drop-down menus to their original positions and then use the 'Classification' drop-down menu in the second column for the categories identified in step 3. Label each special set identified in Table 3.1.

5 Set the drop-down menus back to their original positions. Use the 'Properties' drop-down menu to investigate the states of the elements at room temperature. Label the gaseous elements with 'g' and liquid elements with 'l'. The remaining elements on the periodic table are all solids. You do not need to fill these in.

Note: IUPAC keeps the most up-to-date and latest version of the periodic table. Go to their website to download and print the latest version.

WEBLINK
Latest version of the periodic table

Questions 3.2
What have you learnt?

WORKSPACE
What have you learnt? 3.2
SCI10SUWR00072

Understand

1 True or false? Modify the statements you believe are false to make them true.
   a Today's periodic table has elements listed by atomic weight.
   b Elements are manufactured in stars.
   c In the periodic table, elements with similar properties are in the same row.
   d Dmitri Mendeleev based his periodic table on the properties of elements.

2 Examine the periodic table and answer the following questions.
   a How many elements are there?
   b State what the number of each element is called and what it tells us.

ISBN 9780170189071

c How many groups are there?
d How many periods are there?
e What family name is given to the elements of group 18?
f What do the elements of group 18 have in common?
g Name an element that is in the same period as chlorine.
h Name an element that is in the same group as chlorine.

3 Complete the following sentences using the words below to fill in the gaps. Each word is to be used once.

heat wires electricity high
malleable metals brittle

a Metals usually have _____ melting points, while non-metals vary from very low to very high.
b All _____ conduct electricity and _____.
c Metals are _____ and ductile, meaning they can be beaten into shapes and drawn into _____.
d Solid non-metals are _____.
e Metalloids are brittle but may conduct _____.

Apply

4 Which of the following pairs of elements would you predict to have the most similar chemical properties: carbon and silicon, or nitrogen and oxygen? Justify your answer.

5 Which element has twice as many protons as an oxygen atom? Explain your reasoning.

6 Revise your knowledge of the periodic table so far by completing the quiz in the weblink 'Periodic table quiz'.

WEBLINK
Periodic table quiz

Electrons drive the chemistry of atoms

So far we have learnt about the structure of the atom and how the similarity in properties of elements is used to organise them into groups in the periodic table. Now it is time to connect these two ideas.

The most reactive groups in the periodic table are the group 1 alkali metals and the group 17 halogens. Group 18 (the noble gases) are completely unreactive under normal conditions. This was a puzzle chemists set out to solve by examining the arrangement of the electrons in the atoms.

Chemically, the electrons are the most important part of the atom. They take up almost all of the atom's space orbiting around the nucleus. If an atom was the size of a sports stadium, the nucleus would be equivalent to a tennis ball in the centre and the electrons would be pinheads flying around it. However, the electrons are moving so fast that, similar to the blades of a high-speed propeller, they would be like a solid wall. Consequently, it is the electrons that are gained, lost or shared when atoms combine. The protons remain in the nucleus and do not get involved in bonding.

The Bohr model

At the time Danish physicist Niels Bohr (1885–1962) proposed his model of the atom, the elements in the periodic table had been reordered on the basis of atomic number – that is, the number of protons. The number of protons defined the element. For example, if it is a helium atom, it has two protons; and conversely, if it has two protons, it must be helium. It was also known that the number of electrons could vary. However, why this was the case was not understood.

By the early 1900s, scientists had observed that atoms emitted light when heated. When this light passes through a scientific instrument called a spectroscope, it is broken into a set of coloured lines unique to each element (Figure 3.13). This set of lines is called an atomic emission spectrum.

Spectroscope

The spectroscope was invented in 1859 by German chemist Robert Bunsen (1811–1899) and his colleague physicist Gustav Kirchhoff (1824–1887). Both used it to discover two new alkali metals – caesium (in 1860) and rubidium (in 1861). The development of this technology allowed scientists to see the unique energy emission spectrum of each element.

ISBN 9780170189071

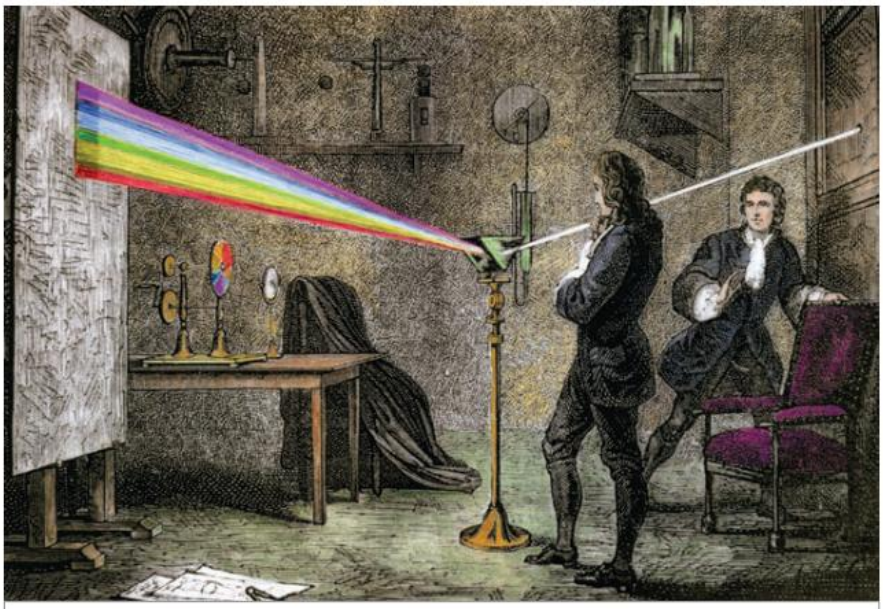


Figure 3.13 A spectroscope, showing the atomic emission spectrum

The new information about atoms revealed by the spectroscope provided experimental evidence that led Bohr to propose his model of the atom. He suggested the electrons of an atom could not be just anywhere; rather, they have only certain amounts of energy and revolve around the nucleus with different, fixed energy in a fixed path called an orbit. He focused on the spectrum of hydrogen, and was able to support his model using calculations based on energy values from the spectrum (Figure 3.14).

The Bohr model is based on the following assumptions.

- The electron in a hydrogen atom travels around the nucleus in a circular orbit.
- Only a limited number of orbits (called energy shells) with certain energies are allowed.
- The energy of the electron in an orbit is proportional to its distance from the nucleus. The further the electron is from the nucleus, the more energy it has.

Figure 3.14 The atomic emission spectrum of hydrogen

glossary terms

atomic emission spectrum
the set of wavelengths of light emitted by heated atoms; this is seen as a set of coloured lines on a black background when viewed through a spectroscope

Bohr model
the model of the atom developed by Niels Bohr that proposed the electrons orbited the nucleus in energy shells

bonding
the joining together of two or more atoms or ions

energy shell
a possible energy level that an electron might occupy; in the Bohr model of the atom, electrons can only be found in the electron shells according to definite rules

orbit
a circular path taken by an electron as it revolves around the nucleus

spectroscope
an instrument that is constructed from lenses and prisms and designed to break up light into its wavelengths

ISBN 9780170189071

- Electrons will always be located in the lowest possible energy shell (unless they are given extra energy).
- Energy is absorbed when an electron jumps from a lower energy shell to a higher one. It is emitted when an electron falls from a higher to a lower energy shell.
- The energy of the light emitted or absorbed is exactly equal to the difference between the energies of the shells.
- The energy shells are numbered outwards, with the energy level closest to the nucleus being level number 1, the next number 2 and so on.

The Bohr model was a marvellous success in explaining the spectrum of the hydrogen atom (Figure 3.15). His calculations agreed perfectly with the experimentally measured values of the spectral lines. Bohr knew that he was on to something – matching theory with experimental data is successful science.

Applying the Bohr model

The Bohr model can be used to deduce the electron arrangement for the first 20 elements according to the following rules.

1. The energy shells are filled from the innermost first.
2. Each energy shell can only hold a certain number of electrons according to Table 3.5.

Table 3.5 The maximum number of electrons for the first 20 elements

Shell number *n* (from nucleus outwards)	Maximum number of electrons
1	2
2	8
3	8
4	18

ANIMATION
Electron arrangement
SCI10SUAN00073

VIDEO
Electronic structure
SCI10SUVD00074

Modelling elements

The following example shows how to model the electron arrangement (or electron configuration) for carbon.

From the periodic table, we can see that carbon has an atomic number of 6, which means it has 6 protons. It is element number 6, telling us that a neutral atom of carbon has 6 protons and 6 electrons. Therefore, 6 electrons have to be placed into shells.

These electrons must be placed in the lowest energy shells possible. From Table 3.5, we see the first 2 electrons can fit in shell number 1, which has the lowest energy. This leaves 4 more electrons. These can all fit into the next shell. Figure 3.16 demonstrates how we show the electron arrangement.

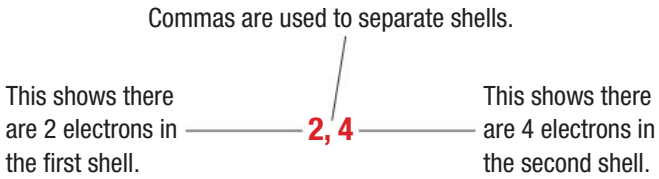


Figure 3.16 The electron arrangement of carbon

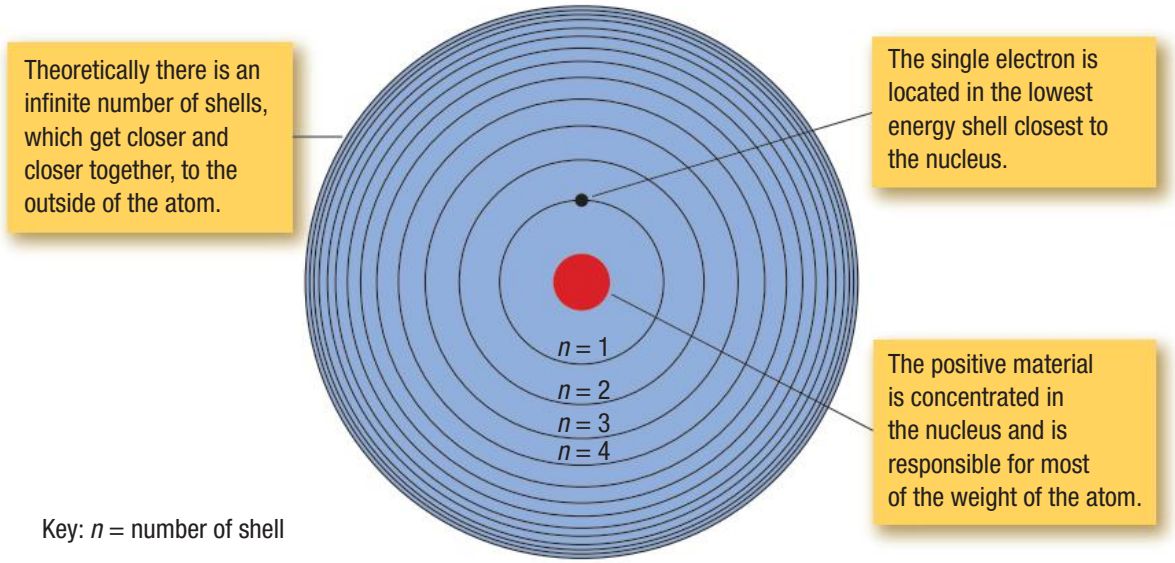


Figure 3.15 The Bohr model of the hydrogen atom

ISBN 9780170189071

Figure 3.17 shows how we model the carbon atom. Notice that, for convenience, we write the number of protons in the nucleus; we do not attempt to draw the particles in the nucleus. For the same reason, generally only the occupied shells are shown.

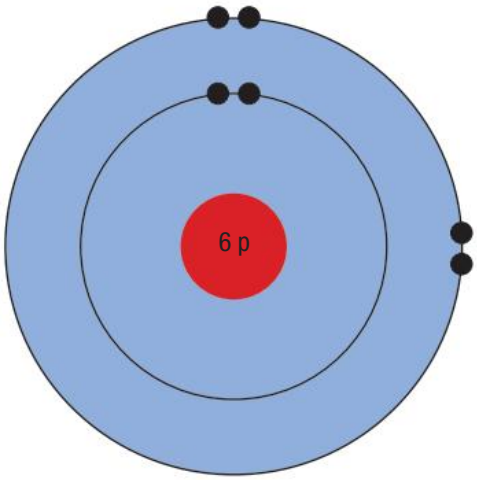


Figure 3.17 A model of the carbon atom

ACTIVITY SHEET
Using the Bohr model
SCI10SUAS00075

INTERACTIVE
Physical science: Bohr model – introduction
SCI10SUIN00068

Limitations of the Bohr model

Whenever you make a model to try to understand how something works, it always has its limitations. It is important to note that this is true of the model drawn in Figure 3.17.

- Real atoms are not coloured. Materials can only appear coloured to us if their particles absorb some of the wavelengths of light that fall on them. For example, the blue in the diagram only appears blue because the particles in the colour pigments absorb wavelengths in the red and green region of the spectrum of the light that hits them, and only reflect wavelengths in the blue region.
- Electron shells are invisible; it is only when they are occupied by electrons that their presence can be detected.
- The atom is not drawn to scale. For an atom to be sufficiently magnified so that its nucleus is visible, the scale drawing of the atom would have to be bigger than your school!
- The electron is drawn out of scale as well. Electrons are much, much smaller than the nucleus and they are not black.
- The nucleus contains particles that are not shown here.
- The atom is spherical; we can only show a two-dimensional image.
- Electrons spin around the nucleus at almost the speed of light – we have to 'freeze' them into a particular position to make them visible. They also do not actually orbit the nucleus in concentric shells

Bohr's model of the atom itself is also limited. It is very helpful for explaining in simple terms many aspects of how atoms interact. However, it must be remembered that, long ago, the far more complex Schrödinger model replaced the Bohr model. As more accurate spectroscopes were developed, it was found that what had appeared to be one spectral line on a spectrum was often a number of fine lines located close together.

Bohr's model was able to explain how the coloured lines on the atomic emission spectrum of hydrogen arose. However, it could not explain the additional or differing intensity spectral lines on the spectra of other elements. It therefore had to be refined. You will learn about the Schrödinger model if you study senior Chemistry.

glossary term

electron configuration
a listing of how many electrons are in each successive shell of an atom

ISBN 9780170189071

Questions 3.3

What have you learnt?

WORKSPACE

What have you learnt? 3.3

SCI10SUWR00076

Understand

1 True or false? If false, rewrite so that it is correct.
   - **a** The nucleus occupies only about one-tenth of the volume of the atom.
   - **b** The Bohr model of the atom states that electrons move in shells.
   - **c** The atom is practically empty space.
   - **d** The maximum number of electrons in any shell depends on whether it is the outside shell.

2 **a** Define an electron shell.
   - **b** Define an electron orbit.
   - **c** In which electron shell are electrons with the lowest possible energy to be found?
   - **d** How big is the nucleus compared with the size of the atom?

Apply

3 What is the difference between an electron shell and an electron orbit?

4 What is the electron arrangement of the uncharged atoms of the following elements?
   - **a** Oxygen
   - **b** Magnesium
   - **c** Argon
   - **d** Potassium

5 Draw the models of each of the atoms in Question **4**.

6 If a certain element has the electron arrangement 2, 8, 7, which element must it be?

Student research task

How has technology led to understanding atomic structure?

WORKSPACE

How has technology led to understanding atomic structure?

SCI10SHWR00077

You are to find out how scientists' understanding of atomic structure changed as a result of the development and use of particular technologies.

Research two technological devices from the following list.

- Cathode ray tube
- Spectroscope
- Mass spectrograph
- Linear accelerator
- Scanning electron microscope
- Particle accelerator

For each device, outline:

1 when the device was first developed and by whom

2 what scientific discovery it led to

3 how this discovery changed scientists' understanding

4 if and how this device is being used today.

ISBN 9780170189071

Electron arrangement and the periodic table

The development of the periodic table was based on experimental evidence of the chemical and physical properties of elements. The properties were known; however, the reason why elements had properties in common was not understood until Bohr proposed his model of the atom. It is the electrons that drive the patterns in the periodic table.

As we have discovered, there is a link between an atom's electronic arrangement and its position in the periodic table. For the first 20 elements, we can work out not only an atom's electron arrangement from its place in the periodic table, but also the atom's place in the periodic table from its electron arrangement.

Once you get past element 20, the organisation becomes more complicated. You will learn about the reasons for this in senior Chemistry.

Figure 3.18 on page 92 shows a section of the periodic table with the electrons arranged in order of their atomic number from 1 to 20. Moving down the table, we can see the number of the highest-occupied energy shell is the same as the period number. For example, all the elements in period 3 are filling the third energy shell. Moving across, from left to right, the energy shell becomes filled with electrons. By the time we get to the noble gases, the whole energy shell is filled.

Each element in a group has the same number of electrons in the outer shell. For example, all elements in group 2 have two electrons in their outer energy shell.

It is easy to work out how many electrons are in the outer shell. Simply count across the table, or look at the group number for the pattern.

Questions 3.4
What have you learnt?

WORKSPACE
What have you learnt? 3.4
SCI10SUWR00079

Understand

1 True or false? If the statement is false, rewrite it so that it is correct.
- **a** Atoms of elements in the same period have the same number of electrons in their outer shell.
- **b** The atoms of elements in group 14 have 14 electrons in their outer shell.
- **c** Elements in group 2 have similar chemical properties.

Apply

2 Use your periodic table to identify the elements from the following clues. State their names and chemical symbol.
- **a** Its atoms have 12 protons in their nuclei.
- **b** It is located in period 3, group 2.
- **c** It is the alkali metal in period 4.
- **d** It has similar chemical properties to carbon and is in period 5.
- **e** It is a noble gas and its highest filled energy level is 2.

3 Write the electron arrangement of the following elements.
- **a** Element number 8
- **b** Element number 15
- **c** Chlorine
- **d** Helium

4 The following electron configurations belong to uncharged atoms of certain elements. Identify the elements.
- **a** 2, 2
- **b** 2, 8, 6
- **c** 2, 8, 8, 1

Analyse

5 Predict how the size of atoms will change as you move:
- **a** across a period
- **b** down a group.

CONNECTION
History: Making new elements
SCI10SHCN00080

ISBN 9780170189071

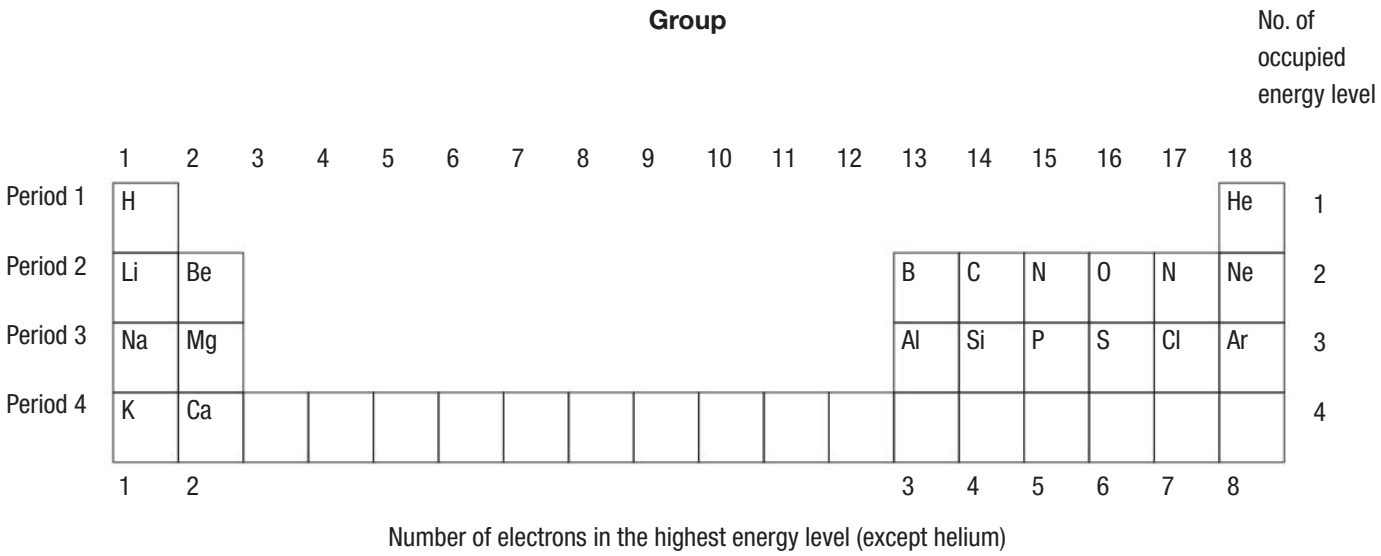


Figure 3.18 Periodic table with electrons arranged in order of their atomic number from 1 to 20

Activity 3.11
Organising elements by electronic structure

WORKSPACE
Organising elements by electronic structure
SCI10SIWR00078

Materials

- 20 pieces of paper, approximately the size of a playing card

Method

1. Divide into small groups.
2. On separate pieces of paper, draw a model of an atom for each of the first 20 elements. Be sure to clearly show the electron arrangement of each atom.
3. Arrange the atoms as they are located in the periodic table.
4. Using a blank periodic table (see Figure 3.10 on page 80), write the electron arrangement for each of the atoms in group 1.
5. Repeat this for groups 2 and 13–18.
6. Compare the electron arrangements of elements in the same group.
7. Compare the electron arrangements of elements in the same period.

Results

1. How is the electron arrangement for atoms in the same group similar?
2. What pattern do atoms in the same period have in common?

Conclusion

3. Suggest why elements in the same group have similar properties.
4. How does the number of electrons in the outer shell relate to the group number?
5. How could you identify groups of elements in the same period?

Extension

6. Predict the electron arrangement for element number 26 (iron) using the information in Table 3.5 on page 88.
7. Visit the website 'Atomic structure revision', which has a revise section and an activity that explains the ideas. Complete the test also there to check your understanding.

WEBLINK
Atomic structure revision

ISBN 9780170189071

Explaining the properties of elements

The chemical and physical properties of an element are determined by the number of electrons in the outer shell. Elements in the same group have the same number of electrons in their outer shell, so it is to be expected that they will have similar chemical properties.

As the noble gases are chemically unreactive, they must have the most stable electron arrangement. They are the only elements that exist in nature as separate, individual atoms. All other elements attempt to react to attain the same electron arrangement as the noble gases – that is, filled outer shells.

Chemists believe the structure of metals and non-metals lies in their electron arrangement. When metals and non-metals react, they do so in an attempt to attain a filled outer shell. This usually occurs by the metal donating electrons to another atom, usually a non-metal, which needs to gain electrons to attain a filled outer shell. The result of this process is the formation of charged particles called ions.

Forming ions

An ion is an atom that has lost or gained electrons. If an atom loses electrons, it has more positively charged protons than negatively charged electrons. It therefore forms a positive ion or cation. For example, if sodium (Na) loses one electron, it attains the same electron arrangement as that of neon (Ne) – the nearest noble gas with 10 electrons. The symbol for a sodium ion is Na^+ (Figure 3.19).

The element that gains the electron (electrons have to go somewhere) will become negatively charged and is called an anion. For example, if fluorine gains an electron, it acquires the same electron arrangement as that of neon (Ne). It is called a fluoride ion and has the symbol F^- (Figure 3.20 on page 94).

Notice that the ion of sodium has the same name as its 'parent' atom. This convention is used for all metal ions. However, the ion of fluorine now has a different name from its parent atom. It is called the fluoride ion, not the fluorine ion. This convention is applied to the ions of the other non-metals as well. The end of their name is replaced with '–ide'. For example, oxygen becomes oxide and bromine becomes bromide.

Ions and the periodic table

Figure 3.21 on page 94 shows the charges on the ions of the periodic table. Remember that these charges arise when metal atoms lose electrons and non-metal atoms gain electrons to attain the stable electron arrangement of the nearest noble gas.

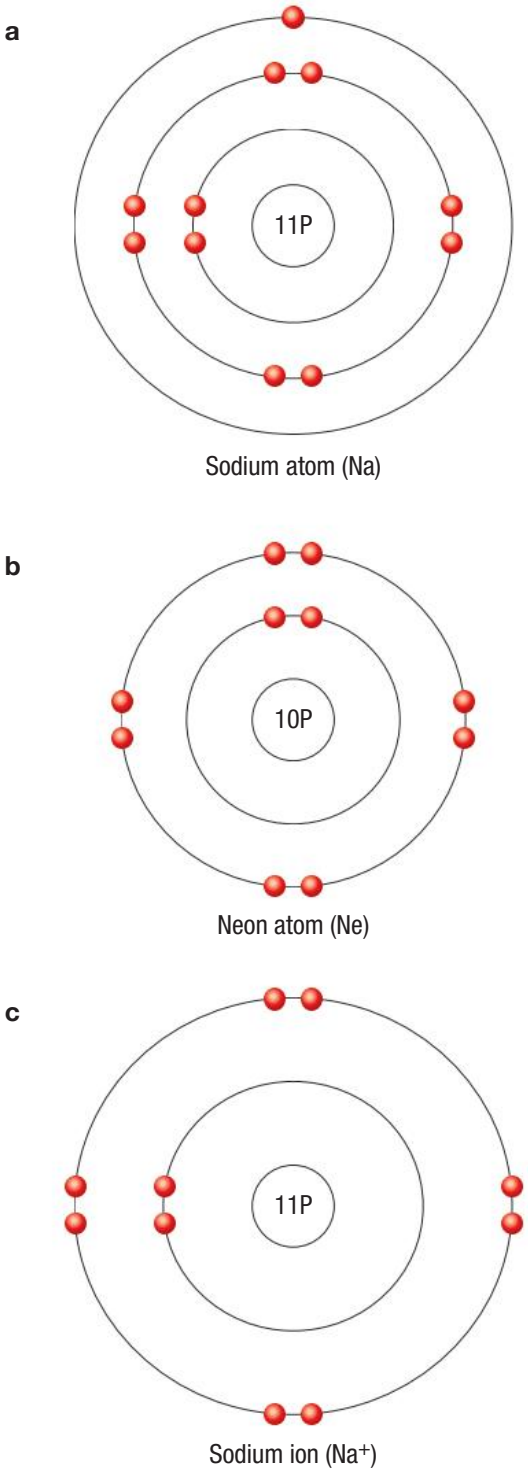


Figure 3.19 Electron arrangement of **a** sodium atom (Na), **b** neon atom (Ne) and **c** sodium ion (Na^+)

glossary terms

anion
a negatively charged ion formed when electrons are gained

cation
a positively charged ion formed when electrons are lost

ion
a positively or negatively charged particle formed when electrons are lost or gained from atoms

ISBN 9780170189071

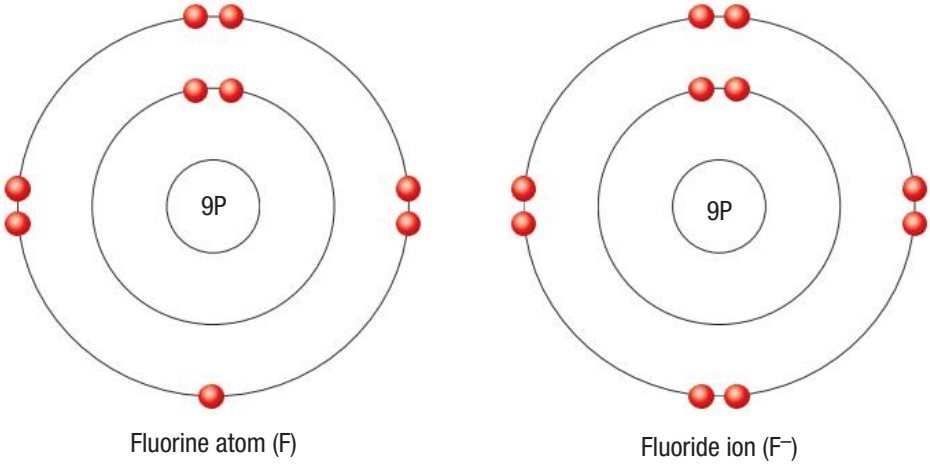


Figure 3.20 Electron arrangement of a fluorine atom and a fluoride ion

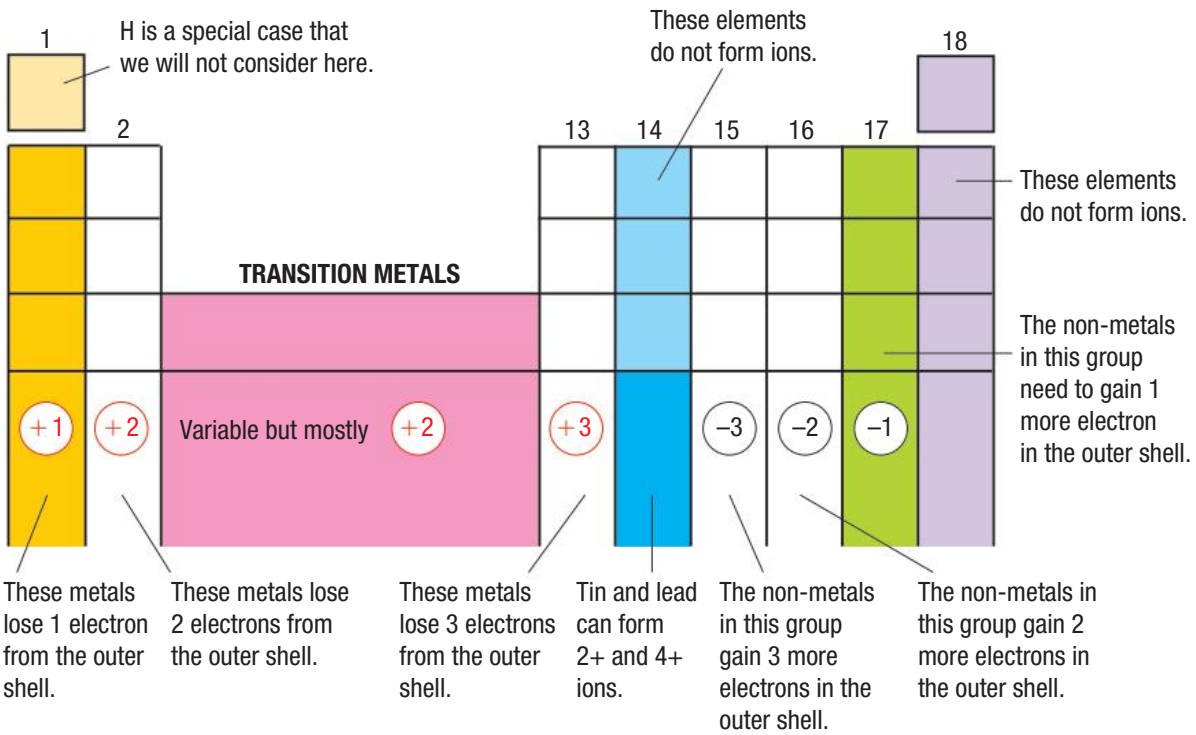


Figure 3.21 The charges on the ions of the periodic table

INTERACTIVE
Exploring atoms: ion builder
SCI10SUIN00068

ANIMATION
Forming ions
SCI10SUAN00081

ISBN 9780170189071

Questions 3.5
What have you learnt?

WORKSPACE
What have you learnt? 3.5
SCI10SUWR00082

Apply

1 **a** Draw the Bohr model of an aluminium atom, and that of the noble gas nearest to aluminium on the periodic table.
b Predict what charge an aluminium atom will gain when it forms compounds with non-metals. Justify your answer.
c Identify the similarities and differences between the aluminium ion and the noble gas atom.

2 Copper has an atomic number of 29. A certain particle of copper has the electron configuration 2, 8, 18. What charge must this particle have?
A Zero (it is uncharged)
B 1+
C 2+
D 1−

3 Write the formulas of the following ions.
a Potassium
b Sulfide
c Calcium
d Aluminium
e Silver
f Phosphide

4 State what charge would be expected on an ion of an element:
a from group 17
b from group 13
c with an electron configuration of 2, 8, 2
d with an electron configuration of 2, 8, 6.

Explaining metallic properties

Earlier in this unit, we explored the properties of metals and non-metals. In this section, the focus is on metals; non-metals will be discussed in Unit 4.

As explained on page 93, metals will react with non-metals to form ions and obtain the same electron arrangement as that of a noble gas. However, metallic properties only apply to a metal in its elemental form, with all its electrons, not to its ions. It is the electron arrangement in metals that explains their metallic properties of lustre, malleability and ductility, and conductivity of electricity and heat.

Why are they shiny?

Suppose, for example, that there are only metal atoms about. When these atoms come close to one another, their weakly held outermost electrons are attracted to the positively charged nuclei of the other atoms as well. So the outermost electrons become detached from their atoms and move among all the atoms. They are described as delocalised electrons.

As a result, the metal atoms are positively charged and, most importantly, now have a more stable electron arrangement. The overall piece of metal, however, is uncharged since the total positive charge of the cations is equal to the total negative charge of the delocalised electrons. The metal will still give all those delocalised electrons away to another substance at the first opportunity as this will create an even more stable structure. While it is not in contact with any other substance, light rays reflect off the delocalised electrons. This is why untarnished metals look so silvery and shiny (Figures 3.22 below and 3.23 on page 96). In contrast, non-metals do not shine like this.

Figure 3.22 Some freshly cut sodium, showing its metallic lustre

glossary term

delocalised electron
an electron from the outermost occupied shell of a metal atom that has detached from the atom and now moves randomly among the metal ions formed as a result

ISBN 9780170189071

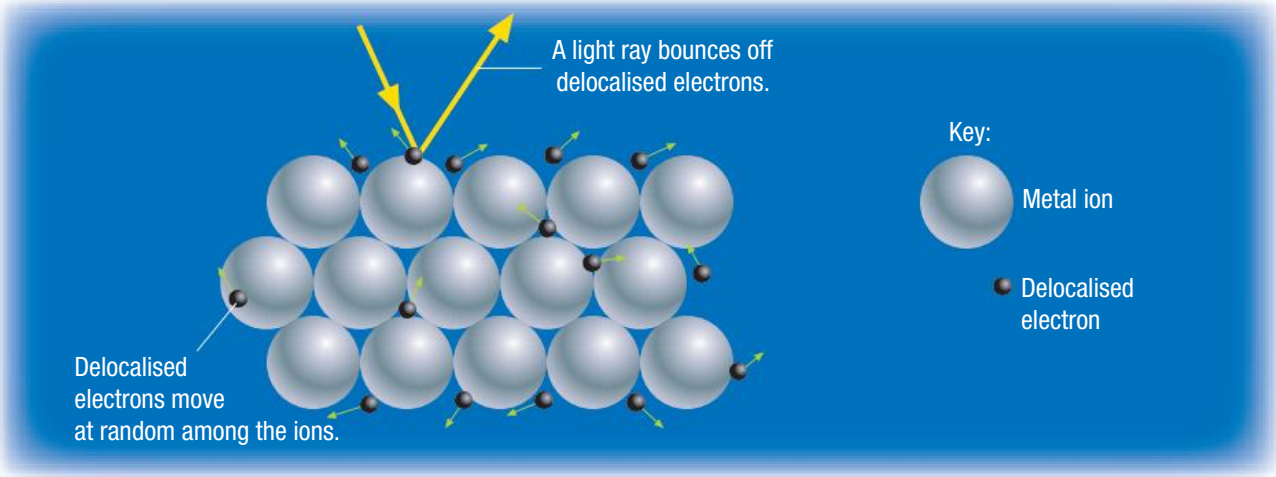


Figure 3.23 Why metals are shiny

Why are they malleable and ductile?

A piece of metal is held together by electrostatic forces of attraction between the negatively charged delocalised electrons and the positively charged metal ions. This force of attraction that bonds the particles together is appropriately termed metallic bonding.

Metals can be hammered into different shapes (malleable) or drawn into thin wires (ductile) because the bonding within the metal is flexible. The positive ions and delocalised electrons simply move to take up the new shape without breaking the bonds within the metal.

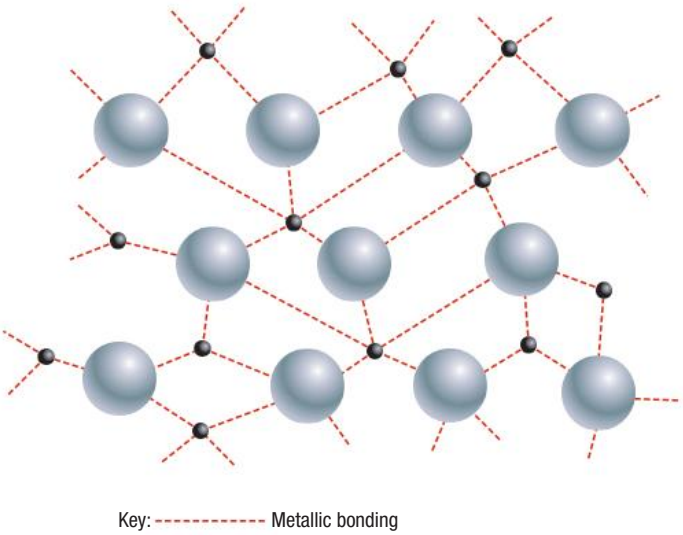


Figure 3.25 Metallic bonding

Why do they conduct electricity and heat?

The moving delocalised electrons do not just explain why metals are shiny. They also explain why they can conduct electricity and heat. When placed in an electric circuit, the delocalised electrons will all start moving towards the positive terminal of the cell, carrying the electrical energy with them. If one end of the metal is heated, these same electrons will swiftly carry the heat energy to the other end (Figure 3.24).

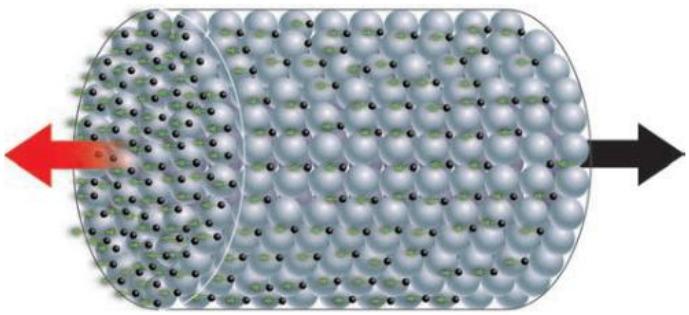


Figure 3.24 Conducting a current

ISBN 9780170189071

Questions 3.6

What have you learnt?

WORKSPACE

What have you learnt? 3.6

SCI10SUWR00083

Understand

1 Use drawings to help explain the following observations.
   - **a** Freshly cut potassium is shiny.
   - **b** Sodium is only found in nature in the form of compounds in which the sodium atoms have a positive charge.

2 Choose the most appropriate phrase in column 1 of the table to match the definition in column 2.

Phrase	Definition
Able to be drawn into thin wires	Malleable
Able to be hammered into sheets	Lustre
Outer electrons in a metal	Cation
Appearance of untarnished metals	Ductile
Positively charged ion	Delocalised

3 For each of the purposes in the table below, suggest an important metallic property that makes it suitable for that purpose.

Purpose	Property
Electrical wiring	
Bridge	
Saucepan	
Jewellery	
Drink can	

4 Give the number of electrons lost by each of the following metals and the charge on the resultant cation.
   - **a** Potassium
   - **b** Magnesium
   - **c** Aluminium
   - **d** Calcium
   - **e** Zinc

Apply

5 Look around your home or school. Name and describe, or take a photo of, two examples of metals that:
   - **a** are shiny
   - **b** conduct electricity
   - **c** conduct heat
   - **d** are malleable
   - **e** are ductile.

6 Explain why delocalised electrons would start moving towards the positive terminal of a cell.

Reflect

7 How can information about the properties of metals assist you in your life? Give at least three examples.

glossary term

metallic bonding
the electrostatic force of attraction that operates between the negatively charged delocalised electrons and positively charged metal ions; it holds the metal together

ISBN 9780170189071

Reactivity of metals

Most metals are found naturally as compounds because they will react with oxygen and water in the atmosphere to lose electrons.

Beating bacteria with copper

The metal copper has antiseptic properties. If certain bacteria, fungi or algae move across a copper surface, they absorb copper atoms, disrupting their metabolism. Copper ducts and tubing are standard in buildings as public safety measures. Copper tubing in air-conditioning ducts cleans out the nasty bacteria that might otherwise grow there.

Not all metals have the same reactivity. Group 1 (alkali) metals are highly dangerous. For example, lithium, sodium and potassium must be stored under oil because they react violently in air and even with water (Figure 3.26). The other alkali metals must be sealed in glass ampoules from which air has been excluded because they will explode on exposure to air. These metals should never be handled. Apart from the risk of explosion, they can severely burn the skin and could cause blindness. Most metals in group 2 (alkaline earth metals) are also dangerous.

Figure 3.26 Potassium reacting with water

Metals such as gold and silver, which are found naturally in their pure state, are fairly unreactive and resistant to corrosion. Copper is relatively unreactive, except in the presence of strong acids (Figure 3.27).

Figure 3.27 Copper reacting with concentrated nitric acid, one of the few acids that will dissolve it.

The more reactive a metal is, the harder it is to obtain from its compound. To obtain the pure metal, it must be extracted from its naturally occurring compound. Because metals are so useful, their production is one of the major industries of the world today. However, over time, most metals will gradually react with substances in the environment to revert back to a compound. This is called corrosion. Methods of extracting metals to obtain their pure form will be considered in Unit 4.

WEBLINK
Reactive metals

VIDEO
Comparing alkali metals
SCI10SUVD00084

ISBN 9780170189071

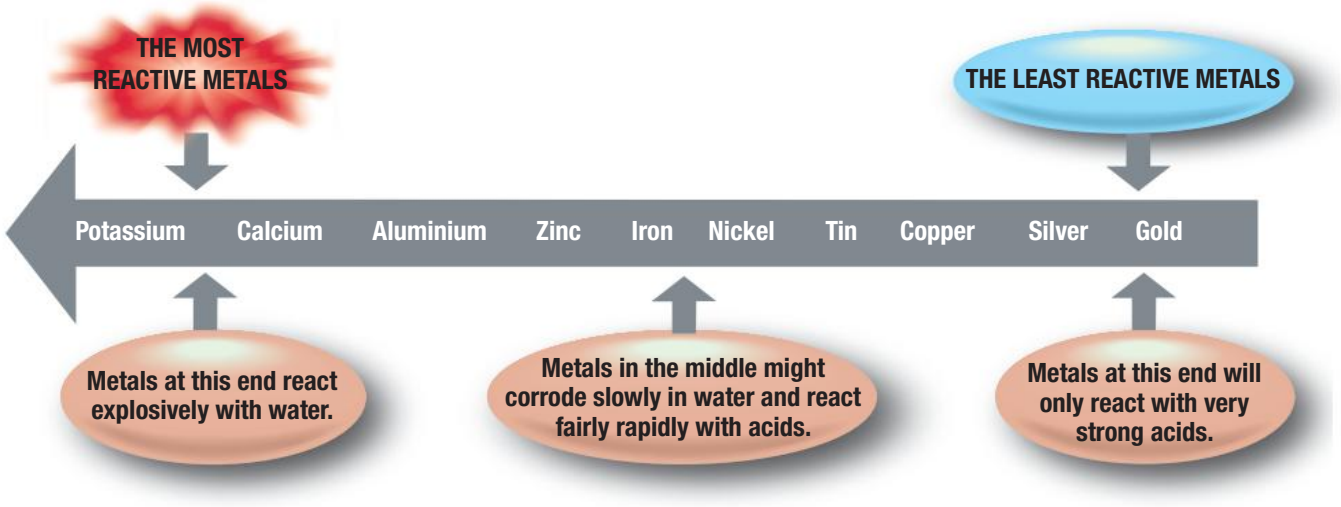


Figure 3.28 The activity series of metals

The activity series of metals

Because metals vary in their ability to react with other chemicals, chemists have been able to devise the activity series of metals. It is a list of metals arranged from the most to the least reactive.

One way to work out the order of reactivity is to observe how metals react with water. Those that react explosively are the most reactive. Those that do not react with water, even if you heat them up, can be tested with acids. The stronger the acid needed to make them react, the less reactive the metal. This is summarised in Figure 3.28. Note that only some of the metals in the series are shown in the diagram.

Using the activity series of metals

The activity series of metals not only tells chemists which metals are the most reactive, but it also shows how easily metals will give up electrons and which metal ions have the greatest attraction for electrons. Metal displacement reactions are reactions in which metals and metal ions 'swap electrons'. These are fascinating to watch because crystals of one metal can be seen growing over another – instantly!

A typical example is the reaction between copper metal and silver nitrate, which is a compound of silver metal (Figure 3.29). As soon as a piece of copper is dipped into

Figure 3.29 The reaction between copper and silver nitrate

glossary terms

activity series of metals
a list of metals in order from the most reactive to the least reactive

corrosion
the chemical reaction in which a metal reacts with one or more substances in the environment to produce a compound of the metal

metal displacement reaction
a reaction in which metal A is added to a solution of a salt of metal B, producing crystals of metal B and a salt of metal A; that is, the metals swap places

ISBN 9780170189071

silver nitrate solution, crystals of pure silver grow over the copper metal. A short time later, there is no copper left, just a trail of silver crystals where it was. Where did that copper go? After all, in chemical reactions, no element disappears and no new element is made!

The visible clue to the 'missing' copper is that the solution, which originally was colourless, gradually turns blue. The blue colour is caused by the formation of copper nitrate. The balanced equation for this reaction is shown.

$$Cu(s) + 2AgNO_3(aq) \rightarrow Cu(NO_3)_2 + 2Ag(s)$$

copper metal — silver nitrate — copper nitrate — silver metal

This equation illustrates the case of metals swapping places. One starts as an element and ends as a compound; the other starts as a compound and ends as an element.

The activity series of metals is an invaluable aid to predict the products of chemical reactions. The differences in metal activity are also utilised in batteries to produce electricity.

Activity 3.12
Comparing metal reactivity

WORKSPACE
Comparing metal reactivity
SCI10SIWR00086

What are the risks in doing this experiment?	How can you manage these risks to stay safe?
Copper sulfate is toxic. Silver nitrate will stain the skin.	Safety goggles must be worn at all times. Avoid contact with the solutions. Wash with plenty of water if contact occurs. Wash your hands with soap and water after the experiment, before you leave the room. **Do not** dispose of these solutions down the sink – use the chemical waste jar.

Use the activity series of metals and what you have learnt to predict the order of activity of the metals given in the materials list below.

Materials

- small pieces of copper, iron, magnesium, zinc
- 20 mL of each of the following 0.1 mol/L solutions:
  - copper(II) sulfate ($CuSO_4$)
  - iron(II) sulfate ($FeSO_4$)
  - zinc sulfate ($ZnSO_4$)
  - magnesium sulfate ($MgSO_4$)
  - silver nitrate ($AgNO_3$)
  - sodium nitrate ($NaNO_3$)
- 5 test tubes for each of the metals tested and sufficient test-tube racks to hold them
- sandpaper
- safety goggles, lab coat and gloves

Add any more risks you can think of, and ways to manage them.

Method

1. Draw up a results table similar to the one on page 101.
2. Select 5 pieces of one of the metals to be tested. Clean them with sandpaper so that they are shiny.
3. Place 5 test tubes in a rack and add a small piece of the same metal to each.
4. Add just enough of each of the different solutions to the separate test tubes to cover the piece of metal. There is no need to test the metal with a solution of the same ion.
5. Observe and record your results. If no change is visible within 5 minutes, write 'No reaction'.
6. Repeat steps 2–5 with the other metals.
7. Dispose of the solutions as directed by your teacher. Do not pour the pieces of metal down the sink.

ISBN 9780170189071

Results

1 Complete the table of results below for this activity.

Solution/metal	Copper	Iron	Zinc	Magnesium
Copper(II) sulfate				
Iron(II) sulfate				
Zinc sulfate				
Magnesium sulfate				
Silver nitrate				
Sodium nitrate				

Discussion

2 Write down the number of reactions each metal underwent. Use this information to list the four metals in order of most reactive to least reactive.

3 You did not use a piece of silver, but you did use a silver ion solution. Consider the reactivity of silver ions relative to the other metals. Where would you place silver in the activity list?

4 If you had used a piece of silver, what, if any, reactions would it have undergone?

5 Write down the number of reactions the sodium ion underwent. Use this information to place sodium in your activity list.

Conclusion

6 Write a conclusion to this activity.

Investigation 3.1

Comparing the corrosion of different metals

WORKSPACE

Comparing the corrosion of different metals

SCI10SIWR00085

Your challenge

To plan and perform an investigation to compare the rate of corrosion of iron, aluminium, zinc and copper.

This might help

1 Write an aim for your experiment.

2 Write a hypothesis. Which metal do you predict will corrode the most? Which will corrode the least?

3 Consider the conditions that promote corrosion and choose equipment that will allow for the comparison of corrosion under those conditions. Obtain samples to be tested.

4 Write a step-by-step method to set up your equipment to compare the rates of corrosion.

5 Draw up a results data table and record the changes to the samples every 2–3 days until a difference in corrosion is evident.

ISBN 9780170189071

Safety

Use a table like the one below to outline the risks in your investigation.

Things to think about

1 How are you going to ensure you have performed a controlled investigation?

2 List the dependent, independent and controlled variables.

3 How are you going to decide on the degree of corrosion that has occurred?

4 Will diagrams or photos assist with your observations?

5 How can you make the experiment more reliable?

What did you discover?

6 Compare the rate of corrosion of the four samples.

7 Compare your results with those of other groups.

What do you think?

8 How did your results compare with your hypothesis?

9 Could you have improved on your investigation method? Explain how.

10 How do your results relate to theory?

What are the risks in doing this investigation?	How can you manage these risks to stay safe?

Questions 3.7

What have you learnt?

WORKSPACE

What have you learnt? 3.7

SCI10SUWR00087

Understand

1 Why are most metals not found in their pure state?

2 How does the reactivity of alkali metals change as you go down a group?

3 True or false? For those statements that are false, rewrite them so that they are true.

- **a** Copper sulfate will react with magnesium.
- **b** Calcium does not react with water.
- **c** A metal displacement reaction will occur when a less reactive metal is placed in a solution of a more reactive metal ion.
- **d** Gold is one of the least reactive metals.

Analyse

4 Suggest why the alkaline metals are more reactive than the alkali earth metals.

5 The following table contains information about five metals A, B, C, D and E. Use the information to list the metals from most reactive to least reactive.

Metal	Reaction with cold water	Reaction with hot water
A	No reaction	Extremely slowly
B	No reaction	No reaction
C	Very little reaction	Slowly
D	Slowly	Quickly
E	Quickly	Very violently

ISBN 9780170189071

Unit review

ACTIVITY SHEET
Unit 3 checklist
SCI10SUAS00089

REVIEW QUIZ
Unit 3
SCI10SURQ00088

WORKSPACE
Unit 3 review
SCI10SUWR00090

Understand

1 What is the name of the theory that describes the beginning of the universe?

2 Which is the most abundant element in the universe?

3 Why has the periodic table changed since Dmitri Mendeleev first proposed it?

4 True or false? For those statements that are false, rewrite them so that they are true.

- **a** The vertical columns in the periodic table are called groups.
- **b** Elements in the same period of the periodic table have similar properties.
- **c** Most of the elements in the periodic table are metals.
- **d** All elements tend to undergo chemical reactions to obtain an electron arrangement similar to that of a noble gas.
- **e** Elements in the same group have a different number of electrons in their outer shell.
- **f** The atomic number of an element is the whole number that decreases as you read across each row of the periodic table from left to right.

5 List the properties common to most metals.

6 Describe the Bohr model of the atom.

7 Why do atoms lose or gain electrons to form ions?

8 Describe the activity series of metals and name one use of the series.

9 Give one example of where new technology led to a change in the understanding of the atom.

Apply

10 Following is a list of the electron configurations of a number of elements, which are called A, B, C and so on for the purposes of keeping their identity secret. Answer the questions underneath in terms of A, B, C and so on. Do not look at your periodic table.

A 2, 1
B 2, 7
C 2, 8, 1
D 2, 8, 8
E 2, 8, 8, 7
F 2, 8, 8, 8

- **a** Identify two elements that are in the same group of the periodic table.
- **b** Identify two elements that are in the same period of the periodic table.
- **c** Which elements have atoms that contain electrons in their third shell?
- **d** Which element has an atomic number of 18?

ISBN 9780170189071

e Which elements would be classified as alkali metals?

f Which elements would be classified as noble gases?

g Identify two elements that would have similar-sized atoms.

11 Which one of the following lists a pair of ions for which both have the same electron configuration as the neon atom?

A Mg^{2+} and F^-

B K^+ and Cl^-

C Na^+ and Cl^-

D Li^+ and F^-

12 Part of the activity series of metals is: caesium, potassium, calcium, aluminium, zinc, iron, nickel, tin, lead, copper, silver.

a Predict what caesium might do if you add a piece of it to water. Justify your answer.

b Which of the metals is the least reactive?

13 Use Bohr atomic model drawings to explain why:

a the formula of aluminium chloride is $AlCl_3$ and not AlCl

b elements in group 16 of the periodic table form ions of a 2− charge when they react with metals.

Analyse

14 a Draw a Bohr model of element C in Question **10**.

b Does this drawing mean that atoms are flat? Discuss.

c Explain why the electrons are located as shown, and not just randomly placed anywhere around the nucleus.

15 Hydrogen is a group 1 element, yet it does not belong to the alkali metals group. Describe the similarities and differences between hydrogen and the other group 1 elements.

Synthesise

16 Construct a spiral version of the periodic table, taking electronic configuration into account.

17 Imagine that you are a scientist working with Niels Bohr. List three questions you would ask him about his proposal for a new way of looking at atomic structure.

Evaluate

18 Assess the usefulness of the activity series of metals.

Reflect

19 Discuss the statement: 'Without technology there would be no scientific discoveries.'

20 Consider the implications to the understanding of bonding if the noble gases had not been discovered.

ISBN 9780170189071

4

What a reaction!

What use is chemistry?

Metals and plastics shape the world around us. Chemistry is at the heart of their development. The processes used to extract metals from their ores and produce new plastics have been based on chemical understandings. Chemists have found patterns in the ways compounds form, and they use these patterns to predict the products of different types of chemical reactions. They have also learnt how to manipulate and control chemical reactions to develop new materials, fuels and pharmaceuticals.

What do you already know about chemical reactions?

In *Nelson iScience 9* you learnt about chemical reactions. In Unit 3 of this textbook you learnt about electron shells and patterns in the periodic table. The following activity will give you a chance to find out what you remember.

Activity 4.1
Reactions and structure quiz

WORKSPACE
Reactions and structure quiz
SCI10SUWR00091

1 Match each statement on the left of the table with the correct definition on the right.

Statement	Definition
Group 2 in the periodic table	Conducts electricity
Group with 7 electrons in the outer shell	Oxygen
Maximum number of electrons in the second shell	Mass
Property of metals	Ion
Property of noble gases	Halogens
Shell that holds a maximum of two electrons	pH
Atom that has lost or gained electrons	Alkali earth metals
Conserved in a chemical reaction	1
Needed for a combustion reaction to occur	Unreactive
Measure of acidity	8

2 Complete the following table.

Element	Group in periodic table	Electron arrangement	Charge on ion	Type of ion (anion/cation)
Fluorine				
Magnesium				
Potassium				

Extension

3 Use the online quiz maker in Survey Monkey to develop your own online quiz. Give the quiz to a classmate to see how much he or she remembers.

WEBLINK
Survey Monkey

ISBN 9780170189071

Activity 4.2
Chemistry all around us

Click on the weblink 'Chemistry all around us' to watch a video showing everyday applications of chemistry.

WEBLINK
Chemistry all around us

Work with a partner or small group to brainstorm the everyday applications of chemistry you use on weekdays.

Over the course of a week, list the chemical applications you use. Record this information on a timeline. You could do this electronically using online software, such as Timetoast.

Once you have completed your timeline, answer the following questions.

1 Are there times each day when you use more chemical applications than at other times?

2 How can you account for the differences you identified in Question **1**?

3 Compare your use of everyday chemical applications with that of three of your classmates. What are the similarities and what are the differences between what is used and when?

4 Predict what you think a weekend would look like.

5 Collect data over a weekend and compare it with your predictions from Question **4**. Write a comment about what you discovered.

WEBLINK
Revision test

Culminating assessment task
Determining the effect of temperature on a chemical reaction

Your tasks

1 Formulate your hypothesis.

2 Plan the investigation.

3 Conduct a risk assessment (or safety audit).

4 Control the variables.

5 Perform the investigation.

6 Gather and present quantitative data.

7 Evaluate the data and method.

8 Present your investigation as a scientific report (see appendix on page 283).

This might help

- The chemical reaction you could investigate is one between sodium thiosulfate and hydrochloric acid.
- When sodium thiosulfate ($Na_2S_2O_3$) reacts with hydrochloric acid (HCl), it produces a precipitate of sulfur (S) that turns the mixture cloudy and obscures a cross drawn on paper placed under the flask.
- The equation is:

$$Na_2S_2O_3(aq) + 2HCl(aq) \rightarrow H_2O(l) + SO_2(aq) + S(s)$$

- Appropriate concentrations would be: 0.25 mol L^{-1} sodium thiosulfate ($Na_2S_2O_3$) and 2 mol L^{-1} hydrochloric acid (HCl).

Things to think about

1 What equipment will you require?

2 How are you going to control the variables?

3 How are you going to make sure the temperature of the two solutions is the same and remains relatively constant during the test?

4 How many trials will you conduct?

5 How many different temperatures will you need to plot the results graphically?

Presenting your results

1 Record your data in a table.

2 Present your data using two graphs: temperature versus time and temperature versus $\frac{1}{\text{time}}$.

ACTIVITY SHEET
Rubric: Determining the effect of temperature on a chemical reaction
SCI10SUAS00093

ISBN 9780170189071

Review: patterns in chemical reactions

Just as the periodic table is based on patterns in the properties of elements and can be used to make predictions about the properties of elements, chemical reactions can be classified according to patterns. These patterns can be used to make predictions about reaction products.

In *Nelson iScience 9* you learnt about combustion reactions and the reactions of acids with metals, bases and carbonates. We will now explore this further.

Combustion reactions

Combustion is something everyone has experienced. It is used to heat homes, power vehicles and even produce electricity. Combustion requires oxygen as a reactant. All combustion reactions are exothermic – that is, they release heat energy.

Most combustion reactions involve a carbon-based fuel – wood (Figure 4.1), petrol, coal or natural gas – and oxygen. Combustion requires a certain amount of heat to begin; however, once started, the reaction proceeds spontaneously, generating water vapour, carbon dioxide and large amounts of energy in the form of heat and light.

An example of a combustion reaction is methane and oxygen:

Methane gas + oxygen gas → carbon dioxide gas + water vapour + energy

Figure 4.1 The burning of wood is an example of a combustion reaction.

Respiration is a combustion reaction that occurs in the cells of living things. It keeps the human body alive by releasing energy. In respiration, glucose and oxygen react chemically to produce carbon dioxide, water and energy.

INTERACTIVE

Chemical reactions: combustion

SCI10SUIN00094

Reactions of acids

Acids are chemicals that everyone is familiar with. Our environment is naturally acidic, so are many of the drinks and foods we consume. Soft drink contains carbonic acid, citrus fruits such as oranges and lemons contain citric acid, and vinegar contains acetic acid.

Acids are a family of chemical compounds with similar characteristic properties. Such similarities allow chemists to generalise reactions, which can then be used to predict the products of most reactions involving acids.

Neutralisation reactions

Neutralisation reactions have many important applications. For example, pool acid is used to maintain the correct acid level in a swimming pool to kill bacteria and fungi (Figure 4.2). If soil becomes too acidic many plants will not grow, so lime is added to neutralise it. Your stomach contains hydrochloric acid; too much hydrochloric acid can lead to indigestion, so an antacid (which contains a base) is used to relieve the symptoms.

In any neutralisation reaction the acid and base combine to produce a salt and water. A salt is a compound produced when an acid and base react. It can be table salt (NaCl) or it can be other salts, such as potassium nitrate. The neutralisation reaction can be written in the form of a general word equation:

Acid + base → salt + water

Shown below are the word equations for some acid–base reactions in which the base is sodium hydroxide. You will notice that there is a pattern to all these word equations. All follow the general rule given above.

Hydrochloric acid + sodium hydroxide → sodium chloride + water

Citric acid + sodium hydroxide → sodium citrate + water

Sulfuric acid + sodium hydroxide → sodium sulfate + water

Carbonic acid + sodium hydroxide → sodium carbonate + water

ISBN 9780170189071

Figure 4.2 Testing pool water for the correct acid level is important to control bacteria and fungi.

WOW!

Ant acids

When ants sting they inject an acid into you; however, when a wasp stings it injects a base. A knowledge of acids and bases will help you choose the correct remedy for the sting: a weak base, like sodium bicarbonate, for ants and a weak acid, like vinegar, for wasps.

Figure 4.3 For a wasp sting, use a weak acid.

Acid–carbonate reactions

Many products such as bread and sponge cakes have a honeycomb structure that contains bubbles. These bubbles are formed by a gas during cooking, causing the mixture to rise. The gas is carbon dioxide and is formed by adding a carbonate and an acid to the cooking mixture.

When an acid and carbonate react they produce a salt, carbon dioxide and water. This can be represented by the general word equation:

Acid + carbonate → salt + carbon dioxide + water

glossary terms

acid
a substance that tastes sour, stings or burns the skin, reacts with bases and has a pH less than 7

base
a substance that tastes bitter, may feel slimy, reacts with acids and has a pH greater than 7

carbonate
a compound containing the chemical group CO_3

combustion
a chemical reaction with oxygen that produces heat

exothermic
a reaction in which energy is produced

neutralisation
a reaction between an acid and base that produces a salt and water

respiration
a reaction between glucose and oxygen that produces carbon dioxide, water and energy

salt
a compound produced when an acid and base react

ISBN 9780170189071

Figure 4.4 The reaction between vinegar and bicarbonate of soda

Examples of reactions between an acid and bicarbonate of soda (sodium hydrogen carbonate) are:

- baking a cake:

Tartaric acid + sodium hydrogen carbonate → sodium tartrate + carbon dioxide + water

- eating sherbet:

Citric acid + sodium hydrogen carbonate → sodium citrate + carbon dioxide + water

ACTIVITY SHEET
Baking a cake
SCI10SIAS00095

Acid–metal reactions

The third main type of reaction that acids undergo involves metals. For example, when rain becomes acidic owing to pollutants in the air, it reacts with metals, causing them to corrode more quickly.

When an acid reacts with metals, a salt and hydrogen gas are produced. This can be represented by the general word equation:

Acid + metal → salt + hydrogen gas

The following are examples of reactions between an acid and magnesium metal:

Hydrochloric acid + magnesium → magnesium chloride + hydrogen

Sulfuric acid + magnesium → magnesium sulfate + hydrogen

Acetic acid + magnesium → magnesium acetate + hydrogen

Similar to the acid–base and acid–carbonate reactions, you will notice there is a pattern to all the reactions.

Activity 4.3
Reactions of acids

WORKSPACE
Reactions of acids
SCI10SIWR00096

What are the risks in doing this activity?	How can you manage these risks to stay safe?
Hydrochloric acid is corrosive.	Wear safety goggles and protective clothing. Take care when handling the chemicals, and tell the teacher if a spill occurs. If hydrochloric acid contacts the skin, it should be washed off with lots of water immediately and *then* the teacher should be told.
Hydrogen gas is explosive.	Take care when trapping and igniting the gas.
Limewater is dangerous and can seriously burn the eyes.	Wear safety goggles and do not touch your eye after handling the bottle.

ISBN 9780170189071

Aim

To investigate the reactions of acids with metals and with carbonates.

Part A: reaction with metals

Materials

- 1 small piece each of copper, iron, magnesium, zinc and aluminium
- dilute (1 mol/L) hydrochloric acid
- concentrated (5 mol/L) hydrochloric acid
- 6 test tubes
- test-tube rack
- 2 measuring cylinders
- taper
- matches
- sandpaper

Method

1 Using sandpaper, clean a small piece of each of the metals.

2 Place each piece of metal in a separate test tube and add about 5 mL of dilute hydrochloric acid to each. Observe and record any change.

3 If a reaction occurs, collect the gas in the test tube by inverting another clean test tube over it. Test for hydrogen by placing a lit taper near the mouth of the test tube. A 'pop' shows hydrogen is present.

4 Feel the test tube containing the acid and metal. Record your observations.

5 If no reaction occurs after a couple of minutes, add about 5 mL of concentrated acid to the same test tube containing the non-reacting metal. Observe and record any changes. Do not test metals that react with the dilute acid.

Discussion

1 Which metals were the most reactive? Which were the least reactive?

2 Did the temperature of the test tubes change? How? What does this show?

3 Why was hydrogen collected by inverting test tubes over those with the reacting metals?

4 Write general word equations for the reactions that took place.

Part B: reaction with carbonates

Materials

- 2–3 marble chips (calcium carbonate)
- other carbonates, such as sodium carbonate, sodium hydrogen carbonate, potassium carbonate and copper carbonate
- dilute (1 mol/L) hydrochloric acid
- conical flask
- 2 test tubes
- stopper fitted with U-tube
- limewater solution
- stand and clamp
- measuring cylinder
- distilled water

Method

1 Set up the apparatus as shown in Figure 4.5.

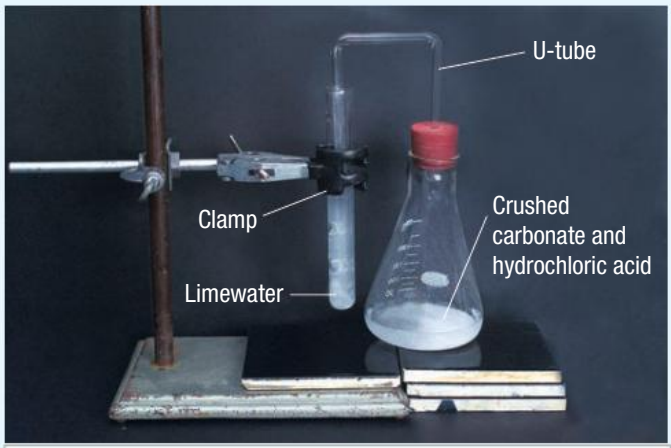


Figure 4.5 The conical flask set-up

2 Add 2–3 pieces of marble chips to the flask. Add 10 mL of dilute hydrochloric acid and quickly place the stopper into the top of the flask.

ISBN 9780170189071

3 One-third fill a test tube with limewater and allow the gas to bubble into the limewater. Record your observations. If the limewater turns milky, it indicates carbon dioxide is present.

4 Feel the flask containing the acid and carbonate. Record your observations.

5 Rinse out the conical flask and test tube with distilled water. Then repeat steps 2–4 with the other carbonates.

Discussion

1 Which of the carbonates were the most reactive? Which were the least reactive?

2 Did the temperature of the conical flask change? How? What does this show?

3 Write general word equations for the reactions that took place.

Questions 4.1

What have you learnt?

WORKSPACE

What have you learnt? 4.1

SCI10SUWR00097

Understand

1 Which of the following is not an indicator that a chemical reaction has taken place?

- **A** Production of gas
- **B** Formation of a precipitate
- **C** Release or absorption of energy
- **D** Solidification of a liquid

2 Which of the following represents a chemical reaction?

- **A** Ice cubes forming in the freezer
- **B** Dry ice boiling off in a stage act
- **C** Exhaust gases produced from a running motor
- **D** Fog vapourising on a sunny morning

3 In a combustion reaction:

- **A** oxygen is a product
- **B** heat is given out
- **C** oxygen is not usually required
- **D** carbon dioxide is a reactant.

4 True or false? For those statements that are false, rewrite them so that they are correct.

- **a** Combustion is a process that produces carbon dioxide and water only.
- **b** An exothermic reaction is one in which heat energy is released.
- **c** The properties of a compound and the elements from which it is made are similar.
- **d** In a chemical reaction, matter is conserved.

5 The answer is exothermic. What are five possible questions?

6 Fill in the spaces with a word or phrase.

A chemical reaction is a process in which the original substances called _____ undergo change to form new substances called _____. The new substances formed have a _____ set of physical and chemical properties. During a chemical reaction, bonds between atoms are _____, atoms are rearranged, and _____ bonds are formed.

ISBN 9780170189071

7 These sentences have been divided into two parts. Half of the sentence has been put in column A and the other half in column B. Match up the two halves correctly.

Column A	Column B
An acid is a chemical substance that causes indicators to	base is called neutralisation.
Chemical salts are formed when acids and	an acid reacts with a metal.
The reaction between an acid and a	written on the left.
Hydrogen gas is produced when	change colour in a specific way.
In a chemical equation the reactants are	neutralise stomach acid.
Antacids are taken to	bases react together.

8 Complete the following general word equations for the reactions of acids.

a Acid + base →

b Acid + metal →

c Acid + carbonate →

9 a The answer is neutralisation. What are three possible questions?

b Give three everyday examples of neutralisation.

Apply

10 Using the general reactions as a guide, complete the following word equations.

a Sulfuric acid + sodium hydroxide →

b Carbonic acid + calcium hydroxide →

c Nitric acid + magnesium →

d Hydrochloric acid + zinc →

e Acetic acid + calcium carbonate →

f Citric acid + copper carbonate →

11 What would you use to neutralise the pain from an ant sting? Explain.

Analyse

12 Some acids are more reactive than others and so may be used for different purposes. Students were given the following information about the reactivity of different acids P, Q, R, S, T and U.

- P is more reactive than U and R.
- Q is more reactive than P, but is less reactive than S.
- T is the least reactive.
- It takes longer for R to react than U.

Use this information to put the acids in order from most reactive to least reactive.

Synthesise

13 Choose a graphic organiser to use as a way of summarising key learnings. Add to this throughout the unit. You could use a mind map, lotus diagram, bubble chart, wiki, blog, glogster or wallwisher to name a few.

Products of chemical reactions

Our world is a material world and it is the work of chemists to study the nature, properties and composition of those materials and to develop new ones. Almost all materials are produced by chemical reactions, and it is an understanding of these reactions that allows chemists to manipulate matter in ways that do not occur naturally or improve on nature.

Chemists developed refining processes through which metals can be extracted from their ores. They then mixed the metals with other elements to produce alloys, such as stainless steel. These alloys are widely used in society.

Chemists worked out how to join many small molecules together to produce plastics. Starting with the first synthetic plastic in 1909, processes have been developed to manufacture the large variety of plastics we use today.

Chemistry and medicine are very strongly linked. From the early natural remedies, chemistry has developed into

glossary terms

alloy
a substance with metallic properties that is a mixture of a metal with one or more other elements

ore
a naturally occurring rock that contains metal or metal compounds in sufficient amount to make it worthwhile extracting them

ISBN 9780170189071

a huge pharmaceuticals industry. In making new drugs, chemists often start by investigating existing treatments or naturally occurring molecules with the desired biological effect. They then make a large number of similar molecules, searching for the one with the desired properties. When this has been discovered, they need to find the best chemical reactions to synthesise it in large quantities.

WEBLINK
Top 10 Aboriginal bush medicines

WOW!

Testing new medicines

Presently, many drugs are tested on animals before being tested on humans. This is far from ideal because there are many biological differences between animals and humans. Tests are also carried out on isolated human cells in the laboratory, but this does not provide information on the drug's effect on other parts of the body. Computational chemists are currently attempting to make a 'virtual human' that can model drug effects on all parts of the body and even take into account existing medical conditions.

CONNECTION
Ethical behaviour: Drug testing on animals
SCI10SHCN00098

Our growing population is putting pressure on the Earth's raw materials, and environmental chemists are continually searching for ways to meet increasing energy demands, develop alternative fuels and minimise waste through recycling (Figure 4.6).

VIDEO
Introducing fuels and their uses
SCI10SUVD00099

In order for chemists to manipulate matter, they need to understand it and the reactions it undergoes. Chemistry has many different career paths and chemists specialise in a diverse range of different areas, including industrial, atmospheric and forensic chemistry; however, they all started at the same point – developing an understanding of the basics of structure, bonding and reactions in chemistry.

Figure 4.6 Useful resources are increasingly being extracted from waste.

Classifying chemical reactions

There are millions of different chemical reactions. Many of these occur as a complex sequence of events. If you look at them closely, however, there are patterns in the chemistry of these reactions. Most simple chemical reactions can be divided into five types based on the number of reactants, how the molecules behave and the products created.

1 Combustion: In these reactions, oxygen reacts with another compound to form carbon dioxide and water. These reactions are exothermic, so heat is released.

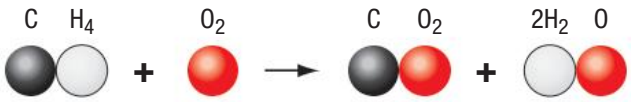


Figure 4.7 An example of a combustion reaction

2 Decomposition reactions: This reaction occurs when a single substance breaks down or decomposes into two or more simpler substances; for example, the electrolysis of water to form hydrogen and oxygen gas.

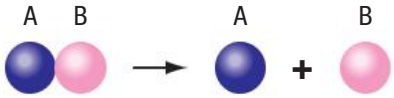


Figure 4.8 An example of a decomposition reaction

ISBN 9780170189071

3 Synthesis reactions: These are also called combination or addition reactions. When synthesis occurs, two or more elements or compounds are combined to form one more complex substance. Synthesis is opposite to decomposition. Photosynthesis, the process in which carbon dioxide and water combine to form glucose, is an example of a synthesis reaction.

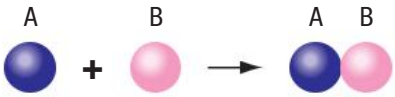


Figure 4.9 An example of a synthesis reaction

4 Single replacement reactions: In these reactions, an atom (or group of atoms) replaces another atom (or group of atoms) in a compound to form a new compound. The metal activity reactions in Unit 3 (see page 101) are an example, in which silver ions and copper metal swap places, resulting in silver metal and copper ions.

Figure 4.10 An example of a single replacement reaction

5 Double replacement reactions: These are more complex than single replacement reactions as they involve two pairs of ions in solution swapping partners to form two new compounds. Acid–base reactions are an example of double replacement reactions.

Figure 4.11 An example of a double replacement reaction

Activity 4.4
Types of reactions

WORKSPACE
Types of reactions
SCI10SIWR00102

What are the risks in doing this experiment?	How can you manage these risks to stay safe?
Copper sulfate and silver nitrate solutions are toxic.	Be extremely careful when using these solutions. Wear safety goggles. If spilt on skin, wash with plenty of water. Dispose of the solutions in the waste jar provided. Do not pour down the sink.
Hot objects can cause serious burns.	Be careful with objects that have been placed in a Bunsen burner flame. Do not allow them to come into contact with skin or clothes.

Reactions can be classified into five main types: combustion, decomposition, synthesis, single replacement and double replacement. In this experiment you will be observing these reactions.

Materials

- 1 large compacted piece of steel wool
- watch glass
- electronic balance
- tongs
- Bunsen burner
- hydrated copper sulfate (solid)
- 4 test tubes
- test-tube holder
- test-tube rack
- distilled water

glossary term

electrolysis
the decomposition of a compound using an electronic current

ISBN 9780170189071

- 10 mL 0.1 mol/L copper sulfate solution
- small piece of magnesium
- small pieces of zinc
- taper
- matches
- 5 mL 0.1 mol/L hydrochloric acid
- 5 mL 0.1 mol/L sodium hydroxide solution
- 5 mL 0.1 mol/L silver nitrate solution
- piece of filter paper
- 10 mL 50% ethanol/50% water solution
- measuring cylinder

Method

Part A

1 Place the piece of steel wool on a watch glass and weigh it. Record the mass.

2 Hold the tongs in the hot part of the Bunsen burner for about a minute to remove any contamination.

3 Using the tongs, hold the piece of steel wool in the hot part of the Bunsen burner flame for 5 minutes. Observe.

4 Allow the steel wool to cool for 1 minute and then reweigh it on the watch glass. Record the mass.

5 Dispose of the solid in the rubbish bin.

Part B

6 Place a spatula of hydrated copper sulfate in a clean, dry test tube.

7 Record the appearance of the hydrated copper sulfate.

8 Weigh the test tube and sample. Record the mass.

9 Heat the test tube in a Bunsen flame for approximately 2 minutes.

10 Allow the test tube to cool. Reweigh it and then record the appearance and mass.

11 Add a few drops of water to the cooled sample in the test tube. Observe and record your observations.

12 Dispose of the chemical in the waste jar provided. Do not pour it down the sink.

Part C

13 Place 5 mL of copper sulfate solution in a test tube.

14 Add a small piece of magnesium to the test tube. Observe the test tube for the next 5 minutes. Record your observations.

15 Repeat steps 13–14 with the hydrochloric acid solution and a small piece of zinc.

Part D

16 Place 5 mL of copper sulfate solution in a clean test tube.

17 Add 5 mL of sodium hydroxide solution. Observe the solution.

18 Place 5 mL of silver nitrate solution in a clean test tube.

19 Add 5 mL of hydrochloric acid. Observe and record your observations.

20 Dispose of both solutions in the waste jar provided. Do not pour them down the sink.

Part E

21 Soak a small piece of filter paper in the ethanol/water solution.

22 Hold the wet paper with a pair of tongs over a lit taper. Observe.

Results

1 Record the masses and your observations in a table.

Discussion

2 For each part, describe the evidence for a chemical reaction.

3 Identify the type of reaction occurring in each part.

4 Write a word equation for the chemical reactions occurring in each part.

ISBN 9780170189071

Balancing chemical equations

A chemical equation is used to represent a chemical reaction. It can be written using words or formulas. The equations for the reactions of acids and combustion discussed earlier were written as word equations.

Equations provide information about the reactants and products of any chemical reaction. Those written in symbolic form – that is, using formulas – provide chemists with more information than word equations. The formulas show how many atoms of different elements are involved and how they are joined together.

A chemical equation must always be balanced. This is because chemical reactions obey the law of conservation of mass – no new element is created and none disappears, so the total number of each element must be the same on both sides of the equation. A balanced chemical equation shows:

- the formulas of all the reactants and products
- the exact proportions in which they react.

The steps for writing a balanced chemical equation are given in Table 4.1, with an example.

Table 4.1 The steps for writing a balanced chemical equation

Step	Example
1 Write the correct chemical formula of all the reactants and products.	$CH_4 + O_2 \rightarrow CO_2 + H_2O$
2 Count the number of atoms of each type appearing on both sides.	• There is 1 atom of C on each side. • There are 4 atoms of H on the left, but only 2 atoms on the right. • There are 2 atoms of oxygen on the left, but 3 atoms on the right.
3 If the numbers on each side are not the same, place numbers in front of the formula until they are. You may need to go back and forth a few times until you get the numbers right. DO NOT CHANGE ANY OF THE FORMULAS. The numbers in front apply to all the symbols in the formula.	• Place a 2 in front of H_2O to get $2(H_2O)$, which is $4 \times H$ and $2 \times O$: $CH_4 + O_2 \rightarrow CO_2 + 2H_2O$ • Now the number of H on each side is the same. • Check for O. There are now 2 atoms on the left and 4 on the right. • Place a 2 in front of O_2 on the left to get $4 \times O$: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
4 Check to make sure the equation is balanced.	• There is 1 atom of C on each side. • There are 4 atoms of H on each side. • There are 4 atoms of O on each side.

WEBLINK
Balancing demonstration

WEBLINK
Practise balancing reactions

INTERACTIVE
Chemical reactions: reaction reshuffles
SCI10SUIN00094

ACTIVITY SHEET
Practice in balancing chemical equations
SCI10SUAS00100

glossary term

law of conservation of mass
the law that states that matter is neither created nor destroyed in a chemical reaction

ISBN 9780170189071

Questions 4.2

What have you learnt?

WORKSPACE

What have you learnt? 4.2

SCI10SUWR00101

Understand

1 Fill in the blanks with the correct type of reaction.

- **a** A _____ reaction is one in which two particles switch places.
- **b** A reaction with oxygen to produce carbon dioxide and water is a _____ reaction.
- **c** When a complex molecule breaks into simpler molecules, a _____ reaction has occurred.
- **d** A _____ reaction has occurred when one element takes the place of another.
- **e** Two simple molecules joining to form a more complex molecule is a _____ reaction.

2 In a balanced chemical equation, why must the number of atoms on each side be the same?

3 Why is it not possible to just change the chemical formulas to make an equation balance?

Apply

4 Highlight the common atoms or compounds in each equation to help you decide the reaction type represented. Write the reaction type in the space provided. Use the following code: C = combustion, D = decomposition, S = synthesis, SR = single replacement, DR = double replacement. (Note: These equations are not balanced.)

- **a** _____ $Mg + O_2 \rightarrow MgO$
- **b** _____ $Cl_2 + NaBr \rightarrow NaCl + Br_2$
- **c** _____ $C_6H_6 + O_2 \rightarrow CO_2 + H_2O$
- **d** _____ $Al_2O_3 \rightarrow Al + O_2$
- **e** _____ $CuCl_2 + H_2S \rightarrow CuS + HCl$
- **f** _____ $Na + Br_2 \rightarrow NaBr$
- **g** _____ $CH_3COOH + O_2 \rightarrow CO_2 + H_2O$
- **h** _____ $HgO + Cl_2 \rightarrow HgCl + O_2$
- **i** _____ $KClO_3 \rightarrow KCl + O_2$
- **j** _____ $BaCl_2 + Na_2SO_4 \rightarrow NaCl + BaSO_4$

5 Balance the following equations.

- **a** $__P + __O_2 \rightarrow __P_2O_4$
- **b** $__Mg + __O_2 \rightarrow __MgO$
- **c** $__HgO \rightarrow __Hg + __O_2$
- **d** $__Al_2O_3 \rightarrow __Al + __O_2$
- **e** $__BaCl_2 + __H_2SO_4 \rightarrow __BaSO_4 + __HCl$
- **f** $__Cl_2 + __NaBr \rightarrow __NaCl + __Br_2$
- **g** $__CuCl_2 + __H_2S \rightarrow __CuS + __HCl$
- **h** $__Na + __Br_2 \rightarrow __NaBr$
- **i** $__C_2H_6 + __O_2 \rightarrow __CO_2 + __H_2O$
- **j** $__P_4O_{10} + __H_2O \rightarrow __H_3PO_4$

Synthesise

6 Create a way to remember the steps for balancing equations. Share these on the class wiki.

Metal meets non-metal

Metals play a very important part in our lives. There are metals you would be very familiar with because you see and use them every day, such as aluminium in drink cans and steel in sinks, taps and cutlery. However, you may not realise that metals are also important components of most modern technologies – mobile phones (Figure 4.12), computers, iPads, cars and in fibres used as part of communication networks (Figure 4.13).

Figure 4.12 Mobile phone

ISBN 9780170189071

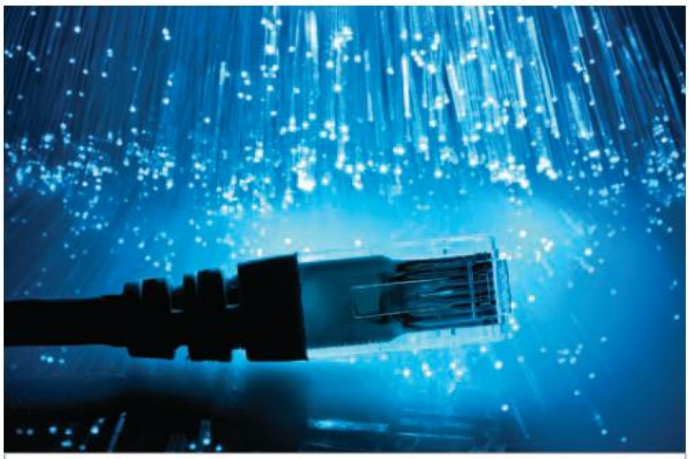


Figure 4.13 Fibre-optic cables

Activity 4.5

Metal mania

Create a list of everything metal that you use in a 24-hour time frame. Name the item, identify the metal and indicate what it is used for. Compare your list with that of someone else. What are the similarities and differences?

Were there items you both used that were made of a different metal or material? Why might this be the case? Is there one metal that you use more than other metals? What are the implications of this?

Create a list of six more questions that your data raises for you.

WOW!

Rare earth metals

The rare earth metals – the group at the bottom of the periodic table – are critical in high-tech devices from fibre optics to precision lenses. Luckily, the term 'rare' is misleading as even the scarcest metals are actually 200 times more common than gold. They were called 'rare' because 19th-century chemists had a lot of difficulty extracting them from their naturally occurring compounds. Fortunately, chemists have now developed methods to separate them more easily and efficiently. Work is currently proceeding globally to increase the production of rare earth metals, with plans for new mines in Australia.

Some metals are rare, such as gold, while others are quite common, such as iron and aluminium. The discovery of certain metals and the ability to extract them from the Earth have dramatically affected developments in human civilisation over the past 5000 years. This is apparent when considering eras of time, such as the Bronze and Iron Ages.

CONNECTION

History: Bronze Age civilisation

SCI10SHCN00103

The most abundant metal in the Earth's crust is aluminium and the second most abundant is iron, although the core of the Earth is believed to be mainly composed of iron. All metals are found in compounds in the Earth's crust, except for silver, gold and platinum, which are found as elements. To obtain the metals, they need to be extracted from their ores, the rock that contains the metal compound.

Why are metals found mainly as compounds?

As you learnt in Unit 3, elements react to attain a full outer electron shell because this electron arrangement is the most stable. Since metals usually have only a few electrons in their outer shell, when they react they tend to lose electrons and form positive ions (or cations).

When non-metals react with metals, they gain electrons and form negative ions (or anions). Figure 3.21 on page 94 showed the charges of the ions of the elements in the groups of the periodic table. Figure 4.14 on page 120 shows the reaction between a sodium atom and a chlorine atom. To make this reaction easier to understand, the Bohr model of the atom has been used. Only the number of protons in each nucleus is shown.

Compounds made up of a metal and a non-metal are called ionic compounds. The positive and negative ions are attracted to one another and this attractive force, called an ionic bond, holds the compound together. Many chemical reactions performed in both the laboratory and industry produce ionic compounds.

glossary terms

ionic compound
a compound that is composed of positively and negatively charged ions

ionic bond
an electrostatic force of attraction between positive and negative ions

ISBN 9780170189071

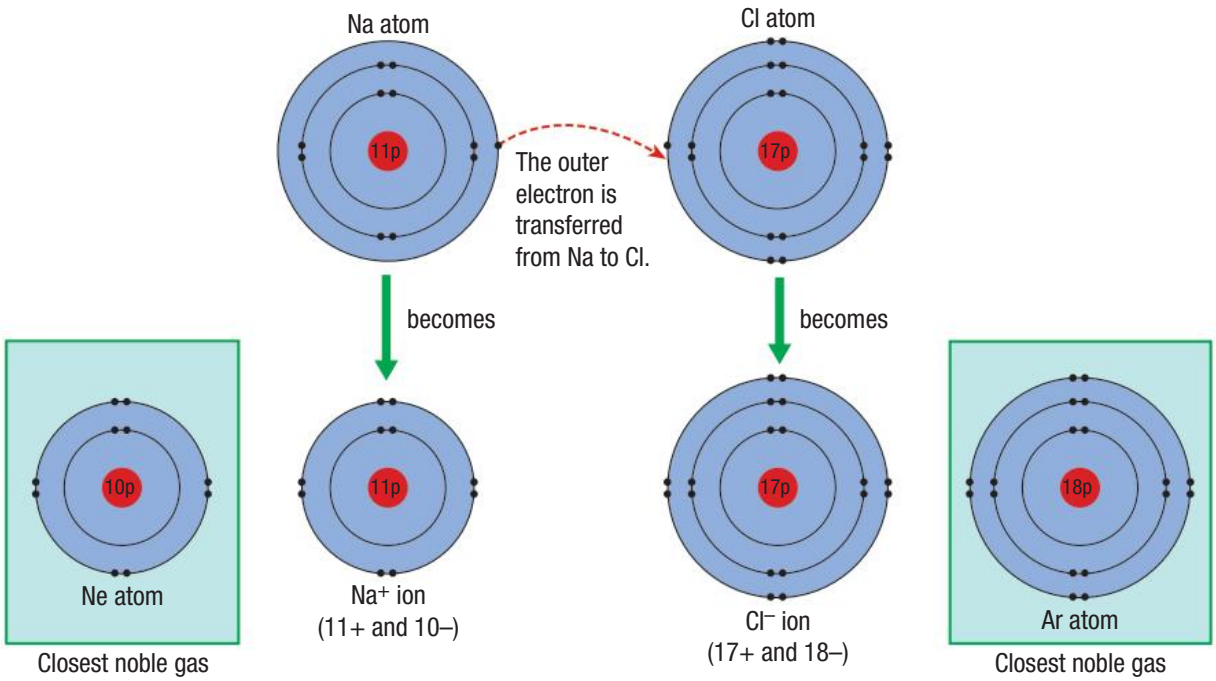


Figure 4.14 When sodium and chlorine atoms meet.

WOW!

Ions in space

Did you know that the Earth is constantly bombarded by ions?

Solar winds are streams of ions (mostly hydrogen ions) that emanate from the Sun. These ions can travel at very high speeds and would be very damaging to us on Earth if they were able to reach us. Fortunately for us, they get caught in the magnetosphere – the portion of the Earth's magnetic field that stretches into space. This draws them towards the magnetic poles, which slows them down.

We can see this happening as the ions create a coloured glow, known as an aurora, in the sky near each of the magnetic poles.

Figure 4.15 shows the Aurora Australis, also called the southern lights. The best place to view the Aurora Australis is Tasmania as it is closest to the South Magnetic Pole.

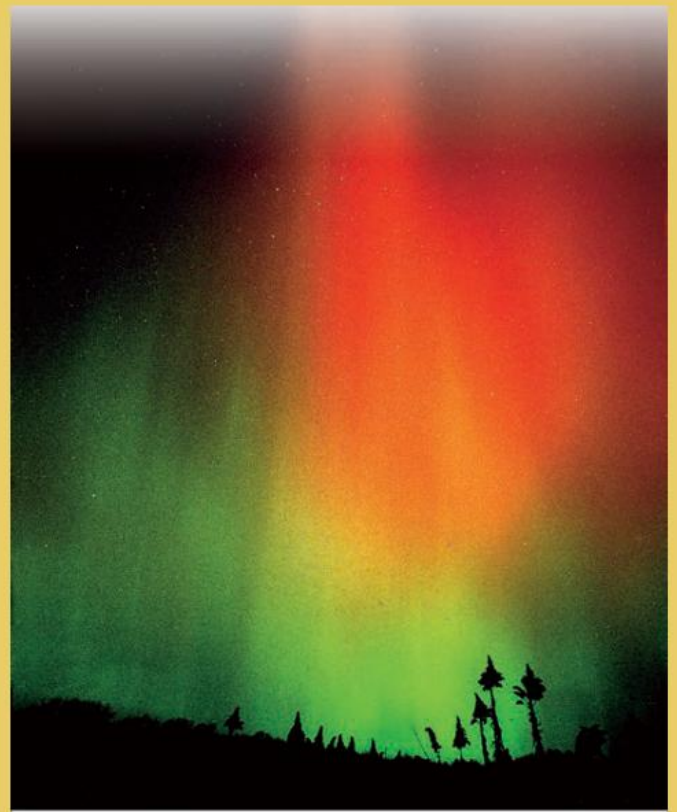


Figure 4.15 Aurora Australis occurs at the South Magnetic Pole.

ISBN 9780170189071

Representing ions: electron dot formulas

Drawing the Bohr model of an atom or ion takes a lot of time. So chemists have a drawing convention that makes the job easier. As it is only the electrons in the outer shell that are involved in chemical reactions, chemists represent these by dots and only show outer-shell electrons. This representation is called an electron dot formula.

Figure 4.16 shows an easier way to represent the formation of sodium chloride from its elements.

More ionic compounds

The example with sodium and chlorine in Figure 4.16 is a simple case because the number of electrons lost by sodium is exactly the same as that gained by chlorine. This would be the same for any reaction between the group 1 alkali metals and the group 17 halogens.

What about if a group 2 alkali earth metal was to react with a group 16 non-metal? As you can see from Figure 3.21 on page 94, group 2 elements want to lose 2 electrons to form 2+ ions, and group 16 elements want to gain 2 electrons to form 2– ions. When elements from these two groups react, the number of electrons lost equals the number gained. For example, in the reaction between magnesium and oxygen, magnesium forms the Mg^{2+} ion and oxygen forms the O^{2-} ion. The compound magnesium oxide has the formula MgO. (The charges therefore cancel each other out.) Figure 4.17 shows this reaction using an electron dot formula.

Not all combinations are this straightforward. Consider the reaction between magnesium and fluorine, for instance. Figure 4.18 shows how each element gains a stable electron arrangement. As you can see, magnesium needs to lose 2 electrons while fluorine only needs to gain 1 electron to obtain a filled outer shell. Therefore, each magnesium atom needs to react with 2 fluorine atoms. When chemists analysed magnesium fluoride, they found its formula was MgF_2. This is how they explain why the atoms combine in this ratio.

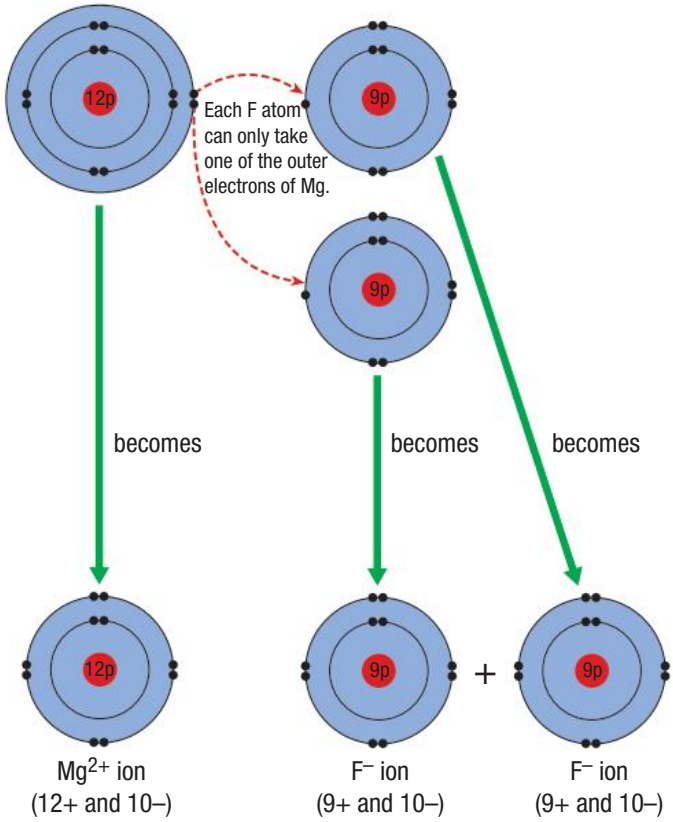


Figure 4.18 When magnesium and fluorine react.

Key:

- • Outer-shell electron
- **Na** Nucleus and inner-shell electrons of a sodium atom
- **Cl** Nucleus and inner-shell electrons of a chlorine atom

Figure 4.16 Electron dot formulas to show the formation of sodium chloride

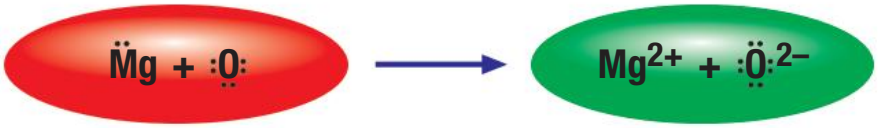


Figure 4.17 The reaction between magnesium and oxygen shown using an electron dot formula

ISBN 9780170189071

WEBLINK
Ionic bonding

WEBLINK
Test your knowledge of ionic bonds

Activity 4.6
Making ionic compounds

WORKSPACE
Making ionic compounds
SCI10SIWR00104

What are the risks in doing this activity?	How can you manage these risks to stay safe?
Hydrochloric acid and potassium hydroxide are corrosive.	Wear safety goggles and protective clothing. Take care when handling the chemicals and tell the teacher if there is a spill.
Magnesium ribbon burns with a very bright flame that can damage the eyes.	Do not look at the flame directly. Do not inhale the powder produced from the burning.
Hot objects can cause severe burns.	Do not touch the crucible or other hot objects. Always use tongs and allow objects to cool before putting them away.

In this activity you will prepare three different ionic compounds using different types of reactions.

Materials

- 8 cm piece of magnesium ribbon
- 2 cm piece of aluminium
- steel wool or sandpaper
- crucible and lid
- Bunsen burner, tripod and gauze mat
- pipe clay triangle
- tongs
- 10 mL 1 mol/L hydrochloric acid
- 10 mL 0.1 mol/L potassium hydroxide
- 2 test tubes
- test-tube rack
- measuring cylinder
- matches
- 2 clock glasses
- safety goggles, lab coat and gloves

Figure 4.19 Experimental set-up

Method

1 Clean the pieces of magnesium and aluminium by rubbing gently with steel wool or sandpaper.

2 Loosely coil the cleaned piece of magnesium and place it in the crucible. Sit the crucible on the pipe clay triangle over a Bunsen burner, as shown in Figure 4.19.

3 Light the Bunsen burner and heat the crucible and its contents until the magnesium begins to glow. Immediately use the tongs to place the lid on the crucible and heat strongly.

4 Continue to heat the crucible for about 10 minutes, occasionally lifting the lid using the tongs to provide oxygen for the reaction.

ISBN 9780170189071

5 When all the magnesium has reacted, turn off the Bunsen burner and allow the crucible and its contents to cool. Record your observations.

6 Place the cleaned piece of aluminium in a test tube and add enough hydrochloric acid to cover the metal. Record your observations.

7 Place 5 mL of potassium hydroxide in a test tube. Add 0.5 mL of hydrochloric acid. Mix and then record your observations.

8 Pour a small amount of the solutions from each of the test tubes onto separate labelled clock glasses and allow them to evaporate overnight. Record your observations.

Results

1 Record all of your observations.

Discussion

2 Write the word equation for each of the reactions that have occurred.

3 Identify the type of reaction that occurred in each reaction.

4 Write the formula of each of the ionic compounds formed.

5 Name the cation and anion in each of these compounds.

Writing formulas of ionic compounds

When writing formulas of ionic compounds, there is one simple rule: ionic compounds do not have a net charge. This means the total positive charge equals the total negative charge. So you simply need to work out the proportions the ions need to be in so that the total positive charge equals the total negative charge. Figure 3.21 on page 94 summarises this information.

Example 1: magnesium oxide

- Ions present: Mg^{2+} and O^{2-}.
- Reasoning: We can see that these ions have an identical charge. If we have one ion of oxygen for each magnesium ion, the total positive charge will equal the total negative charge.
- Conclusion: The formula will be MgO. Note that the charges on the ions are not shown in the overall chemical formula. The positively charged ion is always written first.

Example 2: lithium sulfid

- Ions present: Li^{+} and S^{2-}.
- Reasoning: If we have 2 of the Li^{+} ions for each S^{2-} ion, the total positive charge will equal the total negative charge.

  $2 \times 1+ = 2+$, which matches $2-$
- Conclusion: The formula will be Li_2O.

Example 3: aluminium oxide

- Ions present: Al^{3+} and O^{2-}.
- Reasoning: This is a more difficult example. The only way to solve it is to make the two charges add to a common number. The lowest common multiple of 2 and 3 is 6, so we will make the charges come to 6+ and 6−. If we have 2 of the Al^{3+} ions for every 3 of the O^{2-} ions, the total positive charge will equal the total negative charge.

  $2 \times 3+ = 6+$, which matches $3 \times 2- = 6-$
- Conclusion: The formula will be Al_2O_3.

Transition metal ions

Transition metals have slightly different electron structures from other metals. (The reasons for this are beyond the scope of this course.) Many show more than one possible charge as a result. When this is the case, we have a simple naming system to show which ion we mean.

For example, the metal iron forms Fe^{2+} and Fe^{3+} ions. Previously, the ending of their names was used to indicate the charge. The one with a lower charge had '–ous' at the end of its name, whereas the one with a higher charge had '–ic'. However, these days we have a much easier system in which the charge is shown as a Roman numeral. Two examples are shown in Table 4.2. Notice that there is no gap between the name of the element and the bracket. The former names are still sometimes used in the chemical industry.

Table 4.2 Former and current naming of transition metal ions

Ion	Fe^{2+}	Fe^{3+}	Cu^{+}	Cu^{2+}
Former name	Ferrous	Ferric	Cuprous	Cupric
Current naming	Iron(II)	Iron(III)	Copper(I)	Copper(II)

Example 4: Iron(III) chloride

- Ions present: Fe^{3+} and Cl^{-}.
- Reasoning: If we have 3 of the Cl^{-} ions for each Fe^{3+} ion, the total positive charge will equal the total negative charge.

  $3 \times 1- = 3-$, which matches $3+$
- Conclusion: The formula will be $FeCl_3$.

ISBN 9780170189071

Questions 4.3

What have you learnt?

WORKSPACE

What have you learnt? 4.3

SCI10SUWR00105

Understand

1 Complete the following with a word or phrase to check your understanding.

a Ionic compounds are composed of oppositely charged _____. Although ionic compounds are made up of charged particles, the overall compound is electrically _____. This means that the total number of positive and _____ charges is _____.

b The positively charged ions, called _____, are formed when an atom _____ electrons. These positive ions are attracted to the _____ ions, called anions, which are formed when an atom _____ electrons. The result of this attraction is the formation of an _____ compound held together by an ionic _____. The charge on a single ion can be determined by the position of the element in the _____ table.

c The formula of an ionic compound is actually the _____ in which the ions are present. This ratio can be easily determined because the overall charge on an ionic compound must be _____.

Apply

2 Write the formulas for the following ions and draw their electron dot diagrams.

a Sodium

b Sulfide

c Calcium

d Mercury(I)

e Iron(II)

3 Name the following ionic compounds and draw their electron dot diagrams.

a AlF_3

b AgCl

c K_2S

d $MgCl_2$

e CuS

4 Determine the formulas of the following ionic compounds.

a Sodium iodide

b Potassium oxide

c Mercury(II) oxide

d Potassium nitride

e Iron(II) chloride

f Magnesium sulfide

g Magnesium fluoride

h Chromium(III) oxide

Analyse

5 State the charge that would be expected on an ion of an element:

a from group 17

b from group 13

c with an electron configuration of 2, 8, 2

d with an electron configuration of 2, 8, 6.

6 X stands for different mystery elements. Deduce what charge X must have in each of the following compounds.

a XF

b XO

c XCl_2

d XF_3

e X_2O

f LiX

g CaX_2

WEBLINK

Practise on anions, cations and ionic formula

WEBLINK

Practise naming ionic compounds

ACTIVITY SHEET

Practising ionic formulas

SCI10SUAS00106

ISBN 9780170189071

Extracting metal

Most metals occur naturally in ionic compounds. To obtain the pure metal, it must be extracted from the compound. This process is the reverse of making an ionic compound.

An understanding of the reactivity of metals is important in knowing how to extract a metal from its ore. The more reactive the metal, the more difficult it is to extract it. The method used to extract metals from their ores therefore depends on their reactivity.

In Unit 3, you learnt about the activity series of metals, which summarises the reactivity of different metals (see Figure 3.28 on page 99). As you can see from the activity series, the most reactive metals are potassium and calcium and the least reactive are silver and gold (which is why they are usually found as elements).

Chemists have developed different processes by which metals can be extracted. The more reactive metals – such as potassium, calcium and aluminium – are extracted by electrolysis.

WOW!

More valuable than gold

More reactive metals such as potassium, calcium and aluminium were once worth more than gold. Because they were extremely difficult to obtain in pure form, they were very scarce – more scarce than gold, which could be found naturally in its pure state. Aluminium was too expensive to use for everyday purposes at that time. However, with the development of efficient extraction processes, aluminium is now a very common material and today sells for one-ten-thousandth of the price of gold.

Less reactive metals – such as iron, zinc, tin and lead – are extracted by reacting their ores with carbon (C) or carbon monoxide (CO). Such reactions are conducted in furnaces at very high temperatures.

Extracting iron

Iron is the most widely used metal and the process for extracting it from its ore has been developed and improved over the last 300 years. Iron ore consists of compounds made up of iron and oxygen called iron oxides, such as Fe_3O_4 and Fe_2O_3.

The use of coke instead of charcoal in a blast furnace in 1709 was a major technological achievement for the extraction of iron and allowed for the production of iron in significant quantities. This has been further developed into the modern blast furnace used in today's iron industry.

A blast furnace is a huge steel stack lined with brick. Iron ore, coke and limestone are dumped into the top and preheated air is blasted in at the bottom (Figure 4.20 on page 126). The limestone decomposes and produces carbon dioxide, which reacts with the carbon to produce carbon monoxide. At temperatures of 1800°C, the iron ore reacts with carbon or carbon monoxide to produce molten iron, which runs down to the base of the furnace. The molten iron is drained from a tap hole near the bottom at regular intervals.

Activity 4.7

What if...

Choose one of the following questions to answer.

1 What if there was no iron?

2 What if a blast furnace had not been invented to extract iron?

glossary terms

blast furnace
a huge steel stack lined with brick used to extract iron from iron ore

coke
coal that has been heated to high temperatures in the absence of air

ISBN 9780170189071

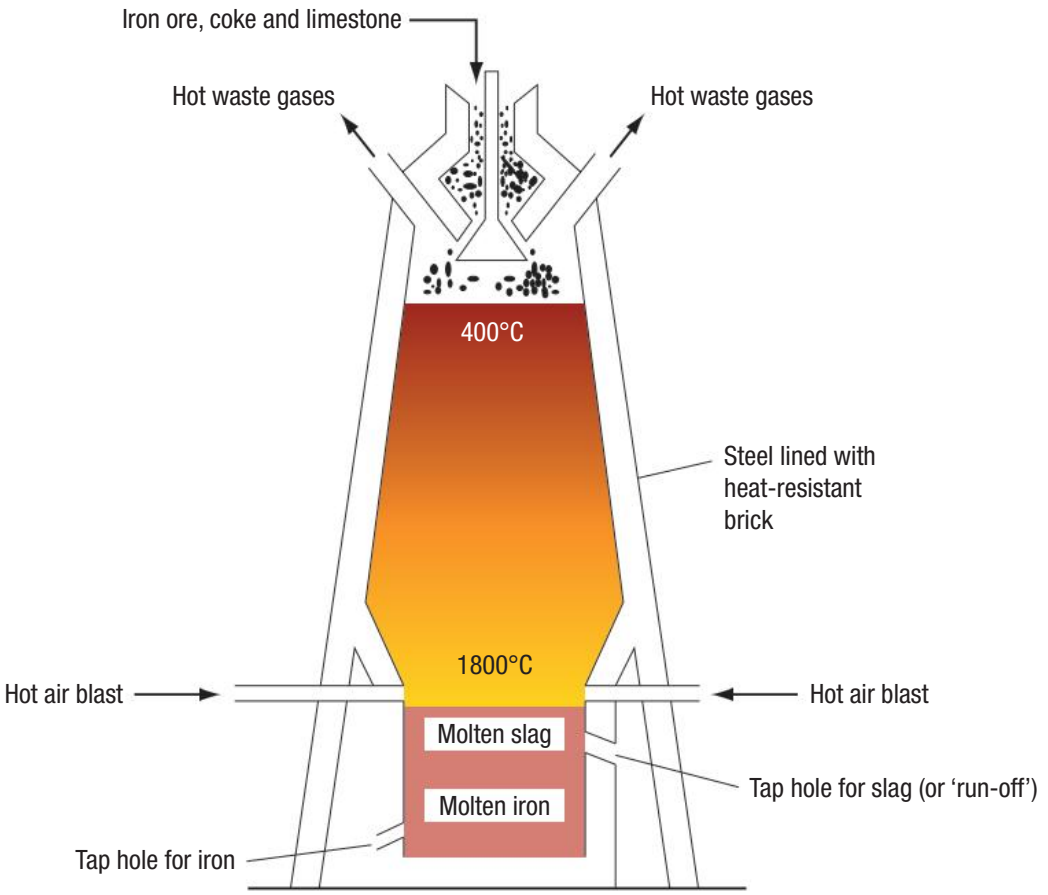


Figure 4.20 Extracting iron using a blast furnace

WEBLINK
How steel is made

In the main part of the blast furnace, the following reaction occurs.

Iron oxide + carbon monoxide → iron + carbon dioxide

$$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$$

In the hotter part the carbon itself reacts:

Iron oxide + carbon → iron + carbon monoxide

$$Fe_2O_3 + 3C \rightarrow 2Fe + 3CO$$

These reactions are single replacement reactions because the pure metal is separated from its compound, and a new compound is formed between the other reactant and the anion from the metallic compound.

The production of iron in a blast furnace is a continuous process. The furnace is heated constantly and recharged with raw materials from the top while being tapped from the bottom. Iron making in a furnace usually continues for about 10 years before the furnace linings need to be renewed.

Activity 4.8
Careers in science

Research a career in the mining industry that is linked to science. Develop five 'W' and one 'H' questions – that is, 'what', 'where', 'when', 'who', 'why' and 'how.' Once you have developed your questions, research the answers to these.

WEB 2.0

Develop a digital presentation to share your findings on the class wiki.

Extracting other metals

Knowledge of the chemistry involved in extracting iron can be applied to the extraction of other metals, including copper, lead, tin and titanium. Although the processes are all slightly different, the end product is the same – the metal.

ISBN 9780170189071

Generally, the compound containing the metal undergoes a reaction to separate the metal from the other element(s) in the compound. The amount of energy needed to do this depends on the reactivity of the metal – that is, the more reactive metals are, the harder it is to separate them, so more energy is needed.

Copper usually occurs as Cu_2S, so its reaction is:

Copper sulfide + oxygen → copper + sulfur dioxide

$$Cu_2S + O_2 \rightarrow 2Cu + SO_2$$

For lead, the reaction is:

Lead oxide + carbon → lead + carbon monoxide

$$PbO + C \rightarrow Pb + CO$$

VIDEO
Reducing metal oxides
SCI10SUVD00107

WEBLINK
Method of extracting metal

Activity 4.9
Extraction of iron

WORKSPACE
Extraction of iron
SCI10SIWR00263

What are the risks in doing this activity?	How can you manage these risks to stay safe?
Hot objects can cause severe burns.	Do not touch the hot objects. Always use tongs and allow the objects to cool before putting them away.

In this activity you will model the process that occurs in a blast furnace by extracting iron from iron(III) oxide using carbon.

Note that the wood in the match is used as the source of carbon. The chemicals in the head do not react – they are used as a source of heat. The sodium carbonate fuses easily, so it is used to hold the iron(III) oxide on the wood of the match.

Materials

- long match
- sodium carbonate powder
- iron(III) oxide powder
- water
- crucible tongs
- watch glass
- spatula
- Bunsen burner
- heat-proof mat
- magnet
- safety goggles, lab coat and gloves

Method

1 Dip the match head in a small amount of water to moisten it.

2 Roll the damp match head first in the sodium carbonate powder and then in the iron(III) oxide powder.

3 Wash your hands to remove any chemicals.

4 Holding the match with a pair of tongs, put the head into a blue Bunsen flame.

5 Allow the match to burn no more than halfway along its length and then extinguish the flame.

6 Allow the match to cool, place it on the watch glass and use the spatula to crush the charred part.

7 Move the magnet around under the watch glass and observe.

Results

1 Record all your observations.

Discussion

2 What was the evidence of iron being extracted?

3 Write word and balanced equations for the reaction.

Conclusion

4 Write a conclusion for this activity.

WEB 2.0

Record this activity and create a movie about what you are doing, why you are doing it, what you observe and why. Include your thoughts about what you have found out. Upload this or the link to your movie to your blog.

ISBN 9780170189071

Questions 4.4

What have you learnt?

WORKSPACE

What have you learnt? 4.4

SCI10SUWR00108

Understand

1 What is the difference between a metal and an ore?

2 What is the relationship between a metal's position in the activity series of metals and the method by which it is extracted?

3 **a** Complete the following reaction.

Iron oxide + carbon →

b What type of reaction is this?

Apply

4 Write word and balanced equations for the reaction between tin(IV) oxide (SnO_2) and carbon (C).

Analyse

5 Explain why more energy is needed to extract more reactive metals.

6 Suggest why the extraction of iron needs to occur at very high temperatures.

Getting the reaction going

As mentioned already, to extract iron from its ore there needs to be lots of energy – in the form of heat – for the reaction to occur. More specifically, energy needs to be added to get the reaction started. An example is when we burn magnesium. The magnesium needs to be ignited before it can burn; however, once lit, it burns very rapidly. Explosions take only a fraction of a second once ignited.

Not all reactions need an energy input to get them going, however. Most of the reactions we have looked at so far occur spontaneously. For instance, as soon as an acid touches aluminium, bubbles begin to form. Can you identify other reactions that occur spontaneously? Do all spontaneous reactions occur rapidly? The answer to the second question is 'No'.

Rusting takes years to occur, the chemical weathering of rocks takes thousands of years, cement sets firmly in a few hours, the digestion of food takes 4–5 hours and garden waste in a compost heap takes many weeks to decompose. Therefore, reactions may occur spontaneously or need energy input. They may occur quickly or slowly. Compare Figures 4.21 below and 4.22 on page 129.

Is there a relationship between energy and the rate at which a reaction occurs? Think about cooking a cake. How long does it take when the oven temperature is higher compared with when it is lower? What else affects how long a reaction will take to occur?

Figure 4.21 Rusting is a slow reaction.

ISBN 9780170189071

Figure 4.22 Fireworks are a fast reaction.

Activity 4.10
How long?

1 Create a table with the following headings: 'Instant', 'Within hours', 'Days', 'Months' and 'Years'. Under each, list a minimum of five reactions that would take that time to occur.

2 Why do some recipes specifically direct you to cook things slowly or quickly? What effect does the rate at which something is cooked have on flavour, texture, colour, general appearance, sound (crunch) and aroma? Give a specific example when you answer this.

Factors affecting reaction rate

The speed at which a reaction occurs is called the reaction rate. When a reaction happens quickly, it has a fast reaction rate; a reaction that takes a longer time to occur has a slow reaction rate. For reactant molecules to react, they need to collide with other reactant molecules with enough energy to cause them to rearrange (remember the particle theory).

You can increase and decrease the reaction rate by changing the conditions under which the reaction occurs. Four factors affect reaction rate: temperature, concentration, surface area and the presence of a catalyst.

Temperature

Temperature plays a major role in increasing the rate of reactions. Chemical reactions performed at high temperatures produce the products faster. However, sometimes you want a reaction to occur slowly. For example, you put food in the refrigerator to make it last longer and freezing makes it last even longer because it slows down the decomposition reactions that occur.

Increasing the temperature increases the reaction rate because the particles have more energy and collide with one another at a much greater rate.

Concentration

The concentration of a substance is the measure of how much there is of a substance in a certain amount of solution. If the concentration is higher, there are more particles that can undergo the reaction; therefore, the reaction rate increases.

Surface area

The rate of a reaction also depends on whether the reactants are in big pieces or if they are more finely divided. To get a fire started, we use small chips of wood because they burn faster than large logs. When large pieces are broken down into smaller pieces, they have a larger surface area. This means more particles are available for reaction.

In the extraction of iron activity on page 127, powdered reactants were used. The result was that they reacted faster.

glossary terms

concentration
a measure of the amount of a substance in a given amount of solution

reaction rate
the speed at which a reaction occurs

spontaneously
occurring without additional energy input

surface area
the area of the surface of a substance; more finely divided substances have a greater surface area than the same mass of larger pieces

ISBN 9780170189071

Exploding flour

We know that wood and wheat can burn, but most people do not realise how dangerous flour is. Because flour particles are so tiny, they burn very quickly and easily. In fact, flour ignites so easily that it is considered an explosive! Flour explosions in bakeries and flour mills have caused hundreds of deaths. Explosions in flour mills have been caused by flour dust being exposed to candle flames, hot electric light bulbs and even cigarettes. Special equipment and materials that will not produce sparks are now used in flour mills.

Activity 4.11
WHS

Research the WHS (work, health and safety) for flour storage in a bakery, stating advice, government regulations and specifications. Develop your own list of questions and answer these in regard to flour storage. Upload your findings to the class wiki.

Catalysts

Another way to increase the rate of a reaction is to add a substance that helps bring the reactants together so that they can react. A substance that helps speed up a reaction, but does not become a product of the reaction, is called a catalyst. Catalysts work by providing a site for reactants to attach to specific parts of the catalyst. At this site the reactants come apart or bond together.

Catalysts are critical in virtually every industrial chemical process. Fertilisers could not be made without them, neither could plastics or petrol. In a single day you will encounter many products that are either made themselves using catalysts or produced using materials formed in catalytic reactions.

Catalysts are widely used in industry because not only do they speed up a reaction, but they also reduce the amount of energy needed for the reaction to occur. This means energy savings to the manufacturer. Catalytic converters in cars reduce the amount of pollutants released. The plastics industry relies on catalysts for the manufacture of most types of plastics.

Catalysts in living things are called enzymes. A common catalyst in the cells of living things is called catalase. Catalase helps to quickly break down hydrogen peroxide, which is produced in cells as a toxic by-product of normal cellular processes (Figure 4.23). A single molecule of catalase can catalyse the breakdown of millions of hydrogen peroxide molecules into oxygen and water every second. Enzymes such as catalase are large complex protein molecules. They are specific catalysts, meaning they only catalyse one particular reaction.

VIDEO
Catalysts
SCI10SUVD00109

INTERACTIVE
Enzymes and digestion
SCI10SUIN00094

Figure 4.23 The breakdown of hydrogen peroxide into oxygen and water is an example of a catalase enzyme reaction.

ISBN 9780170189071

Activity 4.12

Comparing reaction rates

WORKSPACE

Comparing reaction rates

SCI10SIWR00110

What are the risks in doing this activity?	How can you manage these risks to stay safe?
Hydrochloric acid is corrosive.	Wear safety goggles and protective clothing. Take care when handling the chemicals and tell the teacher if there is a spill.

In this activity you will investigate how concentration, surface area and catalysts affect reaction rates.

Part A: concentration

Hypothesis

Write a hypothesis stating which reaction you think will occur the fastest.

Materials

- 0.1 M, 1 M and 2 M hydrochloric acid
- 1.5 g granulated zinc
- 3 test tubes
- test-tube rack
- electronic balance
- measuring cylinder
- stopwatch
- safety goggles, lab coat and gloves

Method

1. Measure 10 mL of each of the different concentrations of hydrochloric acid and pour them into separate test tubes.
2. Weigh out 3 amounts of 0.5 g of granulated zinc. At the same time, add the zinc to each of the three test tubes and start the stopwatch.
3. Time how long it takes for all the zinc to react in each test tube.

Results

1. Record the reaction time in a data table.
2. For which concentration did the reaction proceed the quickest?

Conclusion

3. What effect does concentration have on the speed of the reaction? Write a general statement.

Part B: surface area

Materials

- 3 antacid tablets
- spatula
- distilled water
- 250 mL beaker
- stopwatch
- measuring cylinder
- mortar and pestle

Method

1. Measure 100 mL of distilled water and add it to the beaker.
2. Place a whole antacid tablet in the beaker and time how long it takes to dissolve.
3. Repeat steps 1–2, but this time break a second antacid tablet into smaller pieces before adding it to the beaker.
4. Repeat steps 1–2 again, but this time grind the antacid tablet into very small pieces using the mortar and pestle.

Results

1. Record the reaction time in a data table.
2. Which tablet reacted the fastest?

Discussion

3. Is this a fair test? Explain why or why not.

glossary terms

catalase
an enzyme that catalyses the decomposition of hydrogen peroxide into water and oxygen

catalyst
a chemical that speeds up a chemical reaction but does not itself change

ISBN 9780170189071

What are the risks in doing this activity?	How can you manage these risks to stay safe?
Hydroxide peroxide and manganese dioxide are harmful.	Gloves, safety goggles and protective clothing must be worn at all times. Follow your teacher's instructions about the disposal of the manganese dioxide. If any of these chemicals are spilt, tell your teacher immediately.
Oxygen causes substances to burn.	Follow the safety instructions for the glowing taper test very carefully so that you do not get burnt.

Conclusion

4 Write a general statement relating the size of the particles to the rate of reaction.

Part C: catalysts

Background

The chemical formula of hydrogen peroxide is H_2O_2 (Figure 4.24). The most common compound of oxygen and hydrogen is water (H_2O). The hydrogen peroxide molecule is not nearly as stable as the water molecule, so it will decompose and give off the extra oxygen atom, which will combine with another to form an oxygen molecule. This is shown in the following equation.

$$2H_2O_2(l) \rightarrow 2H_2O(l) + O_2(g) + \text{energy}$$

hydrogen peroxide water oxygen

This decomposition reaction normally occurs very slowly; however, if a catalyst is added, it will proceed very rapidly. Substances that can be used to catalyse (speed up) the decomposition of hydrogen peroxide include enzymes found in potatoes and liver and manganese dioxide, a black compound of formula MnO_2.

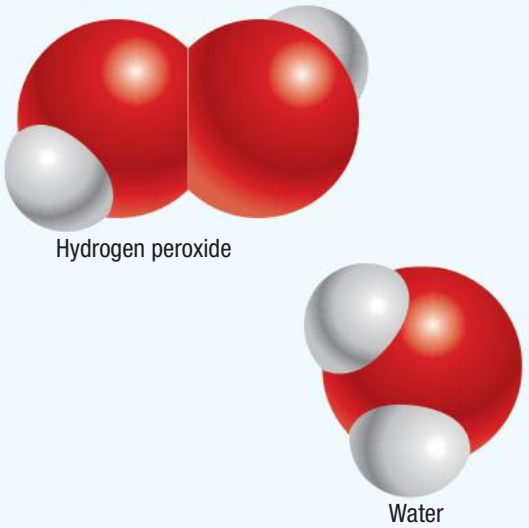


Figure 4.24 Hydrogen peroxide and water

Materials

- 100 mL clean conical flask containing a small amount of hydrogen peroxide
- small spatula of manganese dioxide
- piece of cotton wool
- long taper
- matches
- latex gloves
- heat-proof mat
- safety goggles, lab coat and gloves

Method

1 Very carefully, place the flask containing the hydrogen peroxide onto the middle of the heat-proof mat. Have the catalyst and cotton wool ready.

2 Tip the catalyst into the flask and immediately add the cotton wool plug, as shown in Figure 4.25. Record your observations.

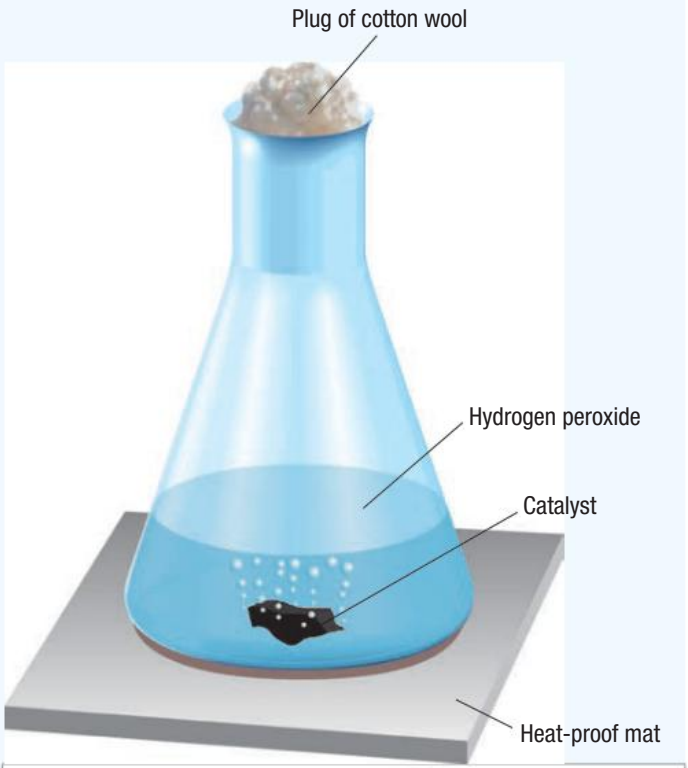


Figure 4.25 The correct way to set up the equipment

ISBN 9780170189071

3 When the reaction appears to have stopped, perform the glowing taper test on the gas you have collected. Ensure that the cotton wool is removed just before you plunge the glowing taper into the space above the liquid. Is there evidence that oxygen was produced? Record your observations.

4 Carefully follow your teacher's instructions for cleaning up.

Results

1 Describe all your observations.

2 Do your results support the equation for the decomposition of hydrogen peroxide?

Discussion

3 Was the catalyst used up in this reaction? If so, how can you tell?

4 Suggest why the cotton wool was used.

5 Which type of reaction has occurred?

6 If different groups in the class used different catalysts, compare your results and comment on the effectiveness of the catalysts.

WEBLINK
Rates of reaction

Questions 4.5
What have you learnt?

WORKSPACE
What have you learnt? 4.5
SCI10SUWR00111

Understand

1 Consider the following reactions. Write them in order from fastest to slowest.
- Fireworks exploding
- Metals rusting
- Digestion
- Burning a candle
- Cooking an egg

2 List the four factors that affect reaction rate.

Apply

3 For each of the following statements, give the factor that causes the reaction rate to increase.
- **a** Scrambled eggs cook faster than whole eggs.
- **b** Hot-water pipes corrode faster than cold-water pipes.
- **c** Bile speeds up the digestion of fat.
- **d** Soluble aspirin works more quickly than taking a tablet.

4 Why should ripe fruit be kept in the refrigerator but green fruit can be left on the counter?

Analyse

5 Four strips of magnesium were placed into four acid solutions. The temperatures and time for the reactions are given in the following table.

Magnesium strip	1	2	3	4
Temperature (°C)	15	25	35	45
Time (s)	48	30	14	7

- **a** Construct a graph of the results, plotting temperature on the horizontal axis and time on the vertical axis.
- **b** How long would it take for the reaction to be completed at a temperature of 30°C?
- **c** On the same graph, sketch the curve you would expect to obtain if a more concentrated acid was used.

6 A 250 mL beaker containing 100 mL of dilute sulfuric acid has 0.5 g of zinc added to it. A reaction occurs, producing zinc sulfate and hydrogen gas. Which of the following changes would increase the reaction rate?
- **A** Warming the acid prior to adding the zinc
- **B** Using a 500 mL beaker
- **C** Using the same mass of granulated zinc
- **D** Using 200 mL of acid of the same concentration
- **E** Using 100 mL of a concentrated sulfuric acid

ISBN 9780170189071

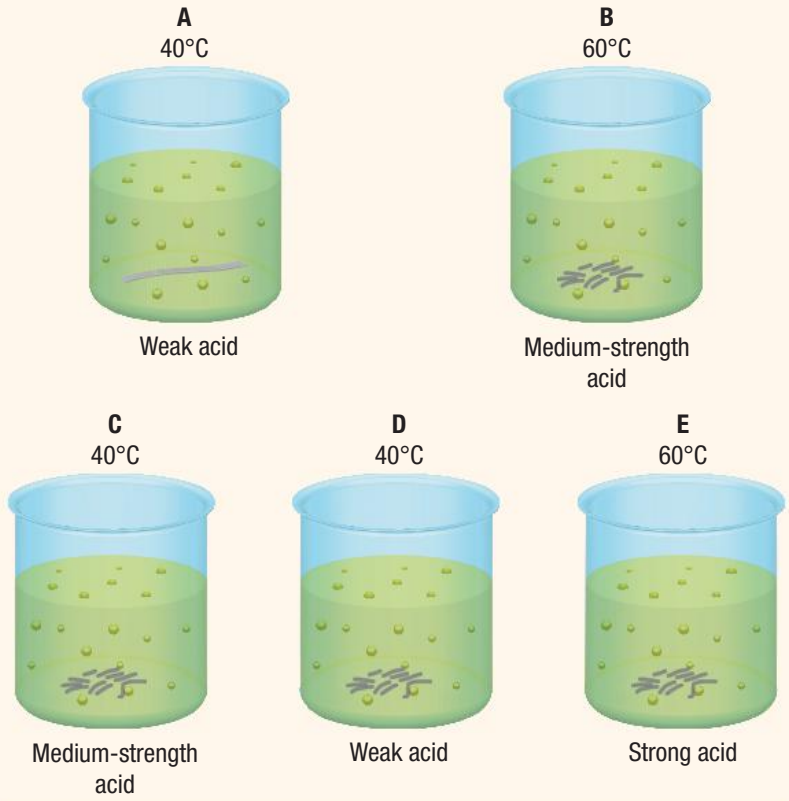


Figure 4.26 Testing acid–magnesium reaction rates

Synthesise

7 Students were given the experimental set-up shown in Figure 4.26, where a reaction between magnesium metal and an acid was to be tested. The same amount of magnesium and acid was used in each beaker. Predict the order of reaction rate, from fastest to slowest.

Evaluate

8 A student wanted to know if the digestion of fat by a pancreatic extract is speeded up by bile. A pink indicator that turns yellow when fat is digested was used to determine when digestion had occurred.

The student set up two test tubes:

- Test tube A: 5 mL full-cream milk + 10 mL pancreatic extract + indicator
- Test tube B: 5 mL full-cream milk + 5 mL pancreatic extract + 5 mL bile solution + indicator

After shaking each test tube, the student timed the indicator's change from pink to yellow. The results are given in the table below.

Test tube	Time taken for indicator to change (min)
A	10
B	3

The student concluded that bile helps an enzyme in the pancreatic extract to break down the fat in milk. Is this a valid conclusion? Justify your answer by giving at least two reasons.

Fuels and pharmaceuticals

It might seem strange to put fuels and pharmaceuticals together. Fuels (namely the fossil fuels coal, oil and natural gas) are used as a source of energy for a wide range of purposes, such as transportation, cooking and the extraction of metals; and pharmaceuticals are drugs with the ability to reduce the level of harmful foreign bodies (such as bacteria or viruses) in our bodies and make us well. So what do fuels and pharmaceuticals have in common? The answer is in their chemistry – that is, both are based on the element carbon, which is the most versatile of all atoms.

Carbon atoms are the basic part of almost every molecule in living things and the products derived from

ISBN 9780170189071

living and once-living things. Humans are carbon-based organisms, as are all living things on Earth.

Carbon is so important that there is whole branch of chemistry devoted to it – organic chemistry. The term 'organic' came about because it was once believed that only living things could make these carbon (organic) compounds. There are millions of organic compounds. There are at least 10 times as many organic compounds as compounds that are not organic, and more are being discovered every day. The study of compounds that are not organic is called inorganic chemistry and the compounds are called inorganic compounds.

Today, chemists are able to synthesise many different organic compounds in the laboratory, from the simplest ones in fossil fuels to the extremely complex ones used in drugs. Hydrogen is always present in these compounds, along with other elements, commonly oxygen and nitrogen.

WOW!

Are oysters organic?

Strangely, although pesticides and herbicides are banned from being sprayed onto organic foods, almost all are in fact organic compounds. On the other hand, living organisms can make inorganic compounds. For example, oysters manufacture pearls and shells, both of which are made from the inorganic compound calcium carbonate ($CaCO_3$).

Versatile carbon

Carbon atoms are unique among all the atoms. They can form molecules of all kinds of shapes, including rings, short chains, giant chains and even cages that look like soccer balls. In addition to bonding to other carbon atoms to form giant cages (see the bucky ball in Figure 4.27), carbon can bond to other carbon atoms to form a giant lattice, such as that found in graphite and diamond (Figure 4.28). This is why carbon is often described as versatile.

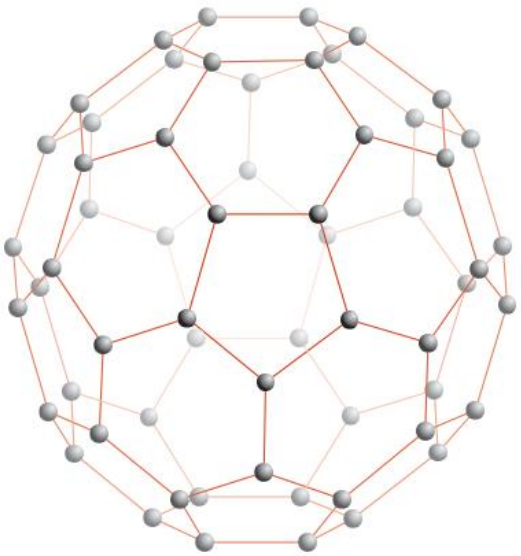


Figure 4.27 A bucky ball (or C_{60} ball)

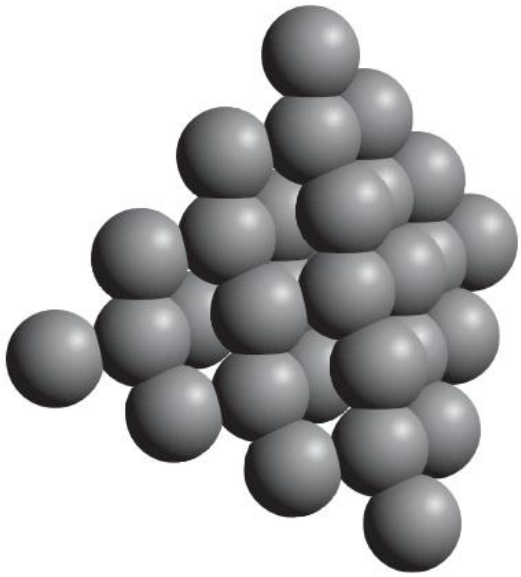


Figure 4.28 Part of a giant diamond lattice

ACTIVITY SHEET

Bucky balls

SCI10SUAS00112

So far we have learnt that compounds form because atoms need to have a filled outer shell to be stable, and that they get this by losing or gaining electrons. The metal atoms lose their outer-shell electrons and the non-metal atoms gain these electrons. What about compounds that contain only non-metals? The atoms still want to have filled-out shells; however, without the metal atoms to donate electrons, the non-metals have to share their electrons.

glossary terms

inorganic chemistry
the branch of chemistry that studies the compounds of elements other than carbon compounds

organic chemistry
the branch of chemistry that studies carbon compounds

ISBN 9780170189071

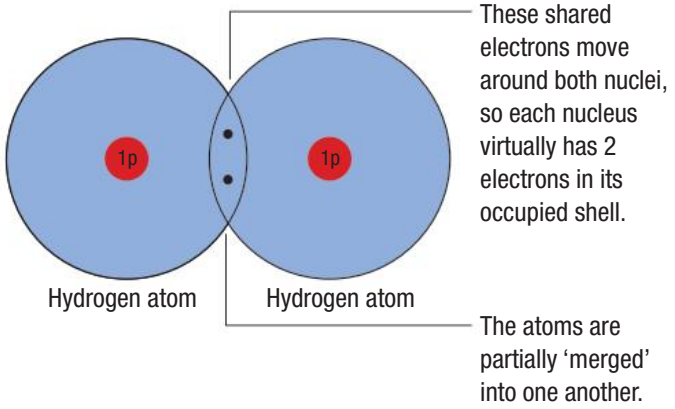


Figure 4.29 A molecule of hydrogen

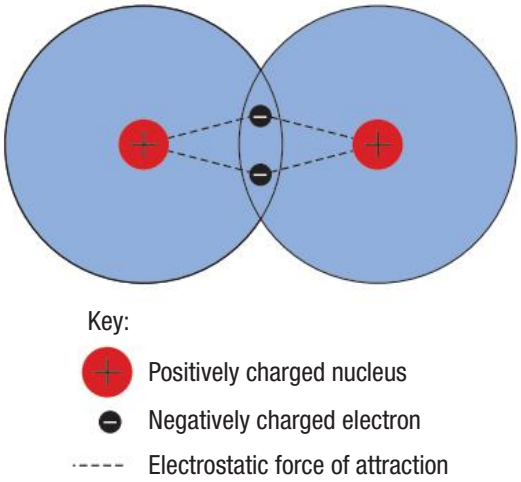


Figure 4.30 Covalent bonding at work

Simple molecules

The simplest atom is hydrogen, which has only one electron. To obtain a filled outer shell, hydrogen needs to gain or share one electron. If there are only hydrogen atoms, the only way hydrogen can obtain this electron is by sharing its electron with another atom. This is shown in Figure 4.29.

The resulting pair of atoms is called a hydrogen molecule. It is represented by the chemical formula H_2. The two atoms in a hydrogen molecule stick strongly to each other because there is a very strong electrostatic attraction between the negatively charged shared electrons and the positively charged nuclei they lie between (Figure 4.30). This strong force of attraction is termed covalent bonding, which is so strong that it takes a lot of energy to force the two atoms apart. Covalent bonding is similar in strength to the attraction between the ions in an ionic bond.

All molecules are held together by strong covalent bonding. In all cases, each atom in the molecule achieves a stable electron arrangement by sharing electrons with the atoms next to it. When a pair of atoms shares one pair of electrons, such as in the case of hydrogen, we say there is a single covalent bond between the atoms. Chemists represent the molecule of hydrogen in various ways, as shown in Figure 4.31.

Bonding with carbon

Consider the carbon atom. It has four electrons in its outer shell, so it needs four more electrons to gain a stable electron structure (Figure 4.32).

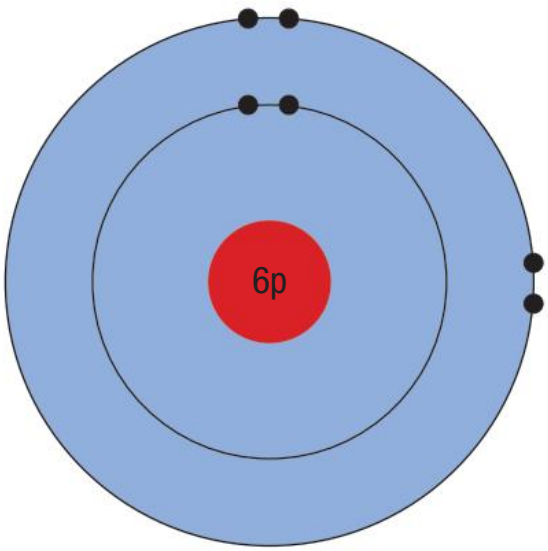


Figure 4.32 The carbon atom

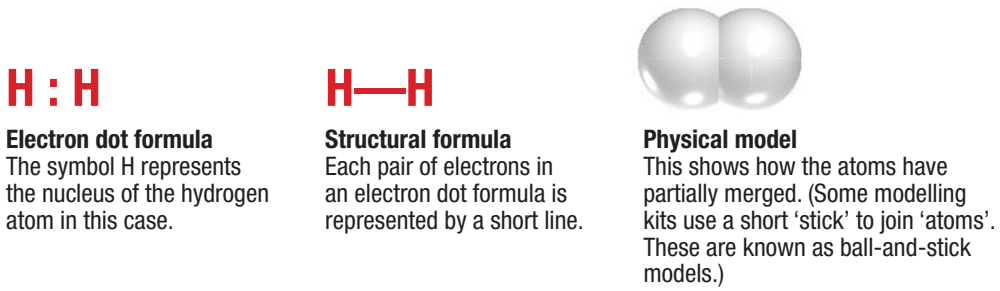
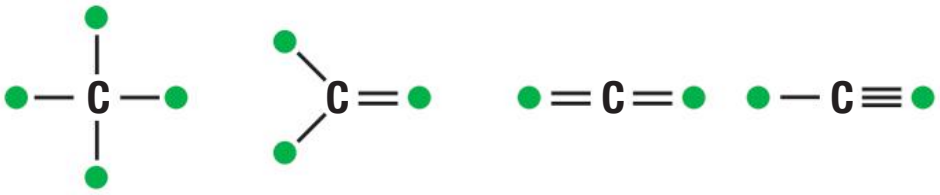


Figure 4.31 Modelling the hydrogen molecule

ISBN 9780170189071



Sharing 1 electron pair with each of 4 atoms

Sharing 1 electron pair with each of 2 atoms and 2 electron pairs with one other atom

Sharing 2 electron pairs with each of two atoms

Sharing 1 electron pair with 1 atom and 3 electron pairs with another atom

Figure 4.33 The different ways that carbon atoms can gain four electrons

There are many possible ways of gaining four electrons, as shown in Figure 4.33. This is why so many different kinds of structures can be built from carbon atoms!

Notice that two possibilities are missing in Figure 4.33. The two things that carbon atoms *cannot* do to obtain those extra four electrons are shown Figure 4.34.

Share 4 electrons and form an ion.

Gain 4 electron pairs with one atom.

Figure 4.34 What carbon *cannot* do!

Fossil fuels

Coal, oil and natural gas are called fossil fuels because they have been produced from the remains of plants and animals that lived millions of years ago. Through decomposition in the absence of oxygen, a range of chemical substances that mostly consist of just carbon and hydrogen was produced. Compounds of only carbon and hydrogen are termed hydrocarbons.

VIDEO

Introducing fuels and their uses

SCI10SUVD00099

The main family of hydrocarbons present in crude oil and natural gas is known as the alkanes. The alkane family is very important because among its members are the fuels that we use every day to supply us with energy. For most Australians, alkanes run our cars, supply us with hot water, heat our homes and cook our foods. In addition, alkanes supply us with the raw materials to make many other substances, including plastics (Figure 4.35).

In the molecules of the alkane family, each carbon atom is joined to four other atoms. The result is molecules that look rather like caterpillars (Figure 4.36 on page 138).

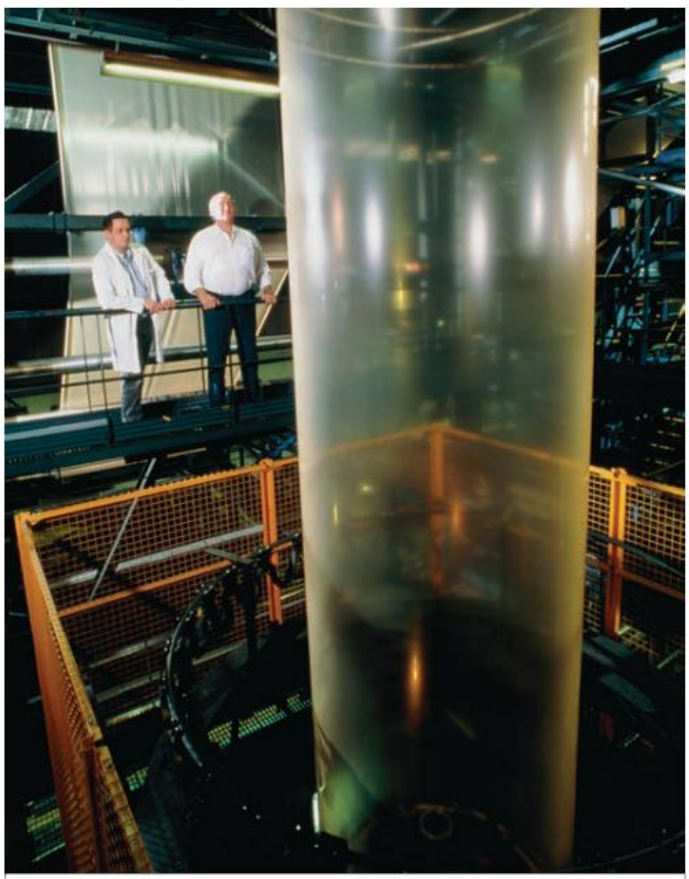


Figure 4.35 Polyethene (common name polyethylene, or PE) is a plastic that has molecules that are like giant alkane molecules. It is manufactured from simple alkanes.

glossary terms

alkanes
the main family of hydrocarbons present in crude oil and natural gas

covalent bonding
the strong electrostatic force of attraction between the negatively charged electrons shared between two atoms and their positively charged nuclei

hydrocarbon
an organic compound that contains only hydrogen and carbon

molecule
two or more atoms joined by sharing a pair of electrons

single covalent bond
a covalent bond in which one pair of electrons is shared

ISBN 9780170189071

Figure 4.36 A model of a simple alkane

WEBLINK
Fuels from crude oil

Table 4.3 shows the formulas and names of the first five hydrocarbons.

Table 4.3 The formulas and names of the first five hydrocarbons

Name	Formula
Methane	CH_4
Ethane	C_2H_6
Propane	C_3H_8
Butane	C_4H_{10}
Pentane	C_5H_{12}

Activity 4.13
Making alkanes

WORKSPACE
Making alkanes
SCI10SIWR00262

In this activity you will use models of atoms to build up models of members of the family of alkanes.

Materials

- atoms kit or paper models of carbon and hydrogen atoms

Method

1 Make a model of methane (CH_4), the simplest member of the family of alkanes, as shown in Figure 4.37. Notice how the electrons are arranged so that each atom gains a stable electron arrangement, like that of the nearest noble gas. Draw the structure of methane on a results sheet.

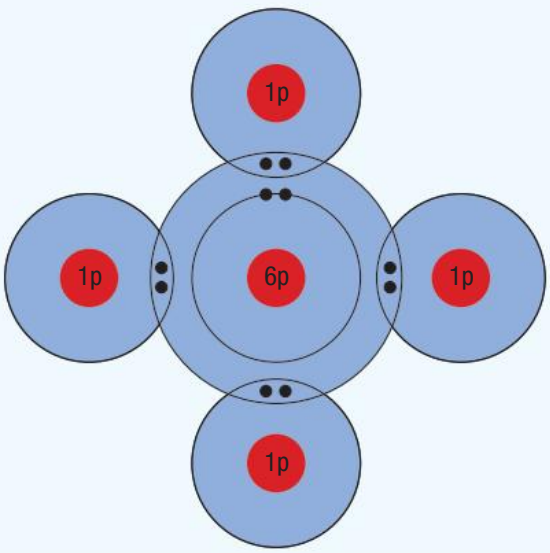


Figure 4.37 A model of the methane molecule

2 Now remove one of the hydrogen atoms from the methane molecule and replace it with a new carbon atom, as shown in Figure 4.38. Notice that the new carbon atom is sharing only one electron pair with the original carbon atom.

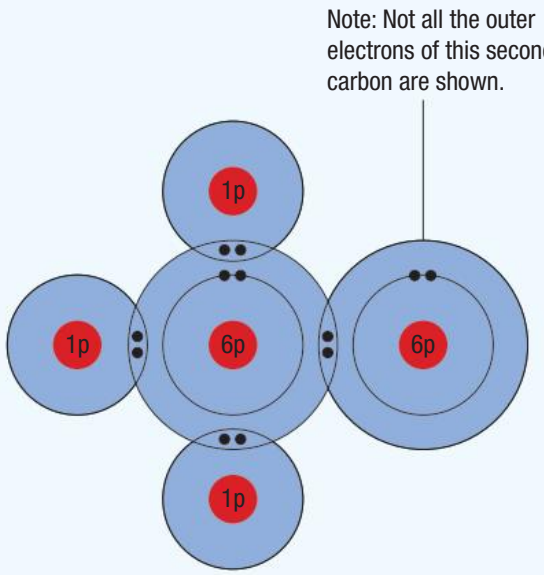


Figure 4.38 Substituting a carbon atom

3 In your group, discuss what other hydrogen atoms you will need to add so that the new carbon atom can gain a stable electron arrangement like that of the nearest noble gas. Add them on and check that every atom in your molecule arrangement has a stable electron arrangement, similar to that of its nearest noble gas.

ISBN 9780170189071

4 Draw the structure of the molecule you have created on your results sheet. What will be the formula of the molecule you have constructed? Write it in the following form: C_xH_y.

5 Keep repeating steps 2–3 so that you produce a succession of family members with an increasing number of carbon atoms. Make a class display of the last molecule you made in the time available.

Results

1 For each family member, was each carbon atom bonded to four other atoms?

2 As the number of carbon atoms increased, what did you notice about the number of possible molecules you could make?

Discussion

3 Identify the mathematical relationship between the number of carbon atoms and the number of hydrogen atoms in the formulas of the members of this family.

Biofuels

Fossil fuels are a finite resource. They take millions of years to form, and the supply is being used at a rate that has many scientists predicting we will run out by the middle of this decade. Consequently, scientists are undertaking research to develop alternative fuels.

One group of alternative fuels is biofuels, which are produced from recently formed plant material. Some of the fuels are produced directly from the plant, such as ethanol from sugar cane and diesel from vegetable oils (Figure 4.39). There is a lot of research looking at the production of biofuels from biomass waste.

WEBLINK
Biofuels from waste

The chemistry of producing biofuels is too complex to study at this stage; however, the weblink below will provide information on the current research being conducted into biofuels.

WEBLINK
Gatsby Science Enhancement Programme

Activity 4.13
If fossil fuels ran out tomorrow...

If fossil fuels ran out tomorrow, what would be the:

- immediate consequences (1 day)?
- medium-term consequences (1 month)?
- longer-term consequences (decades)?

Add ideas to your blog.

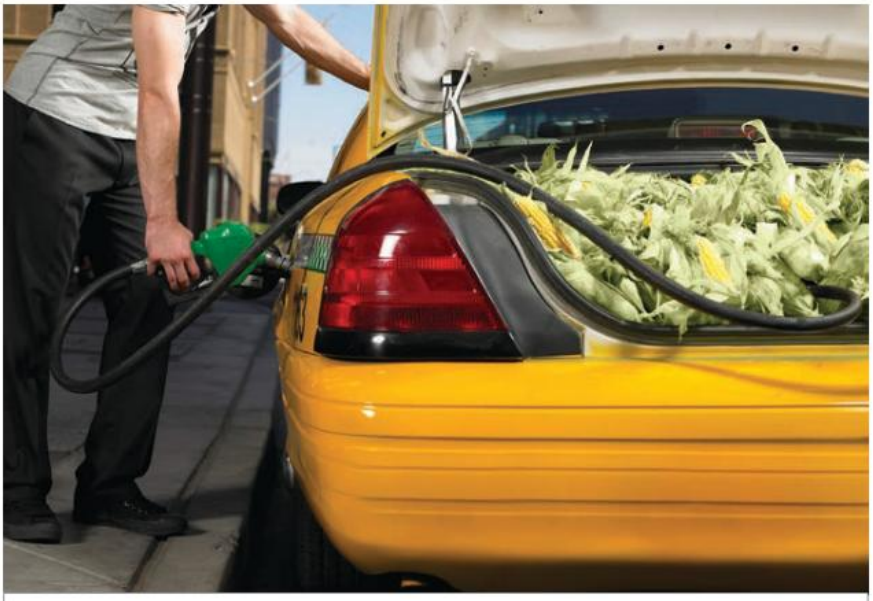


Figure 4.39 Corn can be used to make biofuel.

ISBN 9780170189071

Pharmaceuticals

The chemical structure of drugs is very complex, so how do chemists develop drugs and work out their structure? There are many different roles for chemists in the pharmaceutical industry – such as medicinal, process and pharmaceutical chemists – and each one makes a specific contribution to the development a new drug (Figure 4.40).

The initial identification and development of a compound that will eventually become a drug are the role of medicinal chemists. They will have identified a drug candidate, and then modified the structure of the compound several times to improve its good characteristics and minimise the bad points. At this stage only a few milligrams of the compound will have been produced.

Process chemists are the link in the chain from the initial idea to a new drug making it to the market. First, they develop efficient chemical reactions to produce larger quantities of the most promising compounds for the initial study of the effects of the drug candidates on animals, such as rats. Then the chemists develop the actual drug after clinical trials on humans have taken place.

Pharmaceutical chemists have the job of transforming the actual drug substance into a product for ingestion by patients.

Use the weblink below to learn more about the jobs of chemists in the pharmaceutical industry.

WEBLINK
Careers in the pharmaceutical industry

Figure 4.40 A chemist working in a pharmaceutical laboratory

Questions 4.6
What have you learnt?

WORKSPACE
What have you learnt? 4.6
SCI10SUWR00113

Understand

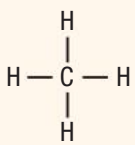
1 What is the difference between organic and inorganic compounds?

2 About how many organic compounds are known to exist?
- **A** Hundreds
- **B** Thousands
- **C** Tens of thousands
- **D** Millions

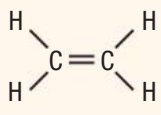
3 Distinguish between:
- **a** a molecular compound and an ionic compound
- **b** covalent bonding and ionic bonding.

4 Which one of the structures (**A**–**D**) shown in Figure 4.41 is impossible for carbon?

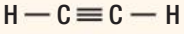
A



B



C



D

Figure 4.41

ISBN 9780170189071

5 Which of the following compounds are hydrocarbons?

A Ethane (C_2H_6)

B Carbon dioxide (CO_2)

C Acetic acid (CH_3COOH)

D Octane (C_8H_{18})

E Diamond

6 What is the difference between a biofuel and a fossil fuel?

Apply

7 Which one of the electron dot diagrams (**A**–**D**) in Figure 4.42 correctly represents the structure of a chlorine molecule?

A Cl ⋮ Cl

B Cl : Cl

C :Cl:Cl:

D ⁚Cl⁚Cl⁚

Figure 4.42

8 Which of the following statements about phosphorus can be deduced from the fact that it is in group 15 of the periodic table?

A It has 15 electrons available for sharing with other atoms.

B It has 5 outer electrons and needs 3 more for a stable electron arrangement.

C It needs to share 5 pairs of electrons to gain a more stable electron arrangement.

D A phosphorus atom must share 3 pairs of electrons with any other atom it combines with.

9 Propane gas (C_3H_8) is the gas used in gas cylinders for barbecues.

a Identify the family of chemicals to which propane belongs.

b Draw the structure of this molecule, showing clearly how each atom has gained a stable electron arrangement in this structure.

c When propane burns in oxygen, carbon dioxide and steam are produced. For the combustion of propane, write:

i a word equation

ii a balanced symbolic equation.

10 The table below shows some information about alkanes. Use it to answer the questions that follow.

Name	Formula	Melting point (°C)	Boiling point (°C)
Methane	CH_4	−182.5	−161.5
Ethane	C_2H_6	−182.8	−88.6
Propane	C_3H_8	−187.7	−42.1
Butane	C_4H_{10}	−138.3	−0.5
Pentane	C_5H_{12}	−129.7	36.1
Hexane	C_6H_{14}	−95.3	68.7
Heptane	C_7H_{16}	−90.6	98.4

a Which alkanes are gases at 25°C?

b Which alkanes are liquids at 25°C?

c Plot a graph of boiling point against the number of carbon atoms.

d Write a general relationship between the number of carbon atoms and boiling point.

ISBN 9780170189071

Unit review

ACTIVITY SHEET
Unit 4 checklist
SCI10SUAS00114

REVIEW QUIZ
Unit 4
SCI10SURQ00115

WORKSPACE
Unit 4 review
SCI10SUWR00116

Understand

1 Match the type of reaction on the left side of the table with the correct definition on the right.

Type of reaction	Definition
Combustion	This occurs when different atoms in two different compounds trade places.
Decomposition	This occurs when one element replaces another in a compound.
Synthesis	A substance reacts with oxygen to form carbon dioxide and water.
Single replacement	Two or more substances combine to form a more complex substance.
Double replacement	Compounds break down into simpler substances.

2 Complete the following with a word or phrase.

a Cations are _____ charged ions that have _____ electrons.

b When an atom _____ electrons, it becomes negatively charged and forms an _____.

c A _____ is extracted from an ore.

d Metals that are more reactive are _____ extracted than metals that are less reactive.

3 List the four factors that affect the rate of a reaction and describe how they affect the rate.

4 Using examples, explain the difference between ionic bonding and covalent bonding.

5 Draw a diagram showing the electron arrangement of the covalent substance CH_4.

Apply

6 For each of the following equations, classify the reaction as: C = combustion, D = decomposition, S = synthesis, SR = single replacement, DR = double replacement.

a _____ $CaO + CO_2 \rightarrow CaCO_3$

b _____ $2H_2O_2 \rightarrow 2H_2O + O_2$

c _____ $C_5H_{12} + 8O_2 \rightarrow 5CO_2 + 6H_2O$

d _____ $8Al + Fe_3O_4 \rightarrow 4Al_2O_3 + 9Fe$

e _____ $2H_2 + O_2 \rightarrow 2H_2O$

f _____ $2HCl + Zn \rightarrow ZnCl_2 + H_2$

g _____ $ZnS + 2HCl \rightarrow ZnCl_2 + H_2S$

ISBN 9780170189071

7 Balance the following equations.

a $__C_3H_8 + __O_2 \rightarrow __CO_2 + __H_2O$

b $__C_7H_6O_2 + __O_2 \rightarrow __CO_2 + __H_2O$

c $__P_4O_{10} + __H_2O \rightarrow __H_3PO_4$

d $__FeS_2 + __O_2 \rightarrow __Fe_2O_3 + __SO_2$

e $__NH_3 + __O_2 \rightarrow __NO + __H_2O$

f $__Fe + __HCl \rightarrow __H_2 + __FeCl_2$

g $__Al + __Fe_3O_4 \rightarrow __Al_2O_3 + __Fe$

8 a State the chemical name for the following ionic compounds.

i Na_2S

ii $BaBr_2$

iii Al_2O_3

iv LiCl

v FeF_3

vi AlP

vii CuI_2

b Draw electron dot diagrams for compounds **i**, **ii** and **vi**.

9 Write formulas for:

a sodium oxide

b potassium nitride

c aluminium oxide

d copper(II) chloride

e silver bromide

f lithium fluoride

g lead sulfide.

Analyse

10 X stands for different mystery elements. Deduce what charge X would have in each of the following compounds.

a XS

b XCl

c X_2O

d KX

e Al_2X_3

11 Hydrogen peroxide decomposes to water and oxygen over time, as shown below.

$$H_2O_2(l) \rightarrow H_2O(l) + O_2(g)$$

Figure 4.43 on page 144 shows the volume of gas collected from 100 mL of hydrogen peroxide solution. All of the oxygen gas had been produced by the 20th minute and the experiment was halted at this time.

ISBN 9780170189071

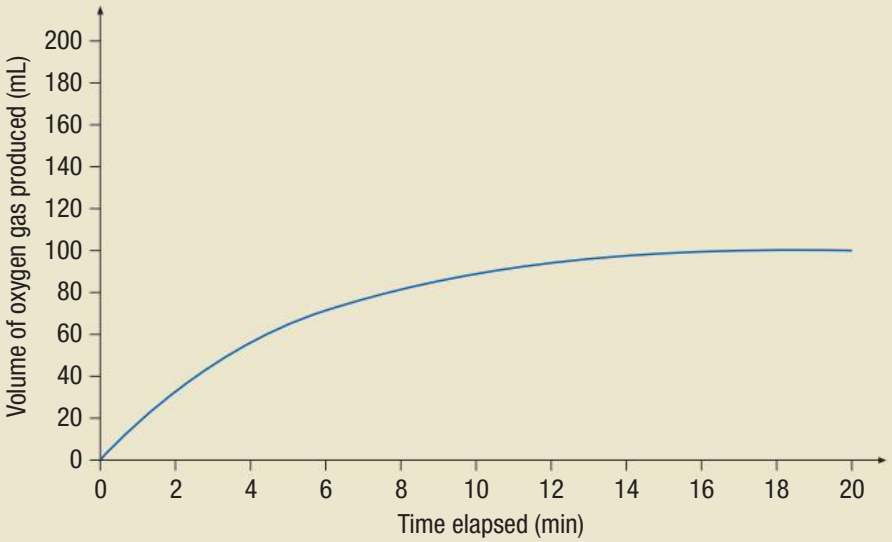


Figure 4.43 Volume of oxygen gas produced over time from the decomposition of hydrogen peroxide

a How much gas has been produced at the 5-minute mark?

b What is the minimum amount of time required to ensure that 75 mL of oxygen gas has been produced?

c The reaction may be catalysed by the addition of cobalt(II) chloride. Explain what you would expect to happen if cobalt chloride was added to the 100 mL of hydrogen peroxide solution.

d Explain what you would expect to happen if you chilled the 100 mL of hydrogen peroxide solution.

Evaluate

12 Assess the role of the chemist in the pharmaceutical industry.

Synthesise

13 Design an experiment to test this statement: 'Liquid washing detergent is more effective than powder washing detergent.'

14 Construct a model of a compound consisting of three carbon and six hydrogen atoms.

Reflect

15 Discuss this statement: 'Without carbon there would be no life.'

ISBN 9780170189071

5

The big universe

How do we know how the universe got to be so big?

When we look into the night sky, we see a wondrous variety of coloured, sparkling objects. Stars, galaxies and nebulae, planets and the Moon are all visible at various times and in various patterns. In between, there is darkness. Beyond our visible gaze, we observe pulsars, quasars and myriad galaxies with different shapes. There are clusters of stars and black holes. At the very edge of our ability to observe is a foggy, opaque background, which limits further observations. How do we measure where they are? How do we explain the origin of the universe?

What do you know about measuring space and time?

When you look into the night sky you see the Moon, stars and sometimes planets. These are objects that you have probably been aware of since you were a very small child. Stories and poems have been written about them. Remember the cow jumping over the Moon? But how much do you really know about these objects and where they came from?

Activity 5.1
Celestial objects

WORKSPACE
Celestial objects
SCI10SUWR00117

1 Working in pairs, list as many different celestial objects as you can think of. Then answer these questions.
   - **a** How far away are they?
   - **b** How do we know if they are moving?
   - **c** How are space and time measured?

2 Join up with another pair to discuss the following questions.
   - **a** Does the universe have a beginning? If so, is it possible to have space and time before that?
   - **b** What is the big bang?
   - **c** What questions do you have? Create a list of things that you want to know.

3 Throughout this unit, keep notes and ideas in a graphic organiser of your choice. Choose one that works for you – that is, one that you can use to organise your thoughts, ideas and what you have learnt. Have a section to record things that you are not sure of and any questions that you have.

WEB 2.0

Upload either a link to your graphic organiser to your blog or the organiser itself to the class wiki so that your teacher can view your work.

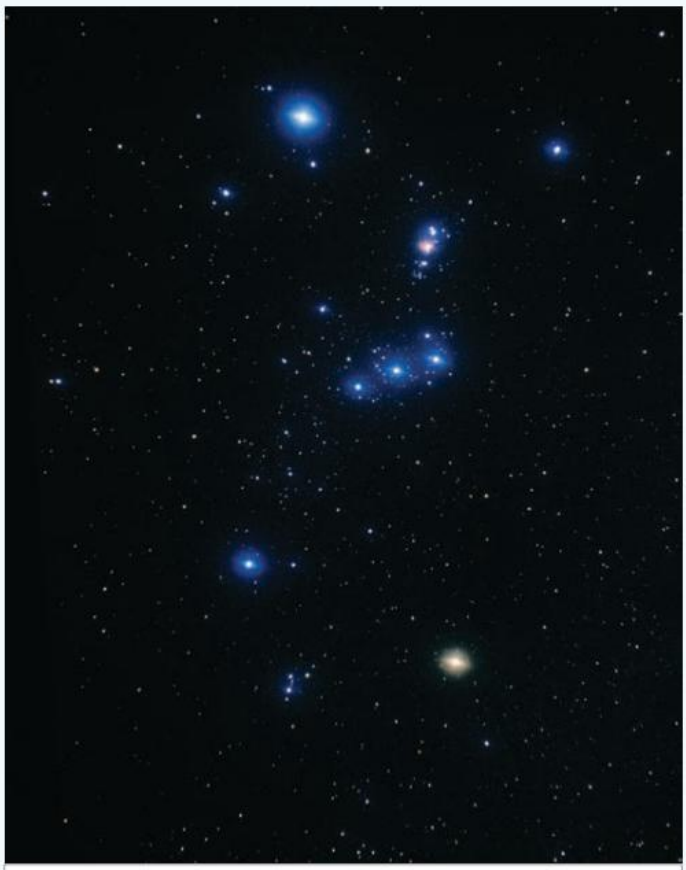


Figure 5.1 The constellation Orion is a star pattern visible in summer in Australia. The lower bright-red star is Betelgeuse. The upper blue star is Rigel. The Great Nebula can be seen with the naked eye in the handle of the 'Saucepan', the constellation's southern nickname.

Culminating assessment task
When and where is a celestial object?

1 Select a main-sequence star, quasar or galaxy.

2 Starting from the big bang, explain when and how this object was formed.

3 Describe how the distance to this object is measured.

4 Produce an electronic report about this object, provide an annotated timeline and use appropriate diagrams and images to support your work.

ACTIVITY SHEET
Rubric: When and where is a celestial object?
SCI10SUAS00118

ISBN 9780170189071

How do we understand the origin of the universe?

> In the early Dreaming Time, when animals and men were all one people, Walik the crow and Bari pari the cat … flew up to the dark night sky. There they found places to camp by the side of the river that runs across the sky. The shining path of Milnguya the Milky Way is really the twinkling of their many campfires, and the small spots of the cats. Many things can be seen along that river. Walik the crow is there, and the burial pole. Ying-arpiya the great crocodile also swims in the river of stars, and big stars mark the spines on his back, and the curve of his tail.
>
> Jennifer Isaacs (ed.), *Australian Dreaming: 40000 years of Aboriginal History*, Sydney: Lansdowne Press, 1980, pp. 150–1.

Humans have an inquisitive streak: we have always asked questions about the stars, the world and everything surrounding us. Such questions arise out of the needs of our culture. The answers reflect the culture and help to form developments within it.

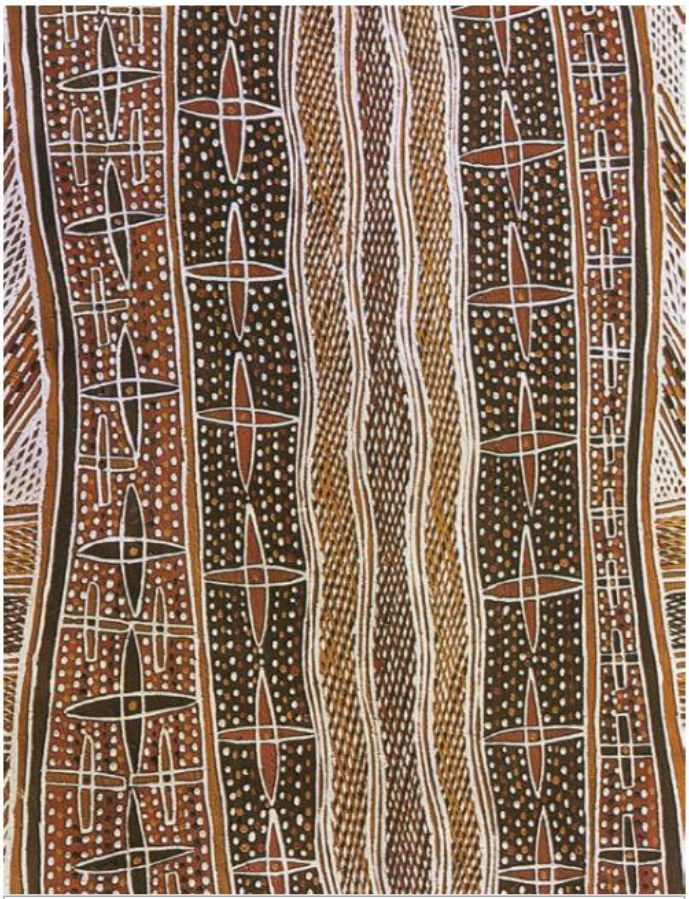


Figure 5.2 Stars in the Milky Way by Yirrkala artist Banapana Maymuru

To explain the origins of what can be seen in the sky, humans have generally used one of two ideas: the universe is eternal or the universe has a beginning.

Ancient Egyptian and Greek cultures, Australian Indigenous cultures and Hindu and Buddhist religions all believe the universe is eternal: it has no beginning and will be renewed eternally. For example, the idea of reincarnation relies on the eternal renewal of material that returns in different forms. Drawing on ideas developed for at least 800 years, the 1200 CE Indian sacred text *The Mahapurana* states: 'Know that the world is uncreated, as time itself is, without beginning and end.'

In Jewish, Christian and Islamic accounts of Creation, there is a unique beginning. The one God brings the universe into being out of chaos and then sustains it. The biblical account of Creation by the one God starts: 'In the beginning, God created the heavens and the earth' (Genesis 1:1).

The western scientific view of the universe has been informed strongly by Jewish and Christian thought. Christianity has provided opportunities for modern scientific investigations of the universe; however, science and Christianity have often come into conflict. The questions that science and religion ask, the answers they provide, and the criteria by which they judge claims frequently shed light on the heritage of both religion and science. The origin of the universe is one of those important questions.

ACTIVITY SHEET

Cultural stories

SCI10SIAS00119

Activity 5.2

What do you think?

You have read a number of different theories and ideas. What is your opinion? Have you ever stopped to wonder how it all began? Have you ever wondered if there is another explanation? Compile your thoughts and ideas on your blog. At the end of the unit, return to this to see if your thoughts and ideas have remained unchanged.

ISBN 9780170189071

WOW!

The Emu in the Sky

The dark nebula in the Southern Cross is given different names within different cultures (Figure 5.3). Frequently, different indigenous Australian cultures refer to the dark nebula in the Milky Way as the Emu in the Sky (Figure 5.4). However, those in the central desert, in the Northern Territory, see the nebula as a wedge-tailed eagle; and the Wotjobaluk, in Victoria, see it as a giant pine tree that you can climb into the sky. The Mara culture sees the Milky Way as a river – it's not 'the Milky Way' to them – so the dark nebula is a deep waterhole. According to an Arnhem Land clan, the dark nebula in the Southern Cross is Wej, an adulterous woman who escaped being punished by her husband by flying out of the fire.

In western science, the dark nebula is called the Coalsack. When you look at it, what do you see?

WEBLINK
Coalsack

Figure 5.3 Dark nebulae in the Southern Cross

Figure 5.4 Indigenous Australians near Sydney call the dark nebulae near the Southern Cross the Emu in the Sky.

How much do we think we know about the universe?

Physicists, cosmologists and astronomers estimate that we know something about 4% of the entire matter and energy in the universe. This 4% includes light energy (photons), atoms and molecules. The remainder consists of dark energy, which seems to account for approximately 76%, and dark matter, approximately 20% (Figure 5.5).

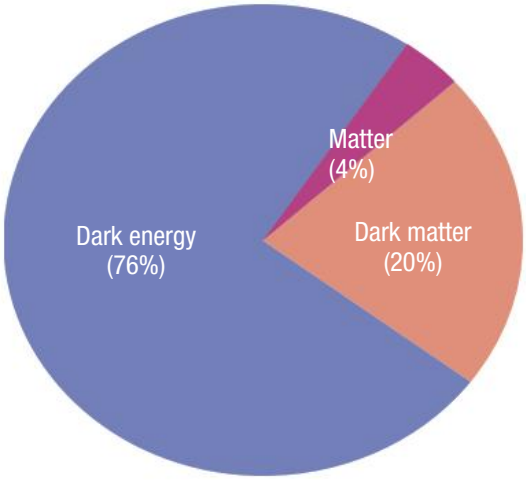


Figure 5.5 Approximately 4% of the universe is matter as we know it. The rest is dark energy and dark matter.

Dark energy appears to have a most odd effect on the universe. The universe is expanding. Dark energy seems to speed up that expansion. Just when you thought the expansion was slowing down, it has been discovered that the universe is now speeding away more quickly.

Dark matter is so-called because it is hard to detect. It interacts weakly with other matter and does not seem to have much part to play in the expansion of the universe. Scientists use collisions between galaxies to calculate the amount of dark matter involved (Figure 5.6).

Figure 5.6 Two galaxies collide.

ISBN 9780170189071

Big bang theory

From the physical evidence so far collected, we now have a useful theory about the beginning of everything. It is called the big bang theory.

At the beginning of the universe, there was only energy. All was chaos. The temperature was extremely high. The space occupied by the energy was extremely small. In fact, there was no space or time at all.

For whatever reason, energy expanded into space and time. Why space expanded is not answered by the big bang theory. Nevertheless, there appears to be very strong scientific evidence for this theory. Even though the evidence is less than 150 years old, the retrodictions (or backwards predictions) go back about 14 billion years.

At the start of the universe, a universe of relationships erupted. Simultaneously, space and time emerged. The question 'What happened "before" the big bang?' cannot be answered because there was no 'before'. In this context 'before' means 'some time previous to the start of time'. This is a nonsensical idea. Similarly, we cannot say where things were before the start of the universe. This is the same as asking the question 'In what space were things to be found before the start of space?'

Einstein's space–time

German-born physicist Albert Einstein (1879–1955) was the most recognisable scientist of the 20th century (Figure 5.7).

In 1905, Einstein devised the special theory of relativity. He showed that the speed of light was intimately connected to our ability to measure distance and time intervals. You need two objects in the universe before you can say where one is, relative to the other. If you only have one thing, how can you tell where it is? Equally, and for exactly the same reasons, you cannot tell when an object is at a place until you know where that place is relative to some other place. This means that you must have two things, and a way of communicating between them – the fastest possible is the speed of light – to establish 'place between' and 'time between' them.

Einstein showed that space and time are so intertwined that we should call it space–time. In space–time, time and distance intervals are brought together in one idea: the space–time interval.

Space–time physics requires the speed of light to be the fastest that anything can go. The speed of light must also be constant throughout the universe. Very accurate measurements of the speed of light have shown its value, which we denote by the letter c, to be 299 792 458 m/s.

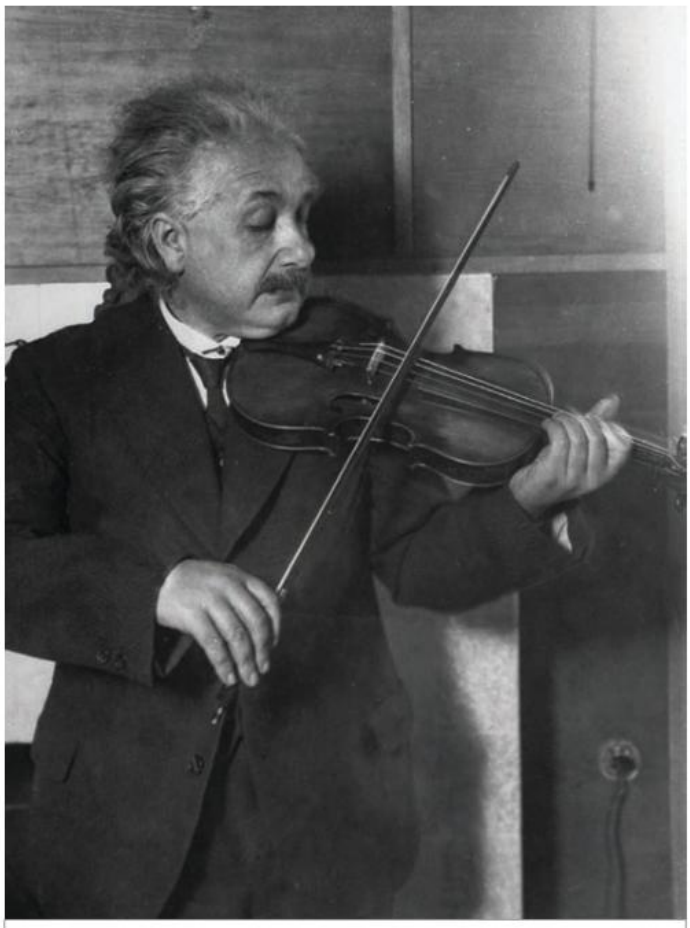


Figure 5.7 Albert Einstein in 1941

For our purposes, a good approximation for the speed of light is 300 million metres per second (m/s):

$$c = 300\,000\,000 \text{ m/s}$$
$$= 3.0 \times 10^8 \text{ m/s}$$
$$= 3.0 \times 10^5 \text{ km/s}$$

glossary terms

dark energy
a kind of negative pressure that is thought to be responsible for the accelerating expansion of the universe

dark matter
very weakly interacting material

photon
a 'particle' of light; an electromagnetic force carrier

retrodiction
a prediction about the past

space–time
the interconnected nature of measurements of space and time

ISBN 9780170189071

WOW!

Neutrinos go faster than light

In 2011, scientists claimed that they could measure neutrinos (a subatomic particle) at speeds faster than the speed of light. Such a result would require physics to re-imagine some of its most basic ideas.

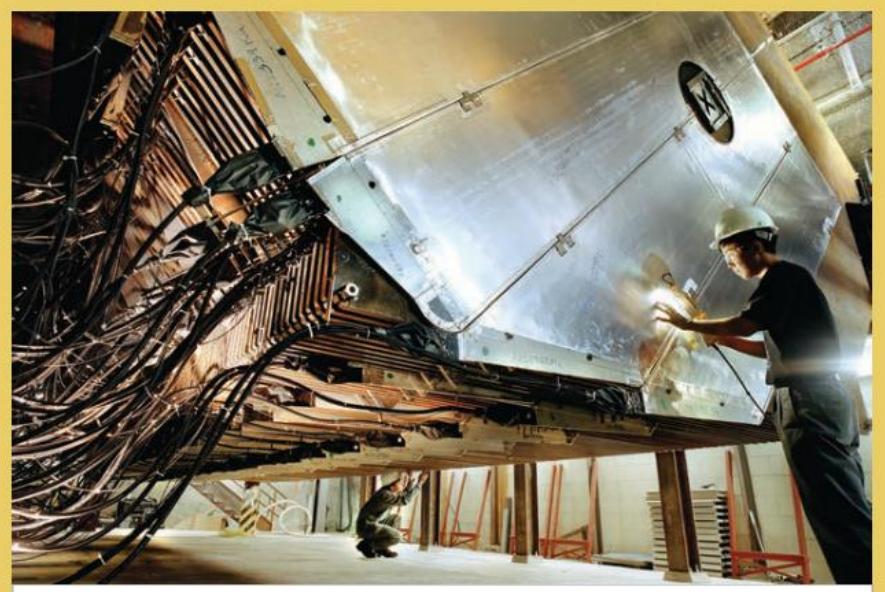


Figure 5.8 A neutrino telescope: the detector is a vast tank of carbon tetrachloroethylene about 1 km underground.

Einstein also developed a theory about the way gravity works. The general theory of relativity shows us that space–time is affected by the presence of matter. Imagine that space is like a flat trampoline. Now, put a bowling ball in the middle. The trampoline 'space' bends and stretches (Figure 5.9).

When we look at very massive things out in space – like planets, stars and supernovae – we can detect this effect. Einstein's gravitational theory seems to work. In fact, the theory is so well accepted that it is used in GPS systems to ensure that aircraft can land in exactly the right place at exactly the right time.

WEBLINK
Einstein and the jumbo jet

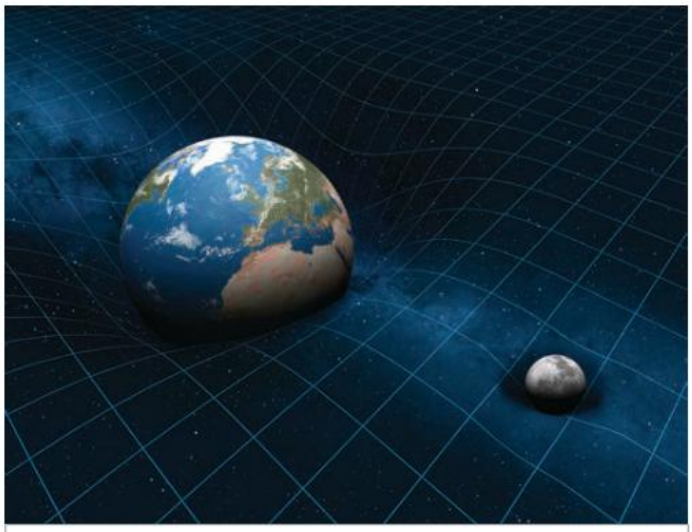


Figure 5.9 Mass shapes space–time.

Cosmological principle

In July 1687, English physicist Isaac Newton (1642–1727) published his theory of gravity in his three-volume *Principia*. He assumed that what he saw out in the heavens obeyed laws that applied on Earth. Before this, most people thought that the heavens obeyed different laws. Using his theory, he made predictions about planets and comets that turned out to work. This confirmed his theory, which became known as Newton's universal gravitational law.

WEBLINK
Sir Isaac Newton

ISBN 9780170189071

Einstein extended Newton's ideas in his general theory of relativity; he also used the cosmological principle. No matter from what vantage point in the universe you look, the laws are the same. What you see are the same kinds of galaxies and you measure the same background temperature. This does not mean that the physical 'look' of the universe is the same from every place; rather, that the types and shapes of things are remarkably similar, and that the relations and interactions throughout the universe always look the same.

WOW!

Extrasolar planets

Is Sol (our Sun) the only star around which planets revolve? The answer is 'No'. The first exoplanet orbiting another star was found in 1989. Since then, a further 708 have been confirmed. Four of the nearest systems are shown in Figure 5.10.

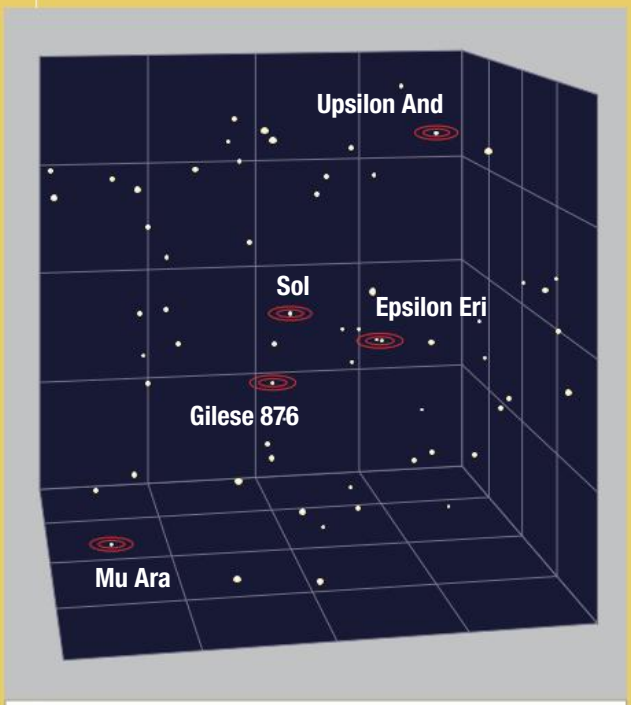


Figure 5.10 Four extrasolar systems closest to Sol's solar system

Exoplanets have been identified as far away as 300 light years, which is about 100 parsecs.

Australia's former Chief Scientist, Penny Sackett, is an astronomer. One of her research interests is extrasolar planets. She is also an expert on dark matter and the structure of galaxies.

WEBLINK
List of exoplanets

WEBLINK
Penny Sackett

WOW!

Newton and that apple

Newton is supposed to have devised the universal gravitational law when an apple dropped from a tree onto his head. This is not likely to be true. It is more likely that, after years of experimenting and thinking about such matters, he became convinced that he could explain things on Earth and beyond in the same way. An apple falling to the ground, the Moon falling around the Earth and a planet falling around the Sun could be described by the same rule. English astronomer Edmund Halley (1656–1742), who encouraged Newton to publish his ideas, predicted the return of a comet. Its return, as expected, was a powerful confirmation of Newton's universal gravitational law.

WEBLINK
Halley's Comet

Figure 5.11 Halley's Comet in 1986. Its return in 1758, as predicted by Halley, helped to confirm Newton's cosmological principle and universal gravitational law. Halley's Comet will return in 2061.

glossary terms

cosmological principle
the principle that states that the laws of physics are the same throughout the universe

exoplanet
a planet-like object revolving around a star other than the Sun (Sol)

ISBN 9780170189071

Questions 5.1
What have you learnt?

WORKSPACE
What have you learnt? 5.1
SCI10SUWR00121

Understand

1 What are the two main ideas that people have used to explain the origins of what they saw in the sky?

2 a Name the three main components of the universe.

b State the percentage of each in the universe.

3 What is the cosmological principle? Who was the first to use this idea?

Apply

4 Describe how dark matter and dark energy affect the universe.

5 According to the big bang theory, how was space formed?

Analyse

6 Why is it not possible to answer the following question: 'What happened before the big bang?'

7 What do Einstein's two theories explain?

8 How does the cosmological principle help astronomers to explore the universe?

Synthesise

9 Complete a question matrix as you read through this unit – there are many theories and ideas to digest. Record your questions as you proceed. Upload your matrix to your blog at the end of the unit.

Reflect

10 What have you learnt about time, space and the universe?

WEBLINK
Q & A: The Higgs boson

WEBLINK
The Higgs boson explained

Big bang theory in detail

The big bang theory explains how the universe and all that is in it was formed from the beginning of space and time up until now. Several important stages in this theory are the big fizzle, cosmic inflation, nucleosynthesis, nuclear fusion, atoms and galaxies.

The big fizzl

Something happened! For a very short while – 1 trillion-trillion-trillionth part of 1 second – the horizons of space began to stretch. Time was established simultaneously with space. This is the Planck era, which is named after German physicist Max Planck (1858–1947).

At this point the process could have got stuck and not proceeded. The amount of energy involved was almost equivalent to that obtained from a bag of sugar. It was as significant as blowing up a hand grenade in a nuclear war!

Nevertheless, things started to form out of the energy. Relationships between these rather strange things were made. Particles gained mass. Time and space arrived along with these relationships. The energy was the same as that at the beginning, but now it was filling up a larger space. As a consequence, the temperature started to fall.

Cosmic inflatio

A bit later, there was a mighty, rapid expansion of space and time. The things that had been happening managed to release a huge amount of pent-up energy.

For how long did this cosmic inflation occur? The time interval was incredibly short – from about 10 trillion-trillion-trillionths of 1 second (10^{-35} s) to 10 billion-trillion-trillionths of 1 second (10^{-32} s).

Lots of things got made. It was all so extraordinarily energetic that the things that got made also got unmade. All the energy began to spread out. In the first billionth of a second the Higgs boson was born. Its probable discovery was announced in Geneva and Melbourne on 4 July 2012.

A millisecond after the beginning, all the forces we know today – strong force, weak force, electromagnetic force and gravitational force – had separated out. They began to influence different particles.

Gravitational force between masses began to influence the evolution of the universe. The Higgs boson's effect on mass is one crucial key to understanding the universe.

ISBN 9780170189071

Big bang in the laboratory

Working out what happened in the big bang means we need to create similar conditions in the laboratory. This is done in particle smashers, such as the Large Hadron Collider at the European Organization for Nuclear Research (known as CERN). Hadrons are a group of particles that include protons and ions. When hadrons rush at one another at speeds close to the speed of light, the collision produces incredibly high bursts of energy. The debris from the collision is collected to see what the hadrons were made from (Figure 5.12). It's a bit like smashing two cars together at high speed, collecting the bits and pieces that fly off and then using them to work out what the cars looked like originally.

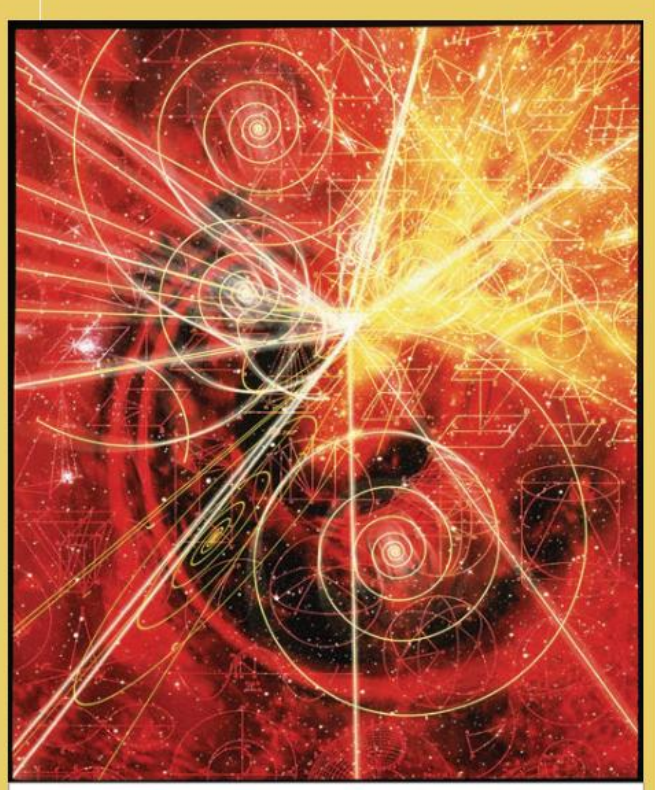


Figure 5.12 Complex patterns used by physicists to piece together the building blocks of the universe

WEBLINK
The Large Hadron Collider

VIDEO
Back to the big bang
SCI10SUVD00122

Nucleosynthesis

In parts of this expanding universe, the things that were made lasted long enough to bump into other things. Sometimes new particles, such as quarks, were made in these collisions. The energy was now carried about with these new particles. The temperature continued to drop.

For the next three minutes, other particles began to form too, some of which persisted – they were not unmade. The most significant of these were the protons, neutrons and electrons that would go on to become atoms. These particles had mass. They were attracted to other masses by gravitational force. Particles started to clump together. Atomic nuclei were made during this period of nucleosynthesis ('nucleo–' means 'nucleus' and '–synthesis' means 'adding things together to make something new'). The temperature dropped further.

Nuclear fusion

The temperature of the universe in the first three minutes was so high that it favoured the process of nuclear fusion. This occurs when two nuclear particles join to produce a new nucleus. If two protons stick together, they form a new helium nucleus. If a proton sticks to a neutron, they form a heavier particle of hydrogen. Usually, the electrostatic forces would push protons apart; however, at these high temperatures, the protons were forced so close together that the short-range weak force overcame the long-range electrostatic force of repulsion. So protons stuck to protons, and protons stuck to neutrons. This produced the first atomic nuclei. There was still too much energy in the universe for electrons to be captured by these nuclei to form atoms.

Atomic nuclei are made of protons and, usually, neutrons stuck together. The number of protons in a nucleus tells us what type of atom it is. A one-proton nucleus is hydrogen, a two-proton nucleus is helium and a three-proton nucleus is lithium.

Let us follow the process of nuclear fusion – at this stage, we only need to get as far as lithium. Figure 5.13 on page 154 shows how a proton and a neutron undergo

glossary terms

cosmic inflation
the incredibly rapid expansion of space

fusion
the process of combining two nuclei to make a third nucleus

hadron
a family of observable particles, including protons and neutrons

nucleosynthesis
the process of making atomic nuclei

quark
a particle that makes up a hadron

ISBN 9780170189071

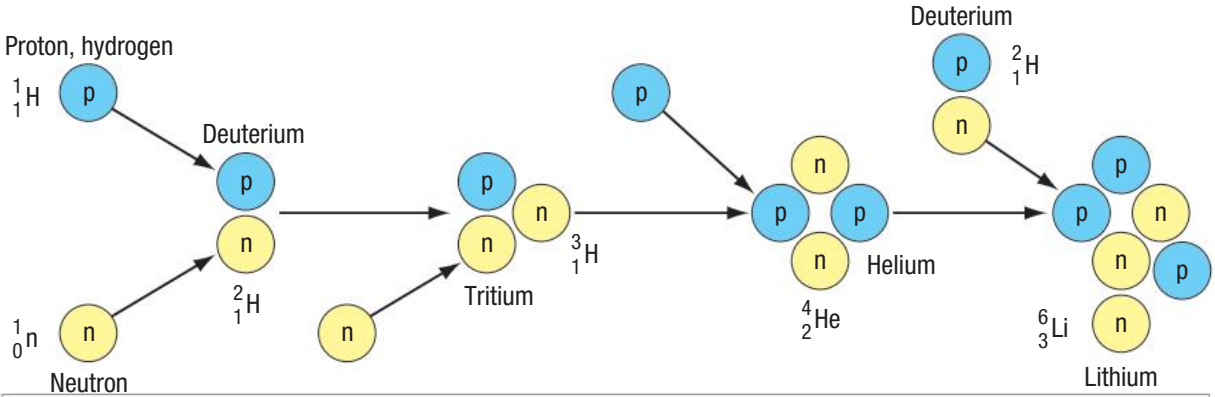


Figure 5.13 The first three atomic nuclei were made in the first three minutes of the universe by nuclear fusion. Short-range forces hold them together, overcoming the long-range electrostatic force of repulsion.

fusion to produce deuterium, which is still hydrogen (one proton) but a bit heavier. Tritium then forms by adding another neutron. Adding an extra proton produces helium. Lithium needs another proton and another neutron fused to the helium. Every time fusion occurs, energy is released.

After 3 minutes, the conditions for fusion subsided. The universe contained about 75% hydrogen, 25% helium and minute traces of lithium. Big bang cosmologists had already predicted these proportions *before* these elements were measured. When we look back in time to early cosmic dust clouds, these are the proportions we find. This gives us confidence that the big bang theory is able to be supported by evidence.

Activity 5.3

A lot can happen in three minutes

Go to the class wallwisher and record how many words you can read or how many steps you can take in three minutes.

WEBLINK
Wallwisher

Nuclei to atoms

For the next 300 000 years, these atomic nuclei swirled around among the particles in a rich, soupy plasma. Photons – light carriers – bounced off the protons, neutrons and electrons. Larger nuclei formed and released energy too. Light was everywhere. It was incredibly bright.

Remember that, according to the law of conservation of energy, the energy at the beginning was the same as before. Only now, the energy was fitted into a much larger space. The temperature continued to drop. Particles formed and gathered together in increasingly larger clumps. Cosmic dust clouds and stars appeared. At last, there was enough space for the photons to be freed. No longer did they bump into particles most of the time. The universe as we see it today became transparent.

Over the next 800 000 years, temperatures dropped sufficiently for nuclei to capture electrons. Atoms were created. In the same period, stars congregated into galaxies (Figure 5.14).

The masses affected one another through the gravitational force. In fact, the gravitational force between these masses started to slow the expansion of the universe.

The history of the universe, for the first 800 000 years, is provided in Table 5.1 on pages 156–7.

Figure 5.14 Galaxy cluster Abell 2218 draws light around it from even more distant galaxies.

WEBLINK
The oldest galaxy

VIDEO
The first stars
SCI10SUVD00123

ISBN 9780170189071

Questions 5.2

What have you learnt?

WORKSPACE

What have you learnt? 5.2

SCI10SUWR00124

Understand

1 What does the big bang theory explain?

2 List the order of formation of the universe from the start of the big bang to the creation of atoms. Specifically include the separation out of the four fundamental forces.

3 Define:
- **a** nucleosynthesis
- **b** fusion.

4 Explain how a helium nucleus was formed.

Apply

5 What happened during the first 10 billion-trillion-trillionths of 1 second (10^{-32} s) after the start of the big bang?

6 How was it possible for the era of nucleosynthesis to begin? When did nucleosynthesis stop? Why?

Synthesise

7 For each era, list the time duration and the temperature range.

8 How is evidence used to support the big bang theory?

9 The answer is Large Hadron Collider at CERN. What are five questions?

Reflect

10 How has your knowledge of the universe improved? What other questions do you now want to add to your question matrix?

Cosmic background radiation

About 300 000 years after the big bang, matter started to form into atoms; there were far fewer particles in the cosmos. Up until this period, light particles bounced around and into other particles inside this dense soup. Suddenly, they were freed to move in all directions. The foggy universe cleared and became transparent. The photons spread out evenly.

What would we expect to see? In the background, we would expect to see an even distribution of radiation – a kind of wall of low-energy radiation. That is just what we do see. German-born physicist Arno Penzias (1933–) and American astronomer Robert Wilson (1936–) discovered cosmic background radiation (CBR) in 1964. The microwave signal from their radio telescope corresponded to about 3° above absolute zero (3 K) everywhere across the sky.

The cosmic background temperature and its distribution were measured more than 20 years ago by the space probe Cosmic Background Explorer (or COBE), also referred to as Explorer 66. COBE's measurements showed an even spread of this background radiation between 2 K and 4 K (Figure 5.15).

Figure 5.15 COBE showed a very even microwave background between 2 K and 4 K. This was predicted, so the result helped us gain confidence for the big bang theory.

glossary terms

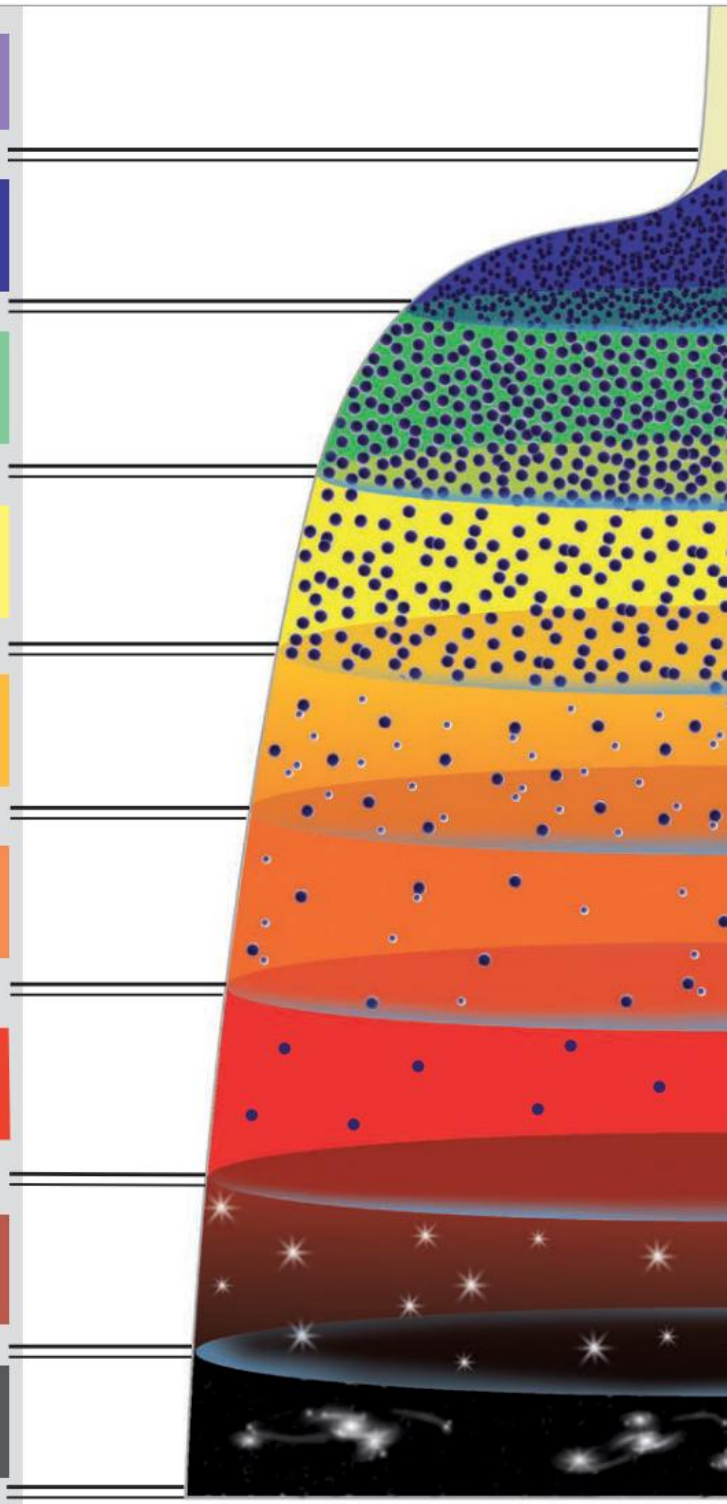
cosmic background radiation
radiation from 300 000 years after the big bang

plasma
the gas of charged particles; the fourth state of matter

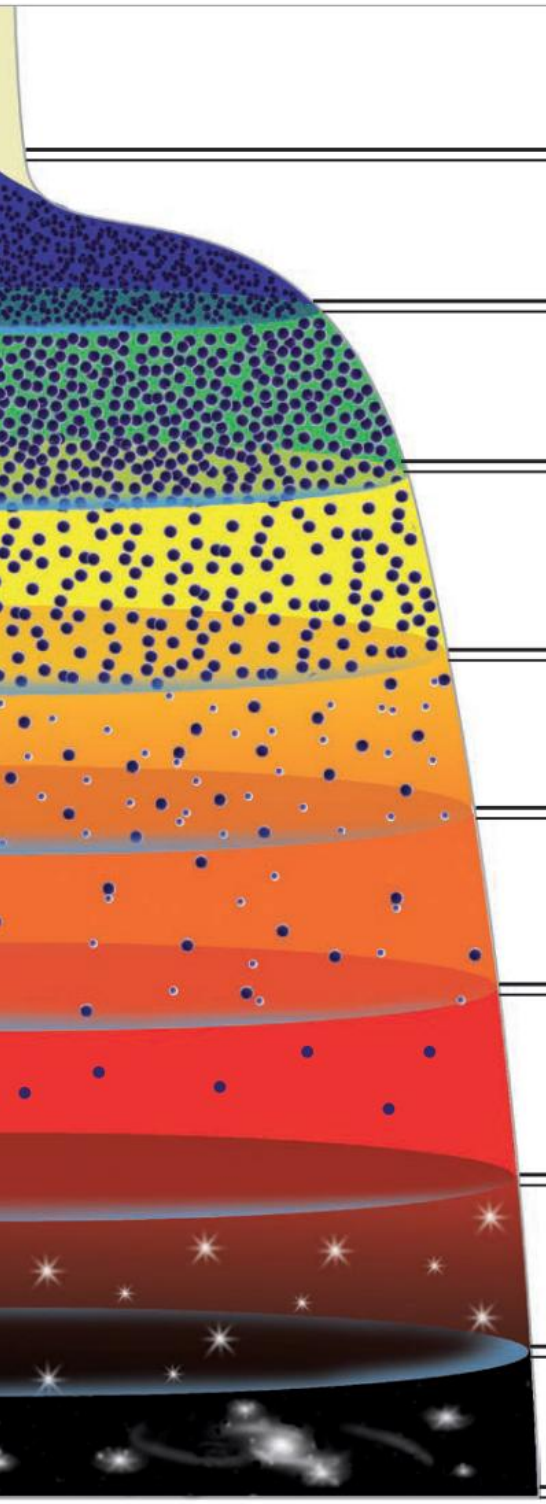
ISBN 9780170189071

Table 5.1 History of the universe

Time since the big bang	Era	Temp. (K)
10^{-43} s	Planck	$>10^{15}$
10^{-39} s	Inflation	10^{14}
10^{-10} s	Force separation	10^{13}
10^{-3} s (0.001 s, or 1 ms)	Particle	10^{12}
3 min	• Nucleosynthesis • Nuclear fusion	10^{9}
300 000 y	Nuclei	4000
500 000 y	Atoms	20
800 000 y	Galaxies	3



ISBN 9780170189071



Description	Major events in the era
Incredibly high temperature	Space and time established
Fundamental particles form and un-form	Strong force becomes distinct; cosmic inflation
Fundamental particles last long enough to interact; explosion of photons as matter and antimatter collide	Four forces separate: strong force, gravity, electromagnetic and weak force
Fundamental particles	Fusion begins
Protons, neutrons, electrons, neutrinos stabilise	Fusion ceases; universe has 75% hydrogen, 25% helium and traces of lithium
Plasma of hydrogen, helium and electrons	Atoms, plasma and formation of stars; photons freed; universe becomes transparent
Atoms start to stabilise; stars start to form	Stars congregate in galaxies and clusters
Stars, galaxies, clusters	

Scientists had predicted the evenness of the background and the value for the cosmic background temperature before it was measured. They did this from their understanding of the big bang theory. A prediction like this, which is later confirmed, helps scientists to be confident that the big bang theory is supportable. The present-day probe, WMAP, has continued to confirm more of the big bang predictions (Figure 5.16).

The CBR is a natural limit to our ability to see the universe earlier than 300 000 years after its birth. No matter where you look, you can see back in time past near and far stars, near and far galaxies and quasars. Eventually, you reach the 'foggy' background, where some energy is sent forwards towards us, but a whole lot is bouncing around inside. This is similar to looking out on a foggy night. That is, there is some light coming towards you, but you can see nothing inside the fog (Figure 5.17).

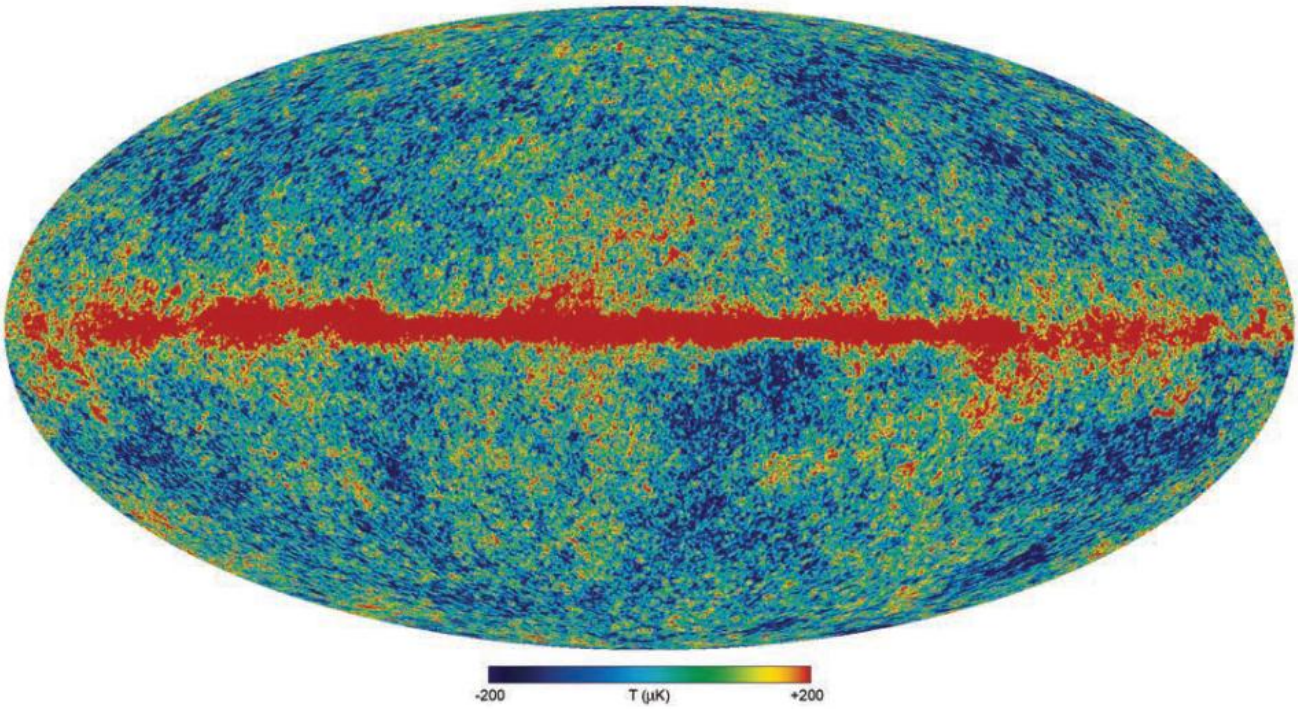


Figure 5.16 WMAP computer-enhanced image of the cosmic microwave background. The red 'hottest' region is 0.00002 K warmer than the 'coldest' blue region. The average temperature is around 2.7 K, or almost absolute zero.

Figure 5.17 There is a limit to what you can see when you look into a fog.

ISBN 9780170189071

Activity 5.4
Animating the big bang

Share your understanding of the big bang theory by creating an animation. Upload your animation to the class wiki.

WEB 2.0

A great website to use to create an animation is xtranormal.

WEBLINK
Xtranormal

Questions 5.3
What have you learnt?

WORKSPACE
What have you learnt? 5.3
SCI10SUWR00129

Understand

1 What is meant by cosmic microwave background radiation?

2 When and how did the universe become transparent?

3 What evidence did Penzias and Wilson observe?

Apply

4 What does the evidence from COBE tell us about the big bang?

5 Why does the temperature fall as time passes in the universe?

Analyse

6 How is it possible to observe direct evidence from 300 000 years after the big bang?

7 Sketch the diagram from Figure 5.16 and place temperatures on each of the sections.

Synthesise

8 Show how the analogy of light on a foggy night is similar to the opaque universe for the first 300 000 years.

9 Add more questions to your question matrix.

Reflect

10 What have you learnt about the way evidence is used to support a theory? Use data from COBE and other evidence about the universe to support your answer.

Astrometry: measuring the universe

How do we measure out to the furthest reaches of the universe? This is a massive task. Astrometry is the study of how to measure the dimensions of the universe. People who complete these measurements are called astrometricians.

We are used to the idea that space is vast. There are vast distances between celestial objects. The distances are so extreme that we use a light year as one measure of distance – even though 'year' suggests time, a light year is a distance. It is the distance covered by a photon when it has travelled in a straight line for one Earth year.

WEBLINK
The known universe

WOW!

Watch this space

You may well have come to believe that light is a wave. We are now talking as though light is a particle – a photon. Believe this or not, but both statements are actually a problem. Light is neither a wave nor a particle.

Light does exhibit lots of wave-like phenomena and lots of particle-like behaviour too. We often say shorthand things such as 'light is a wave'. What we really mean is 'light acts similar to a wave in a particular instance'. Similarly, we say 'light is a photon particle' when we actually mean 'light acts similar to a particle this time around'. Do not forget we have also seen particles acting in a similar way to waves.

Therefore, how far is 1 light year? A photon travels at 3.0×10^8 m/s. That is, 300 km every second (or 3.0×10^5 km/s). If we want to know how far light travels in one year, we need to find out how many seconds there are in a year. For each of these seconds, the photon travels 3.0×10^8 m.

glossary terms

astrometry
the study of the measurement of the universe

light year
the distance a photon travels in one Earth year (or 10 trillion kilometres)

quasar
a highly energetic galactic nucleus

ISBN 9780170189071

Let's calculate this distance:

$$\text{Time for one year (s)} = 365\ \text{d} \times 24\frac{\text{h}}{\text{d}} \times 60\frac{\text{min}}{\text{h}} \times 60\frac{\text{s}}{\text{min}}$$

$$\text{Distance for one year} = 3.0 \times 10^8 \times (365 \times 24 \times 60 \times 60)$$

$$= 9.4605284 \times 10^{15}\ \text{m}$$

$$= 9.4605284 \times 10^{12}\ \text{km}$$

Standard or scientific form

Astronomy deals with very large distances and uses astronomically large numbers with lots of zeros. Some different ways of writing and referring to numbers are therefore needed. Table 5.2 shows some common names, prefixes and powers of 10 that are used to communicate and calculate with large numbers.

Activity 5.5
Googol search

You have no doubt heard and used Google many times. What then is a googol? What about a googolplex? Research to find out the answers.

CONNECTION
Numeracy: Standard or scientific form
SCI10SICN00125

The number 10^{12} is a trillion, so a light year is about 10 trillion kilometres. Jump in a car and travel 100 km/h for 11 400 000 years and you will arrive where the photon reached in 1 year. Jump on a photon and you will arrive at Mars in 4 or 5 minutes, the Sun in 8.3 minutes and our next nearest star, Proxima Centauri, in 4.2 years. To get to the end of the universe, you will need to sit tight for about 14 billion years.

WEBLINK
Astronomical distances

Photons travel not only away from us into space, but also towards us from space. All those coming from one place in space take the same amount of time to arrive. What we see from space is the past. If Mars blows up, we will know 4 or 5 minutes later. If the Sun stops shining, we will find out 8.3 minutes later. If the end of the universe disappears into another space today, we will not know for 14 billion years.

On the other hand, the light we do receive on Earth carries the information from events that happened a long time ago. The light is the only way we receive information from the far reaches of space. The further away the object is, the older the information that arrives is. The light arriving carries information about what happened 'back then' and is used as a measure of time. The timeline in Figure 5.18 shows this idea.

Table 5.2 Some common names and powers of 10 for very large numbers

Prefix	Kilo–	Mega–	Giga–	Tera–	Peta–	Exa–
Common name	Thousand	Million	Billion	Trillion	Thousand trillion	Million trillion
Letter	k	M	G	T	P	E
Power of 10	10^3	10^6	10^9	10^{12}	10^{15}	10^{18}
Number of 0s	3	6	9	12	15	18

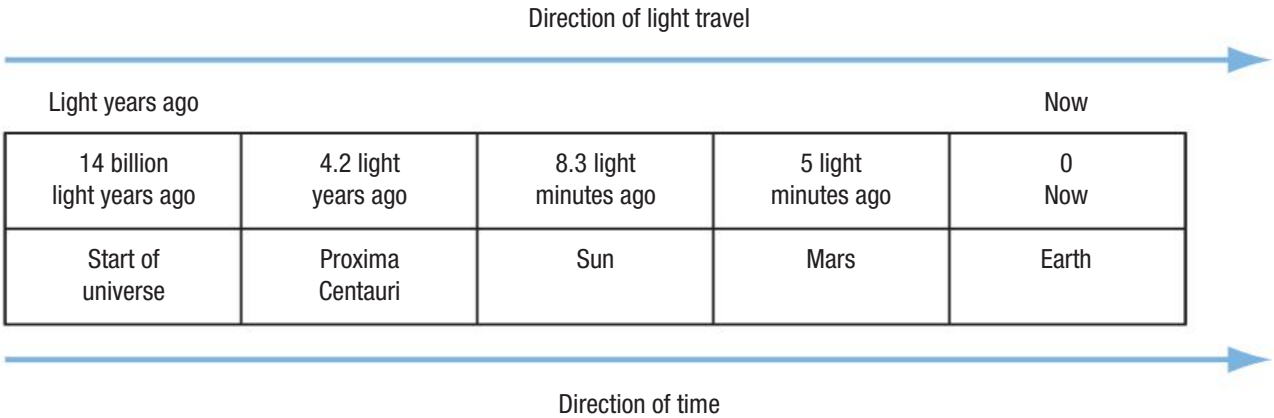


Figure 5.18 Timeline based on the time taken for the light to arrive on its journey from its place in the universe to Earth (not to scale)

ISBN 9780170189071

Activity 5.6
Travelling on a photon

If you had 8 hours and could travel anywhere on a photon, where would you go and why? Map out your travels (list the distance travelled and the time taken) and reasons on your blog.

Cosmic distance ladder

Distances out to the ends of the universe are measured by increasingly sophisticated means. Each procedure relies on earlier procedures, as well as theories about how space and time work. Figure 5.19 shows the procedures and the range of distances for which each is best used.

Radar ranging

Radio waves, or radar, can be reflected from celestial objects. The time taken for the return trip at the speed of light is used to calculate the distance. Unfortunately, this can only work for the Moon and planets. After that, the return signal is too weak to be identified among all the other noise and signals being received from all over the universe.

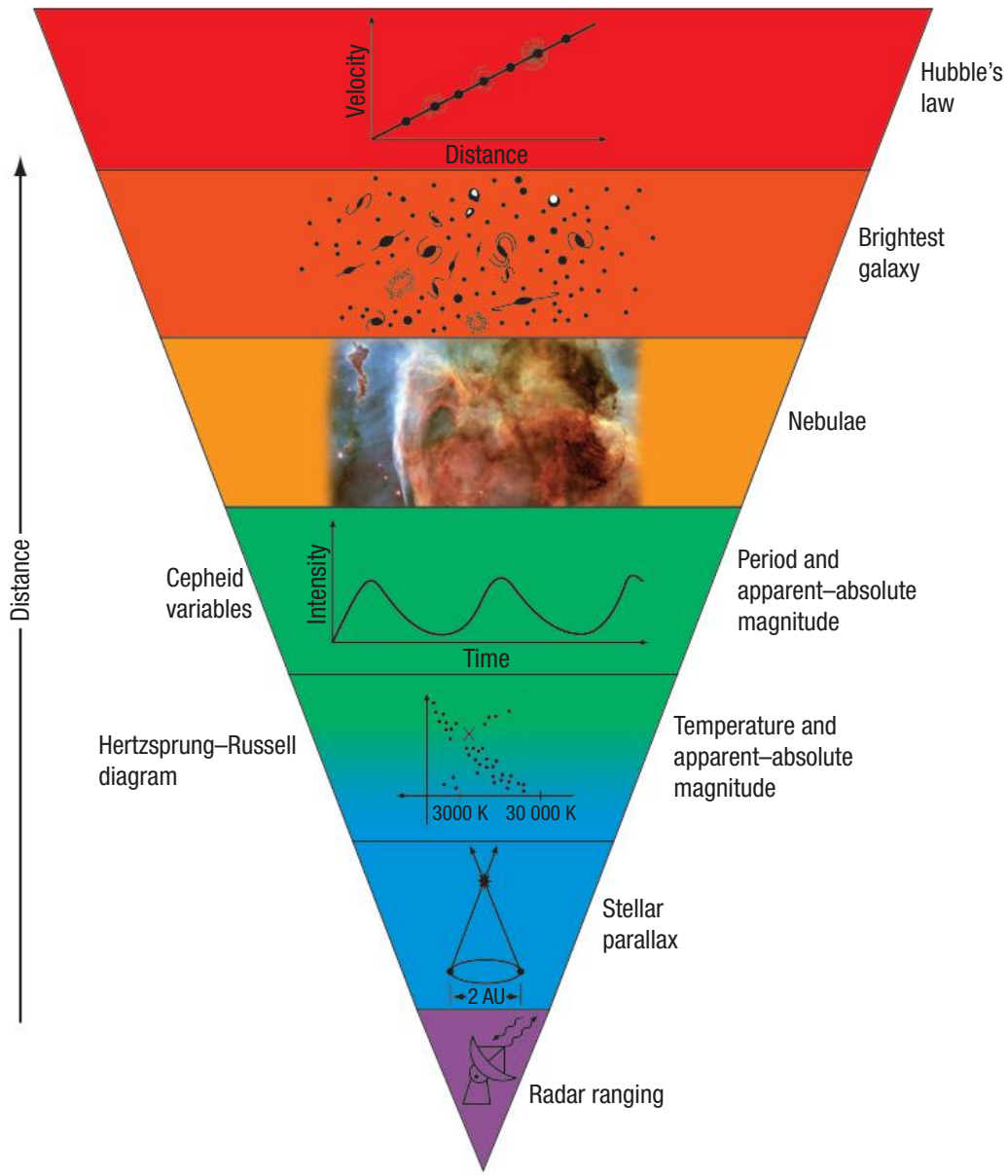


Figure 5.19 The distance scale and how to measure it

ISBN 9780170189071

One way of measuring the Earth–Moon distance is to reflect laser light from a corner mirror (or reflector) array placed on the Moon (Figure 5.20). Corner mirrors reflect a laser or radar beam along a nearly similar path to the original ray. The first were placed on the Moon in 1969 by Neil Armstrong and Buzz Aldrin (Figure 5.21). It is the only experiment they left behind that is still operating.

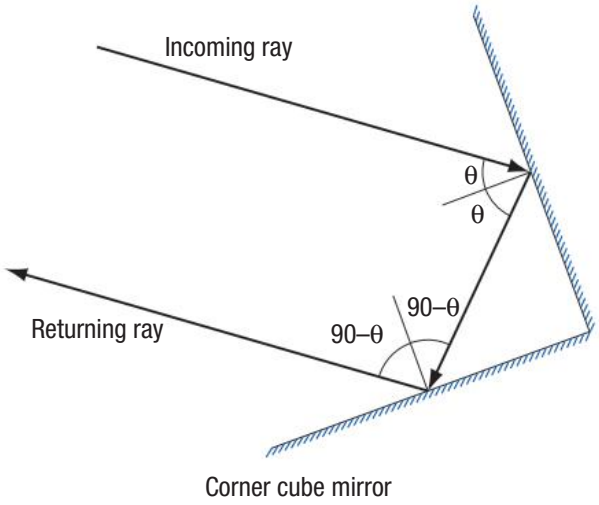


Figure 5.20 Corner reflector made from two mirrors placed at right angles to each other. The returning reflected ray is parallel to the incoming incident ray.

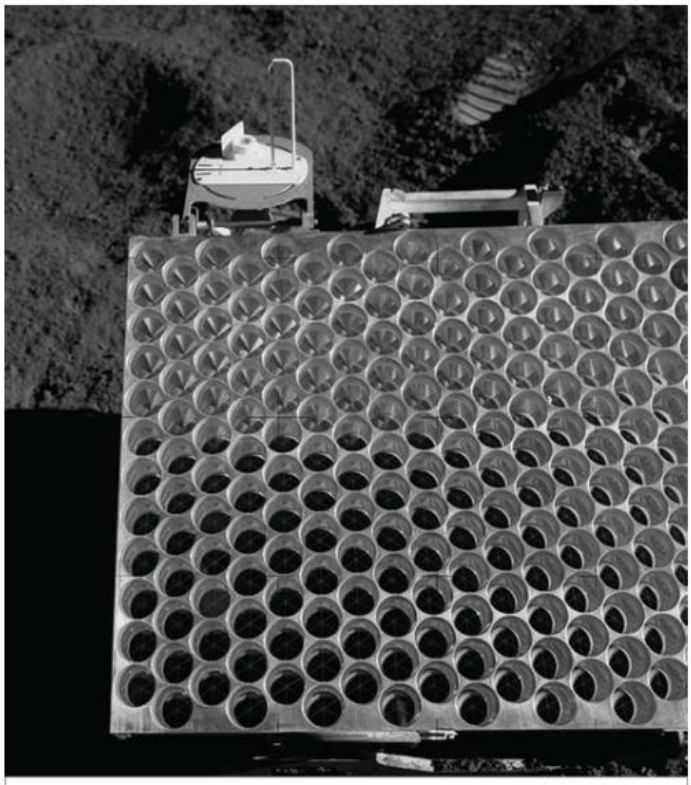


Figure 5.21 The corner mirror array left on the Moon by *Apollo 15*.There are now five similar arrays on the Moon. They are used to measure Earth–Moon distances to within an accuracy of a few millimetres.

Activity 5.7
Corner reflectors

Corner reflectors, or retro-reflectors, are used for many purposes, such as road safety and navigation. They are used in the Solfatara crater at Pozzuoli, near the Italian city of Naples, as part of the early-warning system in case of volcanic eruption.

Corner reflectors come in a variety of three-dimensional shapes. The corner mirror reflector in Figure 5.22 is not the same shape as the retro-reflectors on the Moon. Figure 5.23 shows where corner reflectors have been placed on the Moon.

Figure 5.22 The corner reflector in the Solfatara crater reflects satellite signals. This helps measure the height of the ground, which changes because of volcanic activity beneath the surface.

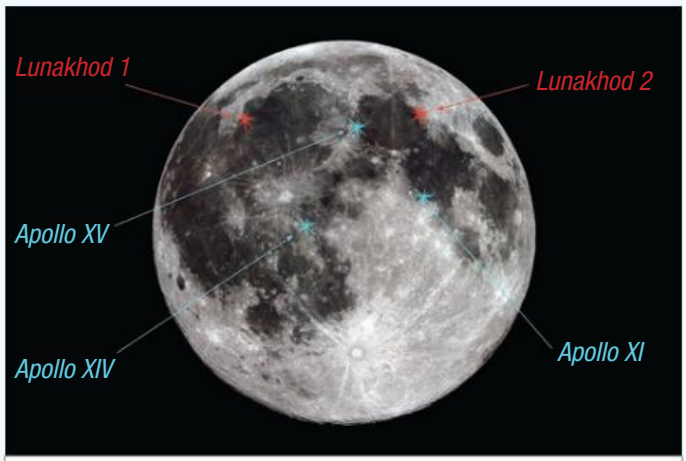


Figure 5.23 Location of lunar laser ranging retro-reflector arrays left on the Moon by American astronauts (green) and Russian robot (red).

ISBN 9780170189071

Your task

1 Identify two different practical purposes for the use of corner reflectors.

2 Design and build two different corner reflectors that could be used for the purposes identified above.

3 For each corner reflector, demonstrate its use for the practical purposes you have identified.

Hint: You may wish to begin by using a ray box and two mirrors at right angles. Demonstrate how a light ray landing on one mirror is reflected back by the other mirror along a path that is parallel to the incoming ray.

There are no convenient mirrors on the planets – no one's been there yet – so the accuracy of their distance measurements is less. However, the data are still reliable.

Radar measurements are accurate as far as the edge of the solar system, approximately one-ten-thousandth of a light year, or 100 million kilometres.

Parallax

Place your thumb in front of you and, with one eye closed, cover a point in the distance with it. Now, change eyes. The point appears to move. Of course, it is just your point of viewing. When you observe the same thing from two different points, the object appears to move. This is the phenomenon of parallax. The line between the observations at different points is called the baseline.

Imagine that you are looking out from the front of your house. In the garden there is a flower. Further away are a tree and then a house. In the distance is a hill. Standing at one corner of your house, you look towards these objects. Then you move to the other corner of the house and make a second set of observations. Figure 5.24 shows that, when you do this, the angle at the object gets smaller and smaller.

If you increase the length of the baseline, you increase the angle at the object, making it easier to measure the angle accurately. By drawing a triangle on the baseline with the angle at its vertex, the distance to the object can be calculated. To do this, you need to make a scale drawing or use trigonometry. Since the baseline and the object form a triangle, the method of parallax is also called triangulation (see Figure 5.26 on page 165).

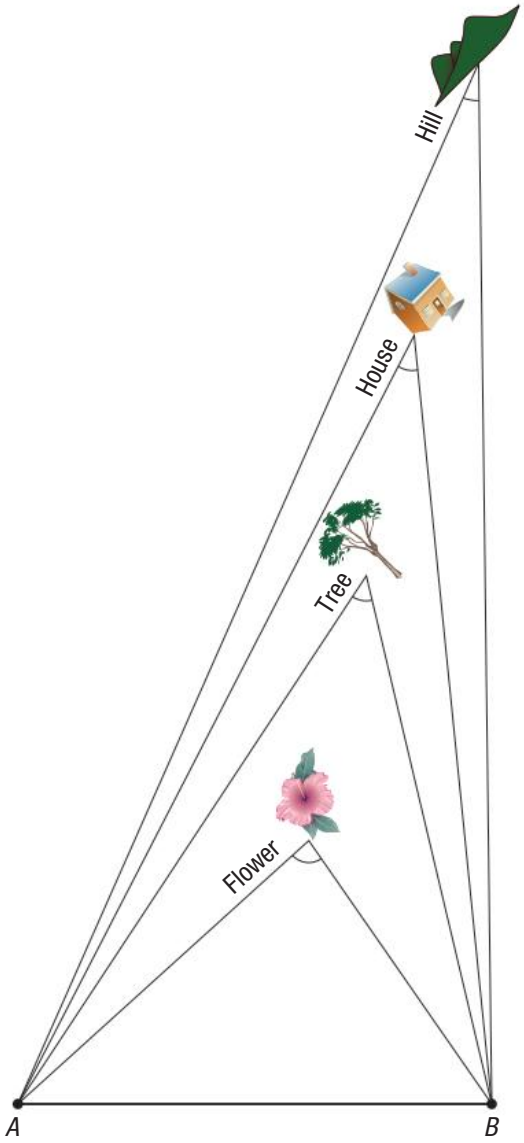


Figure 5.24 For a fixed baseline *AB*, the angle at the object gets smaller as the distance increases.

CONNECTION

Numeracy: Measuring distances by parallax

SCI10SICN00126

glossary terms

baseline
the line between two observation points

corner mirror
an arrangement of mirrors that reflects light parallel to the incoming rays

parallax
the apparent movement of an object as a result of the change of observing position

triangulation
the use of triangles on a baseline to measure distance

ISBN 9780170189071

Parallax and the astronomical unit

Earth's orbit and the astronomical unit

An accurate measurement of the Earth's orbital diameter is useful for building our measurement tools beyond the limits of radar. The Sun is a bit too noisy and a bit too fluid to get a good radar reflection, so Venus is used instead (Figure 5.25).

Two measurements are needed. We 'ping' Venus when it is on the opposite side of the Sun to Earth (position 1) and calculate the distance E_1V_1. When Venus and Earth are on the same side of the Sun (position 2), the measurement is repeated to find E_2V_2. These two distances add up to the diameter of the Earth's orbit around the Sun.

The Earth–Sun orbital diameter is so important that it is used to calculate the astronomical unit (AU), which is the average distance of the Earth from the Sun. One astronomical unit is the Earth–Sun radius. It is half the Earth–Sun orbital diameter.

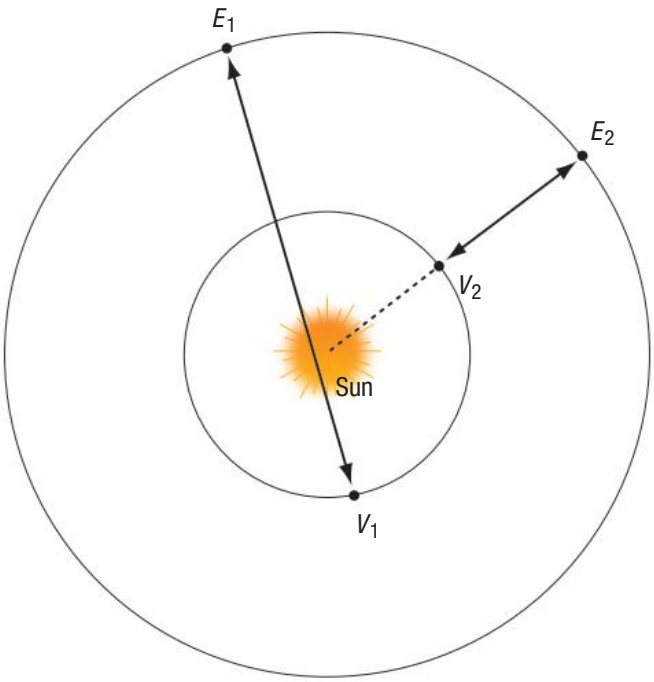


Figure 5.25 Radar measurements of the Earth–Venus distance at two points give an accurate value for the Earth–Sun diameter.

Measuring celestial distances by parallax

Stars are so far away that their parallax angles are much less than 1°. In fact, the angles are a few arc seconds in size. An arc second is $\frac{1}{3600}$ of 1° because degrees are divided into arc minutes ($\frac{1}{60}$ of 1°) and arc minutes are divided into arc seconds ($\frac{1}{60}$ of $\frac{1}{60}$ of 1°). An arc second is therefore an extremely small angle.

The largest baseline available to human investigators is the Earth's orbital diameter; hence, the importance of the astronomical unit.

WOW!

Trigonometry

Trigonometry helps astronomers and navigators to use triangulation relatively quickly. Greek mathematician Hipparchus (c. 190–c. 120 BCE) produced 12 books that recorded trigonometric values for angles. After the fourth century CE, the trigonometric book *Almagest* by Egyptian mathematician Ptolemy (c. 100–c. 170) became the most important in the world. Six hundred years later, Persian mathematician Abû'l-Wefâ (940–998) produced an updated version of Hipparchus' books. A thousand years on, German and English mathematicians, among others, were publishing very accurate tables of trigonometric functions for very small differences in angles. These helped geographers to mark precise boundaries of territory so that sailors and explorers could find their way around the globe.

A new distance unit: the parsec

Astronomers find that, when they use the method of parallax, they have to play with large and complicated numbers to obtain their answers in kilometres. So they do a cunning thing. They get rid of the need to use these numbers by changing to a new set of length measurements that are based on the parallax second. This change of scale makes it easier to talk about distances (Table 5.3). The new unit of distance is given the name parsec (short for **par**allax **sec**ond).

Table 5.3 Astronomical distances in different distance units

Unit	Parsec (pc)	Light year (ly)	Kilometre (km)
Distance	1	3.26	30 trillion

ISBN 9780170189071

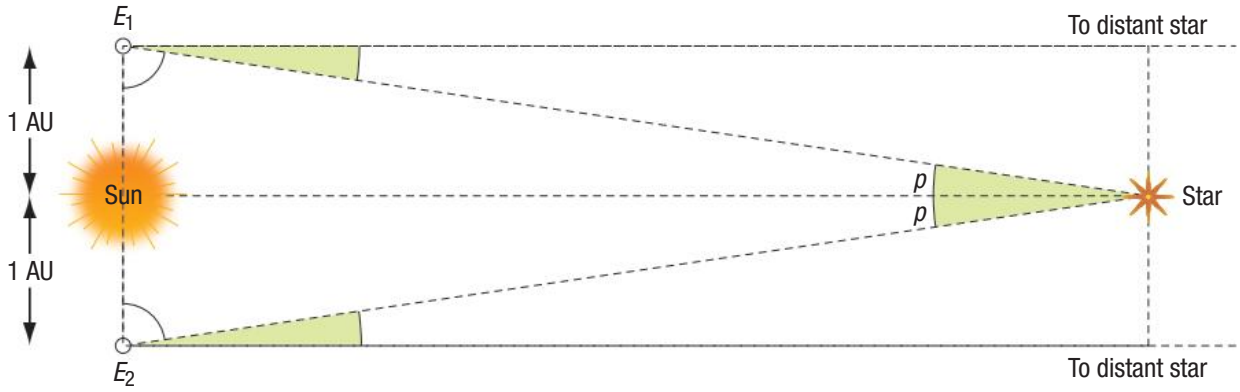


Figure 5.26 The triangle that defines the distance measure, parsec. The baseline is 2 AU, the measured angle is 2 arc seconds and the parallax angle at the object is 1 arc second.

One parsec (pc) is the angle labelled *p* in Figure 5.26. The baseline is the Earth's orbital radius (1 AU).

One of the advantages of the parsec is that it makes it easier to calculate simple numbers for the distances to stars:

$$\text{Distance to star} = \frac{1}{\text{parallax angle in arc seconds}}$$

Example

An astronomer makes two observations of a star that are 6 months apart. This means the astronomer is using the Earth's orbital diameter (2 AU) as baseline. The star shows a parallax angle of 0.2 arc second. How far is it to the star? Give your answer in parsecs (pc) and then convert into kilometres (km).

Solution

$$\text{Distance to star} = \frac{1}{\text{parallax angle in arc seconds}}$$
$$= \frac{1}{0.2}$$
$$= 5\,\text{pc}$$

Table 5.4 shows the conversion of 5 pc into kilometres.

Table 5.4 Converting 5 pc into kilometres

Unit	Parsecs (pc)	Light years (ly)	Kilometres (km)
Distance	5	5 × 3.26 = 16.3	5 × 30 trillion = 150 trillion

ANIMATION
Working out distance
SCI10SUAN00127

Notice that if the parallax angle is smaller, the distance is further away. For example, if the parallax angle is 0.1 arc second, the distance is 10 pc. In general, if the parallax angle gets smaller by half, the distance doubles. Astronomers almost always use parsecs to refer to distance.

WEBLINK
Ask a physicist

ACTIVITY SHEET
Parallax
SCI10SIAS00128

The method of parallax works well out to about 30 pc, which is approximately 100 light years. After that, parallax angles become impossibly small to measure – about one-ten-thousandth of one degree!

glossary terms

astronomical unit (AU)
half the Earth's orbital diameter

parallax second, parsec (pc)
the distance to an object that has a parallax angle of 1 arc second when observed using the Earth's orbital radius as the baseline

ISBN 9780170189071

Questions 5.4

What have you learnt?

WORKSPACE

What have you learnt? 5.4

SCI10SUWR00135

Understand

1 a What is radar ranging for celestial objects?

b How far out can radar measure?

2 a Define the following.

i Light year

ii Parsec

b How many light years are in 1 pc?

3 Using a diagram, show how a corner reflector works.

Apply

4 Explain how radar is used to measure astronomical distances.

5 Radar is directed towards a meteorite. It returns 1.0 s after being sent. How far is it to the meteorite?

6 Complete the following table.

Unit	Parsecs (pc)	Light years (ly)	Kilometres (km)
Distance	50		
			100 000
		14.7	

7 The parallax angle to a star is 0.004 arc second.

a Draw a diagram to represent this situation.

b What is the distance to the star in parsecs?

Analyse

8 Use Mercury to show how 1 AU can be measured from Earth. Why is it not possible to use Mars to measure 1 AU?

Synthesise

9 How would you explain the phenomenon of parallax to an adult? How would you explain it to a small child? Write an explanation of parallax and upload it to the class wiki.

10 Explain why our knowledge of things that happen on far-away celestial objects is always about events a long time ago.

Reflect

11 What have you learnt about measuring astronomical distances?

12 How could you use your knowledge about radar ranging or parallax to complete your culminating assessment task?

Distance by colour, temperature and brightness

We have now measured out to about 100 light years before our first two methods fail us. However, we have said that it is about 14 billion light years out to the end of the universe. How do we measure that?

Our next step is to take advantage of some interesting properties of stars: colour, temperature and brightness. The colour of a star tells us how hot it is at the surface. The surface temperature tells us how bright the star should be. The difference between the brightness we see and the star's actual surface brightness can be used to work out the distance.

The way we work out the distance involves several steps. First, find the temperature of a star from its colour. Then use this to compare the observed brightness with the star's actual brightness, as indicated by its temperature.

Colour and temperature: Planck curves

If you heat a piece of metal, it will first glow red, then yellow, white and finally blue. The same goes for stars. The hotter the star, the bluer it gets (Figure 5.27).

ISBN 9780170189071

Figure 5.27 Kappa Crucis (NGC 4755), also known as the 'Jewel Box', which is in the Southern Cross constellation, has a wide variety of different-coloured stars. It is about 16 million years old and 6400 light years away.

Every hot object radiates light energy according to a similar pattern. This pattern is called the Planck curve (Figure 5.28), which was named after Max Planck who unravelled the secrets this curve contained.

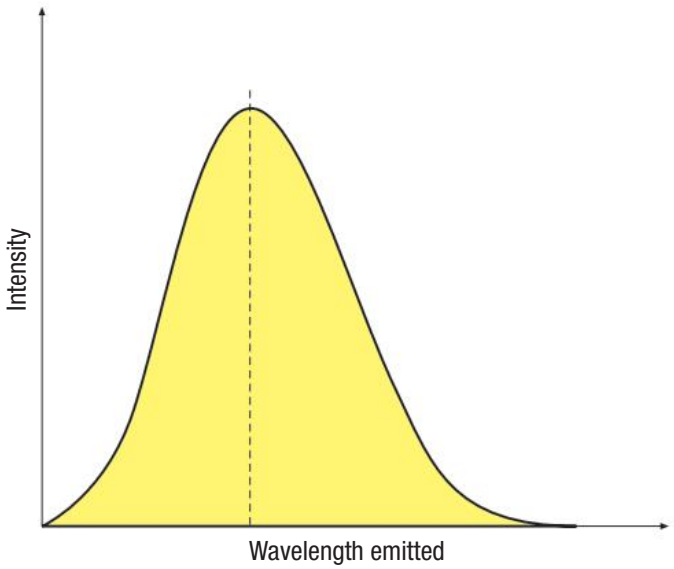


Figure 5.28 The Planck curve for a body that radiates energy

WOW!

Max Planck

Max Planck showed how to explain the pattern of radiation that is emitted from hot bodies. Along the way, he helped to invent a new type of physics – quantum physics – for which he received the Nobel Prize in Physics in 1918.

Which Habits of Mind would Max Planck have been most proficient in?

As a German citizen, Planck supported his country during the Second World War, but he became increasingly concerned about the Jewish holocaust. His son, Erwin Planck (1893–1945), was involved in a plot to assassinate Adolf Hitler on 20 July 1944 and was executed by the Gestapo in early 1945.

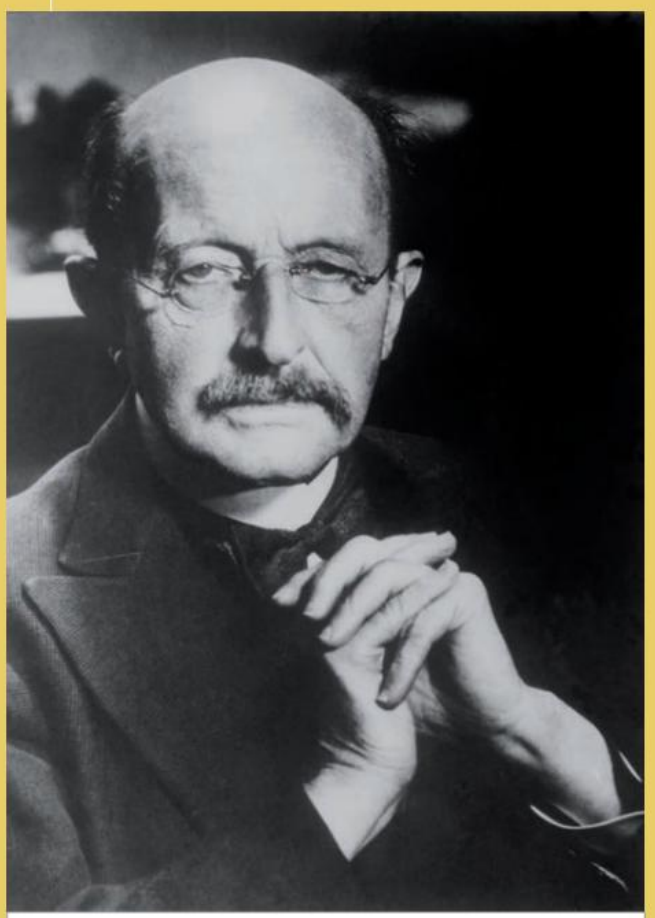


Figure 5.29 Max Planck was very important in developing the new quantum physics.

WEBLINK
Max Planck

glossary term

Planck curve
the continuous spectrum typical of a radiating body

ISBN 9780170189071

The Planck curve shows the intensity of the energy coming from a surface as a function of the type of radiant energy, indicated by the wavelength. The peak is a measure of the highest temperature of the spectrum of radiation (Figure 5.30).

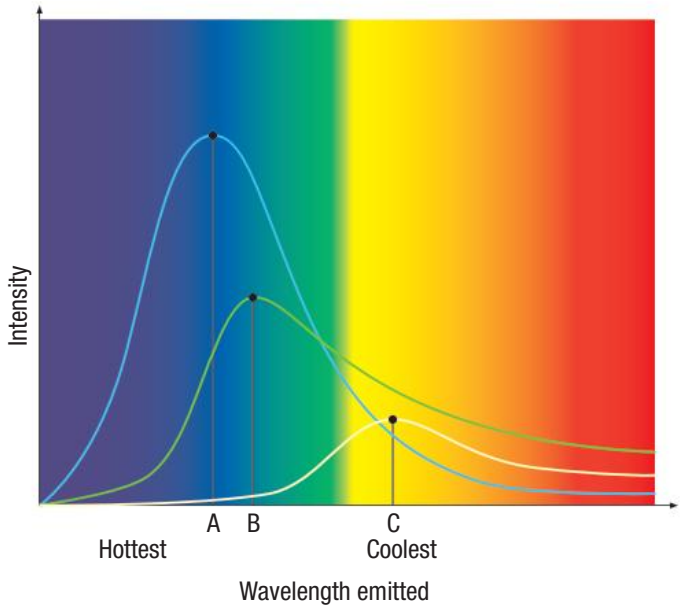


Figure 5.30 Three Planck curves, showing peak intensities corresponding to three objects, A, B and C, at different temperatures: A is the largest and C the smallest temperature.

Stars can be classified by temperature using their colours. Planck curves can therefore be used to tell us how hot a star is. Some examples are shown in Table 5.5.

We see the type of radiant energy as the colour of the surface. Different stars belong to different groups or spectral types, which are denoted by the letters O, B, A, F, G, K, M, L and T. For example, a blue star, spectral type O, has a higher maximum surface temperature than a red star, spectral type M. The way that stars are categorised was developed by American astronomer Annie Jump Cannon (1863–1941), who classified over 200 000 stars during her lifetime.

Figure 5.31 Annie Jump Cannon classified more than 200 000 stars.

Table 5.5 Temperature of stars according to their colours.

Colour	Spectral type	Surface temperature (K)	Examples
Blue	O	> 30 000	Orionis C
Bluish-white	B	11 000–30 000	Achernar, Rigel, Spica
Bluish-white	A	7500–11 000	Sirius (Dog Star), Vega
White	F	6000–7500	Procyon, Canopus
Yellow-white	G	5000–6000	Alpha Centauri A
Yellow-orange	K	3500–6000	Sun
Red	M	< 3500	Proxima Centauri
Orange-brown	L	< 2700	Teide 1
Brown	T	< 900	Gleise 229B

ISBN 9780170189071

Activity 5.8
Colourful stars

For each of the examples in Table 5.5, state the constellation in which these stars are found. Choose six of these constellations. Find and save images of them. Use the images to create a three-dimensional photocube. Upload the photocube to your blog with an explanation of which constellations you chose and why.

WEBLINK
Photocube

Brightness and magnitude

The Sun is the brightest star in our sky. Sirius is the brightest star in the night sky; Canopus is the second brightest. Sirius looks twice as bright as Canopus, and the Sun outshines both of them. How bright would they look if they were each towed out to the same place in space and their brightness measured and compared? Canopus would be first; and Sirius, second. The Sun's brightness would be very small in comparison (Figure 5.32).

ANIMATION
The brightness of stars
SCI10SUAN00130

We can measure brightness by measuring the intensity of the energy received in specially designed instruments. The magnitude scale uses these measurements. It was worked out before there were instruments to measure energy intensity properly. It is possible to convert between magnitude and intensity; however, we will only use the magnitude scale here.

Originally, magnitude referred to the brightest star in the sky. Thus, Sirius was a magnitude 1 star and the dimmest star was magnitude 6. Today, however, the magnitude scale is divided into two parts:

- Apparent magnitude is a measure of the brightness we see when we look out to objects in space. The scale is supported by accurate measurements of the intensity of the light coming from the stars and other celestial objects. Planets such as Venus and Jupiter, as well as the Moon and the Sun, have negative values because they look brighter than Sirius (Figure 5.33 on page 170).

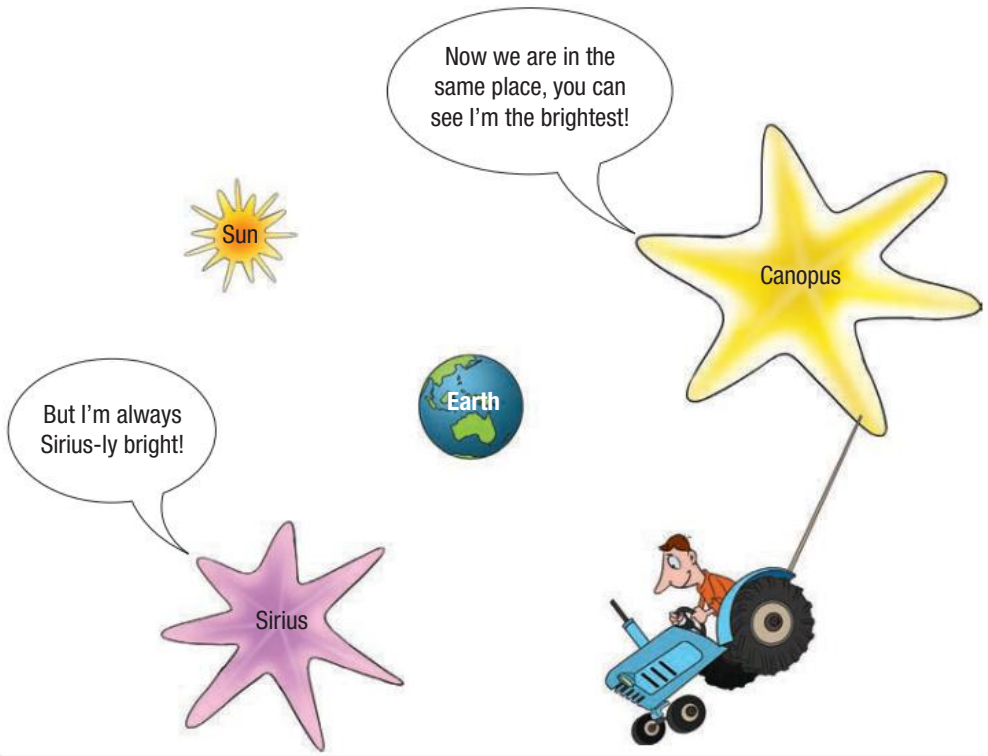


Figure 5.32 A fair comparison of brightness of stars means they all have to be positioned the same distance from Earth.

glossary terms

apparent magnitude
brightness of a celestial object as seen from Earth

magnitude scale
the scale that shows the brightness of a celestial body; negative numbers are very bright, and positive numbers are less bright

ISBN 9780170189071

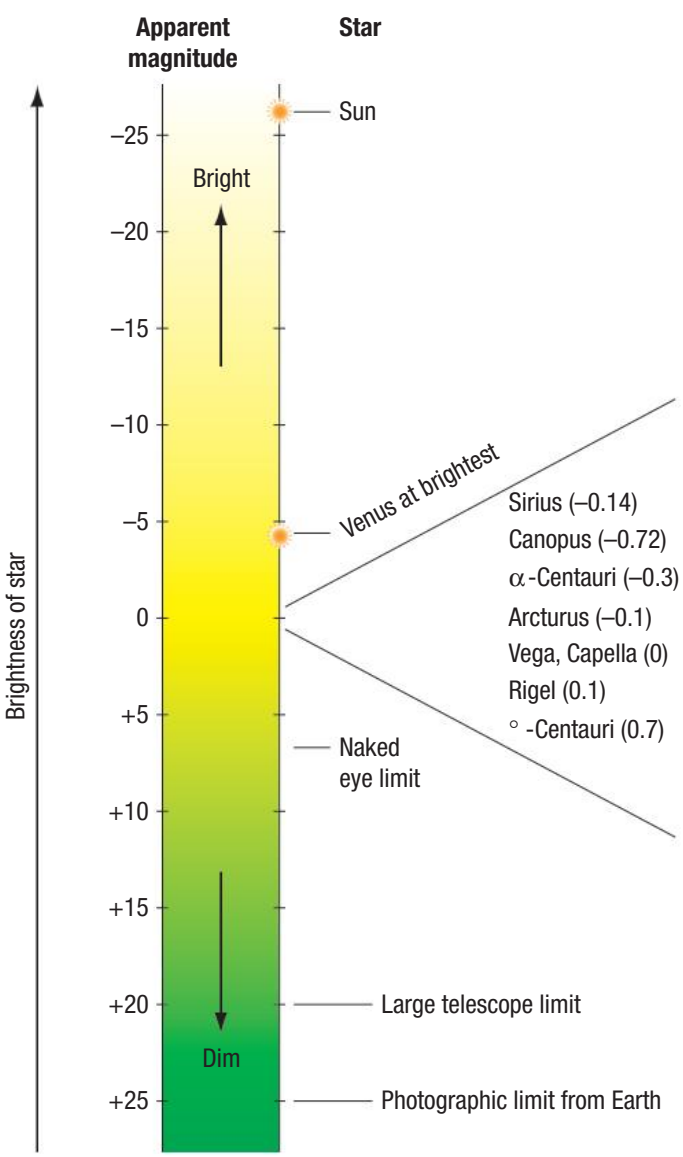


Figure 5.33 Magnitudes of stars and other celestial objects: apparent magnitude from Earth

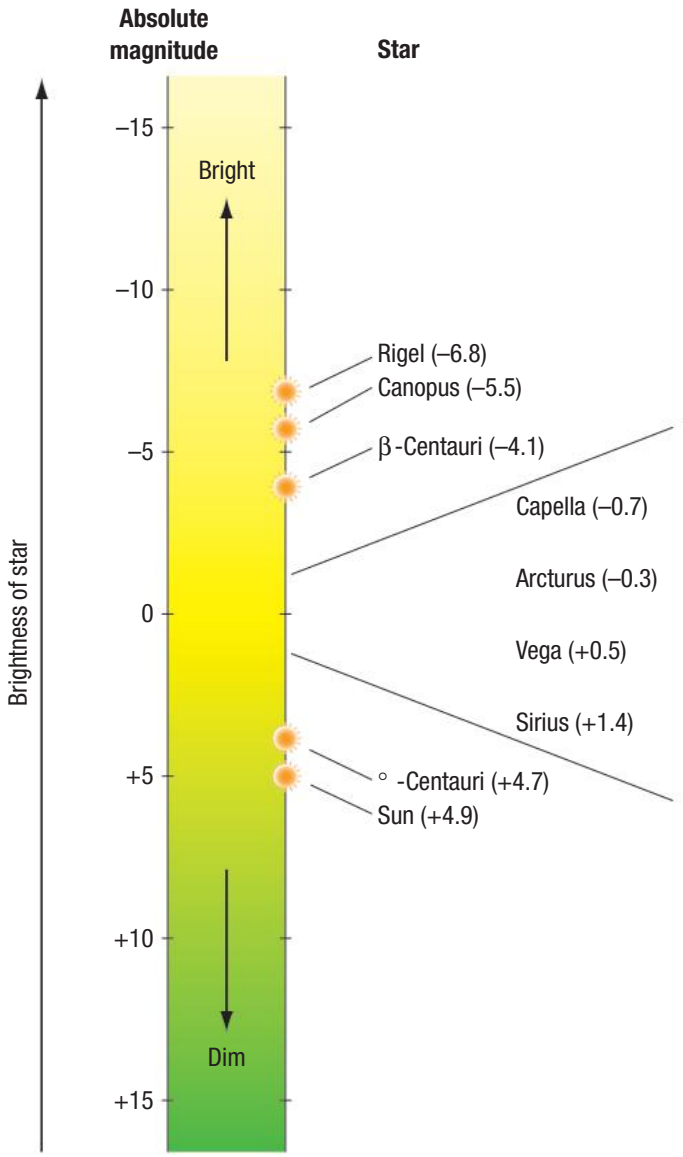


Figure 5.34 Magnitudes of stars and other celestial objects: absolute magnitude at 10 parsecs from Earth

- Absolute magnitude is a fair measure for the brightness of all stars at the same distance from Earth. We know the way that brightness changes with distance – it is quite regular and predictable. Astronomers use this knowledge to compute magnitudes for stars by algebraically 'towing' them to a position 10 pc from Earth (Figure 5.34).

As Figures 5.33 and 5.34 show, a negative number means greater brightness on both scales. From space, the dimmest stars have apparent magnitudes of +25; the brightest have apparent magnitudes of −25. The absolute magnitude scale goes from about +15 (dimmest) to −15 (brightest). Notice that the Sun, whose apparent magnitude is huge (−26) compared with everything else, is placed towards the dimmer end of the absolute magnitude scale (+4.9). This is because it has to be 'towed' a long way away from Earth to get to 10 pc.

We are now nearly in a position to work out the distance to an unknown star further away than 100 light years. First, we need to compare the apparent magnitude with the absolute magnitude. To do this, we take away the absolute magnitude from the apparent magnitude. It is this *difference* between apparent magnitude and absolute magnitude that is important (Figure 5.35). For example, if the difference between apparent magnitude and absolute magnitude is 5, the distance from Earth is 100 pc.

ISBN 9780170189071

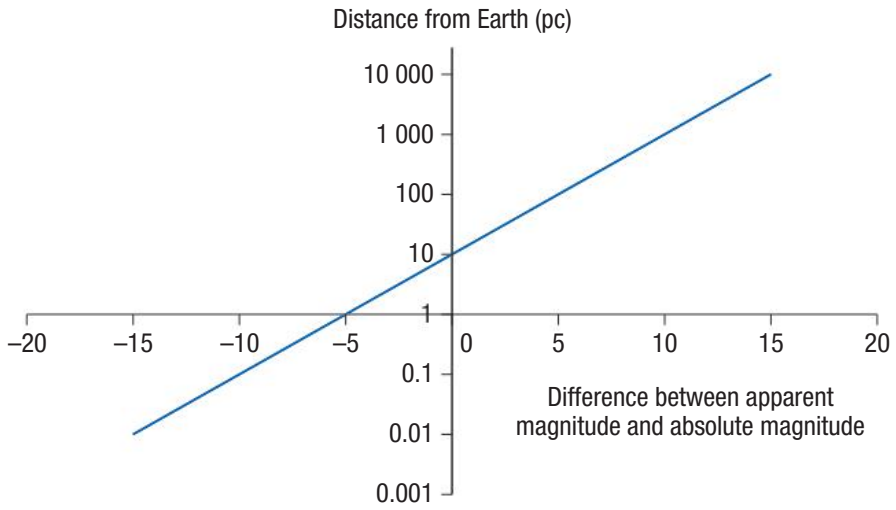


Figure 5.35 A graph of distance from Earth versus difference between apparent magnitude and absolute magnitude. The distance scale (on the *y* axis) is a logarithmic scale.

Hertzsprung–Russell diagram

When we plot the absolute magnitude of stars against their temperatures, an interesting pattern emerges. Temperature is related to the absolute magnitudes of about 90% of all stars.

In 1911, Danish astronomer Ejnar Hertzsprung (1873–1967) plotted the colour – hence, temperature – of stars versus their absolute magnitude. Two years later, American astronomer Henry Norris Russell (1877–1957) did much the same. Between them, they showed there are regular patterns between the absolute magnitudes and the temperatures of stars. This has proved very useful for finding not only the distances to stars, but also their masses and the way they develop over long periods of time. The Hertzsprung–Russell (H–R) diagram, which evolved as a consequence of the work that Hertzsprung and Russell conducted independently, is one of the most important tools in astronomy (Figure 5.36 on page 172). It takes into account the magnitudes of the stars and their temperatures.

WEBLINK
Hertzsprung–Russell diagram

The central band of the H–R diagram is called the main sequence. About 90% of all stars are main-sequence stars. Red giants and white dwarfs form clusters off the main sequence. The distances out to a great many of the main-sequence stars can be calculated by stellar parallax. We can use the H–R diagram to help work out the distances to stars; however, the star needs to be a main-sequence star for this procedure to work.

Worked example

Imagine that we have just viewed a blue star, called Imagine-A, whose distance from Earth we do not know. Imagine-A is too far away to measure its parallax angle and is quite faint, with an apparent magnitude of +7.5. Its Planck curve is shown in Figure 5.37 on page 172. Find the distance to Imagine-A.

Solution

We use the H–R diagram to help work out how far away Imagine-A is. The procedure is as follows.

1 Use the Planck curve to work out the temperature (Figure 5.37). The temperature is 11 000 K.

glossary terms

absolute magnitude
brightness as though all objects were at 10 pc from Earth

logarithmic scale
a scale where equal distances mean the previous number has been multiplied by 10

main sequence
the central band of stars on the Hertzsprung–Russell diagram; stars that fuse hydrogen to helium

ISBN 9780170189071

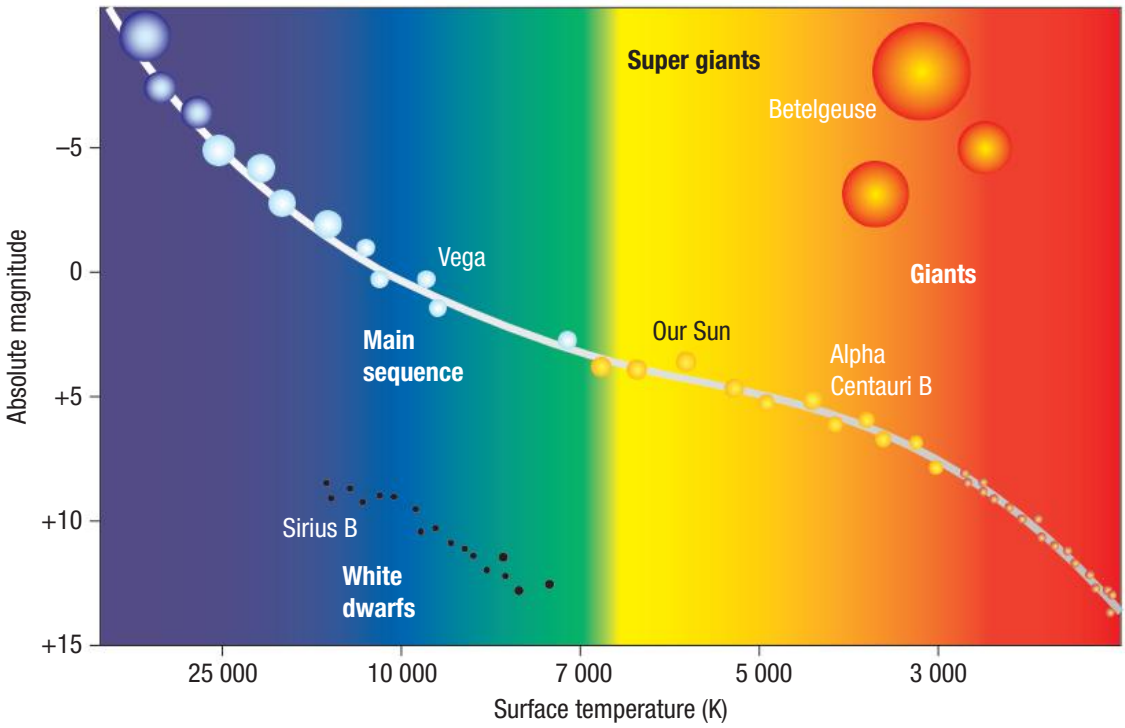


Figure 5.36 Hertzsprung–Russell diagram. Notice that the temperature scale *decreases* as you move to the right.

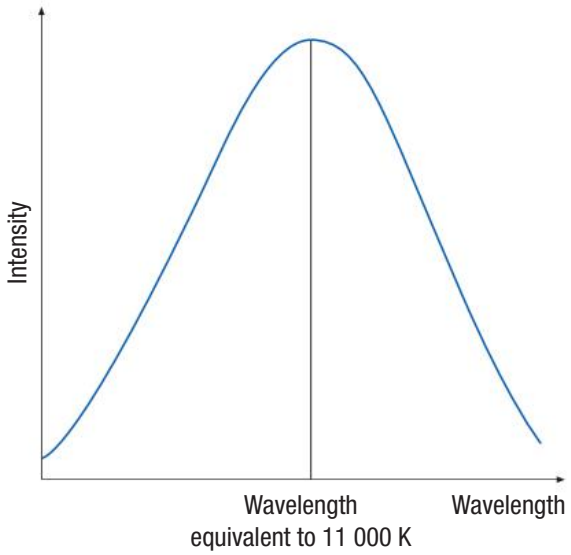


Figure 5.37 Planck curve for imaginary star Imagine-A

2 Use the H–R diagram in Figure 5.36 to plot Imagine-A's position onto the main sequence. Hence, read off its absolute magnitude.

- From 11 000 K on the temperature axis (*x* axis), go vertically up until you come to the main sequence.
- Decide where your star should go on the main sequence. (This is a bit of an approximation, but it works quite well.)
- Read across to the magnitude axis (*y* axis).
- The absolute magnitude of Imagine-A is −2.5.

3 Use Figure 5.35, which links distance to the difference between apparent magnitude and absolute magnitude, to work out the distance to the star.

- The difference between apparent magnitude and absolute magnitude for Imagine-A is:

$$+7.5 - (-2.5) = 10$$

- From 10 on the magnitude difference axis (*x* axis), go vertically up until you come to the line.
- Read across to the distance axis (*y* axis).
- The distance to Imagine-A is 1000 pc, or 3260 light years, from Earth.

The H–R diagram helps us to calculate distances to stars out to about 100 000 light years. This takes us out to the edge of the Milky Way, the galaxy to which we belong. Beyond this, the stars are so faint that their colour make-up cannot be detected well enough.

ACTIVITY SHEET
H–R diagram
SCI10SIAS00131

Cepheid variables

Some stars pulsate. Their apparent magnitudes vary regularly from high to low and back again. The most famous is δ-Cephei, the fourth-brightest object in the constellation Cepheus (Figure 5.38). Stars whose magnitudes vary regularly are called Cepheid variables.

ISBN 9780170189071

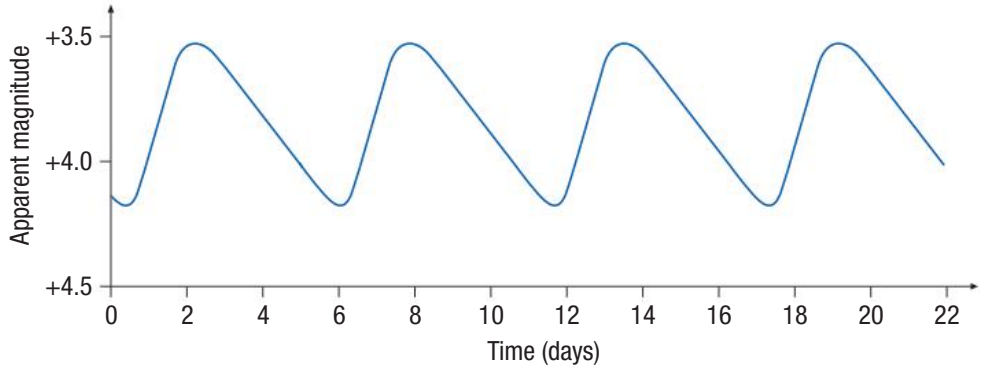


Figure 5.38 The brightness of δ-Cephei varies regularly with its period. Its average apparent magnitude is +3.8.

Figure 5.39 Henrietta Swan Leavitt was one of many women employed to analyse data produced by male astronomers who 'manned' the telescopes.

We can see in Figure 5.38 that the apparent magnitude of δ-Cephei changes from dim (+3.5) to dimmer (+4.2) and back to dim again every six days. δ-Cephei is close enough for its distance to be calculated by parallax. In turn, this enables us to work out its absolute magnitude.

In 1912, American astronomer Henrietta Swan Leavitt (1868–1921), shown in Figure 5.39, was employed to catalogue stars in a nearby galaxy called the Small Magellanic Cloud. She discovered 1777 new variable stars and showed that, for the Cepheid type, the rate of pulsation is mathematically related to their absolute magnitudes.

WEBLINK
Henrietta Swan Leavitt

CONNECTION
Literacy: Rachel Webster
SCI10SHCN00132

ACTIVITY SHEET
Women in science
SCI10SHAS00133

Reading from the graph in Figure 5.40 on page 174, a Cepheid variable with a period of 10 days has an absolute magnitude of −4. The difference between the average apparent magnitude and the absolute magnitude can then be used with Figure 5.36, the H–R diagram, to work out the distance.

Example

A Cepheid variable has a period of 10 days and an average apparent magnitude of +8. How far away is it?

Solution

1 Use Figure 5.40 to find the absolute magnitude of this Cepheid variable.
- Locate 10 days on the period axis (*x* axis). Go vertically up until you intersect with the line.
- Read across to the absolute magnitude axis (*y* axis).
- The absolute magnitude of this Cepheid variable is −3.9.

glossary term

Cepheid variables
stars whose magnitudes vary

ISBN 9780170189071

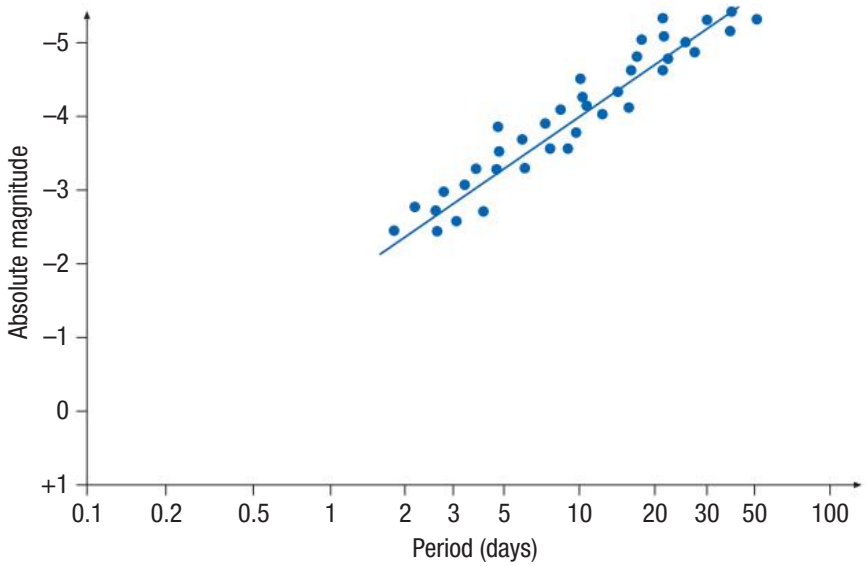


Figure 5.40 The absolute magnitude of Cepheid variables depends on the average period of time that a star takes to repeat its cycle.

2 Use the graph in Figure 5.35 on page 171 to work out the distance to the star.

- The difference between the average apparent magnitude and absolute magnitude for this Cepheid variable is:

$$+8 - (-3.9) = 11.9$$

- From 11.9 on the magnitude difference axis (x axis), go vertically up until you come to the line.
- Read across to the distance axis (y axis).
- The distance to this Cepheid variable is 1100 pc, or 3280 light years, from Earth.

ACTIVITY SHEET
Cepheid variables
SCI10SIAS00134

WOW!

Three types of variables

In 1952 German astronomer Walter Baade (1893–1960) discovered a second type of Cepheid variable in the constellation Virginis. These Cepheid II variables follow the same pattern as Cepheid I variables. Their absolute magnitudes are less than those for Cepheid I. A third type, RR Lyrae, has also been identified.

WEBLINK
Cepheid variable stars

Gaseous nebulae

Out beyond 10 million light years, Cepheid variables are too faint to measure accurately. At this stage we use larger objects – nebulae – as our focus. Nebulae are bright and large (Figure 5.41), so they are readily observable in our best telescopes.

We work out the brightness–distance relationship for nebulae nearby in the Milky Way. Then we use this pattern to estimate distances based on the brightness of very far-distant nebulae. Now we are able to measure distances out to 10 billion light years away from Earth.

Figure 5.41 The Orion Nebula is visible with the naked eye.

ISBN 9780170189071

Questions 5.5
What have you learnt?

WORKSPACE
What have you learnt? 5.5
SCI10SUWR00140

Understand

1 What does a Planck curve represent?

2 Which star colour represents the highest surface temperature?

3 Distinguish between apparent magnitude and absolute magnitude.

Apply

4 A Planck curve for a main-sequence star of apparent magnitude +17.0 has a maximum temperature of 8000 K.
   a What spectral type and colour is this star?
   b How far away is the star in:
      i parsecs
      ii light years?

5 A Cepheid variable star has a period of 5 days. Its apparent magnitude is +25.
   a What is its absolute magnitude?
   b How far away is it in parsecs?

Analyse

6 Why does Mars have a negative apparent magnitude?

7 List the steps, in order, for finding distances to main-sequence stars.

Synthesise

8 Compare and contrast the measurement of astronomical distances using the H–R diagram and Cepheid variables.

Reflect

9 What have you learnt about the different astronomical measuring techniques? Which do you think you will use for your culminating assessment task? What celestial object will you choose for this task?

Redshift and recession

We have seen that every star has a Planck curve that tells us its maximum brightness. The Planck curve shows a continuous spectrum of light with a peak value for a particular colour. This is the curve we use with the H–R diagram to find the distances to stars.

When we look carefully into the continuous spectrum, we see very fine, dark lines. These lines are the absorption spectrum. They tell us what elements are being made in the star. Every element has a characteristic spectrum of light (see Unit 3, pages 86–7). If the element is made in a star, it will emit its characteristic emission spectrum. However, the outer gaseous atmosphere of the star absorbs a lot of this characteristic spectral radiation. The result is a less-bright (dark) line.

WEBLINK
Difference between spectra

ACTIVITY SHEET
Kirchhoff's law and spectroscopy
SCI10SHAS00136

Stellar redshift and blueshift

Stars in our local part of the universe move towards and away from us, and these motions can be deduced from their spectra (Figure 5.42 on page 176). We use the terms 'stellar redshift' and 'stellar blueshift' to do this.

glossary terms

absorption spectrum
dark lines in a continuous spectrum in which radiation that is characteristic of particular elements is absorbed

continuous spectrum
a spectrum in which all radiation 'colours' are emitted

nebula
a huge region of cosmic gas

ISBN 9780170189071

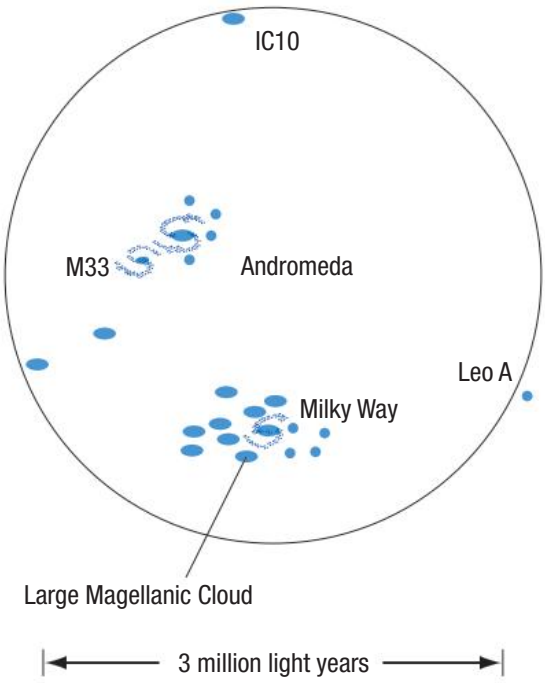


Figure 5.42 The 'local' part of the universe is about 3 million light years, or 1 mega parsec, across.

If the stars are moving away from us, they show a stellar redshift because their spectral lines are shifted towards the lower-frequency red end of the spectrum. If they are moving towards us, they show a stellar blueshift because their spectra are shifted towards the higher-frequency blue end of the spectrum.

Figure 5.43a shows four emission lines that form part of the emission spectrum of iron. Below it is the absorption spectrum for the Sun (Figure 5.43b). We can see that, for the Sun, the emission lines and the absorption lines are at the same place.

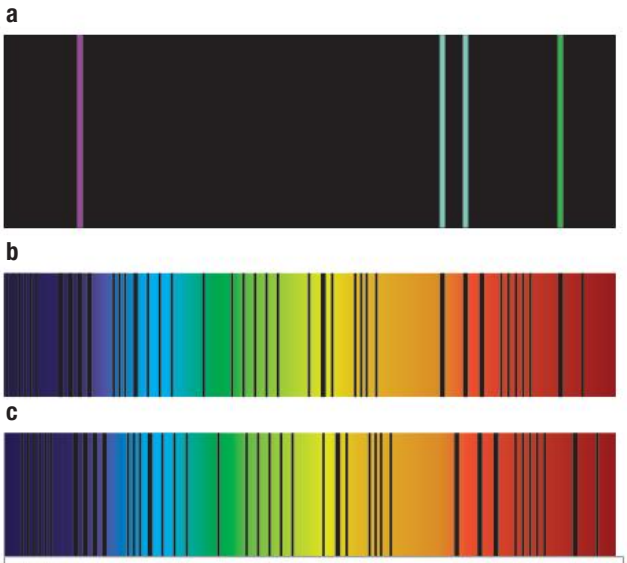


Figure 5.43 **a** Four emission spectral lines for iron. **b** Dark lines in the absorption spectrum of the Sun align with the emission lines. **c** Redshift: absorption lines shift towards the red end of the spectrum for local stars moving away.

Consider then a local star that has the same Planck curve as the Sun, but which is much further away (Figure 5.43c). Since this star is similar to the Sun, it should have the same absorption spectrum. We can see the absorption spectrum is the same, but it has shifted slightly to the red end of the spectrum. This shift tells us that this local star is receding from us. It is showing a stellar redshift.

Doppler effect

Waves from a source, such as a sound or light source, are emitted per second. This is known as the frequency of the source. The waves travel to an observer, where he or she can count the number of waves arriving per second. If both the source and observer are stationary, the observer will count exactly the same number of waves per second as the source emits – that is, the frequencies will be the same. However, if the source is moving away while emitting the waves, the observer will receive fewer waves per second than those emitted per second by the source.

We are quite used to this. For example, an ambulance siren receding from us sounds lower in pitch because we experience fewer sound waves per second than when the ambulance is stationary (Figure 5.44). Obviously, the reverse is true for sources coming towards us. This effect is called the Doppler effect. The frequency of waves per second emitted by the source is different from the frequency observed. This depends on the relative motion of the source and observer.

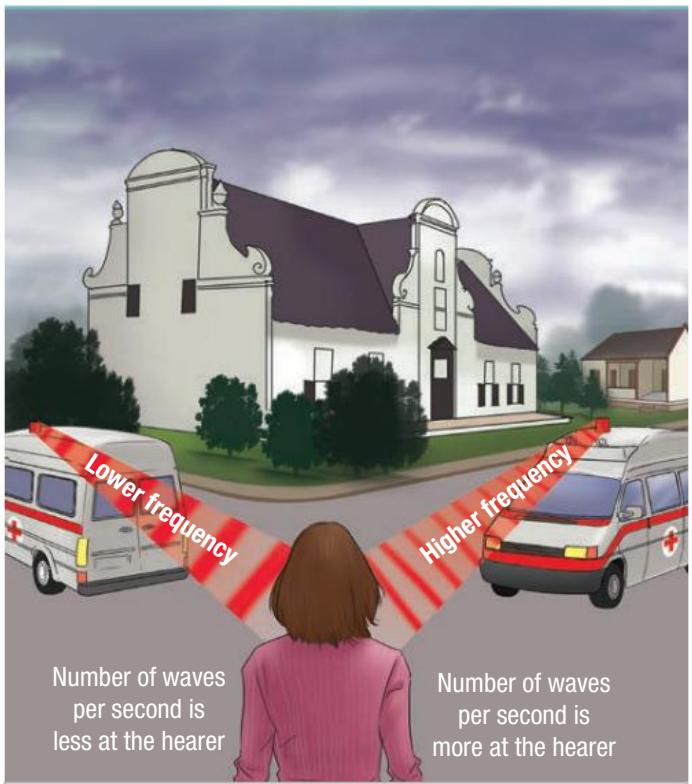


Figure 5.44 Doppler effect: the frequency experienced by the observer is different depending on the motion of the source.

ISBN 9780170189071

The Doppler effect is responsible for redshifts and blueshifts for stars in our local region. A redshift occurs when stars are moving away from us – red light has a smaller frequency. A blueshift occurs when stars are moving towards us. All stars further away from us than our local region display redshifts, which means that their overall motion is away from us.

Cosmic redshift

There is one surprising thing about the absorption spectra of galaxies. The lines are all in their relative positions, but they indicate that these colours are slightly shifted towards the red end of the spectrum. The red end is associated with longer wavelengths and lesser frequencies. The cosmic redshift is therefore evidence that galaxies are receding. Since they are so far away, any relative motion towards the Earth is insignificant when compared with the expansion speed of the universe out there.

The cosmic redshift is apparent for really far-away objects. It is different from stellar redshift, which refers only to objects in our local region of the universe.

WEBLINK

Redshift: stellar and cosmic

Edwin Hubble and the expanding universe

American astronomer Edwin Hubble (1889–1953) used Henrietta Swan Leavitt's work and his own and colleagues' investigations to show that the universe is expanding. In fact, he showed that the speed with which galaxies are moving away from one another – the recessional speed v – is proportional to their distance from Earth d. That is:

$$v = H_0 d$$

This equation is Hubble's law, where H_0 is the Hubble constant. Figure 5.45 shows currently measured data that supports Hubble's law. The Hubble constant is calculated from the gradient of this graph.

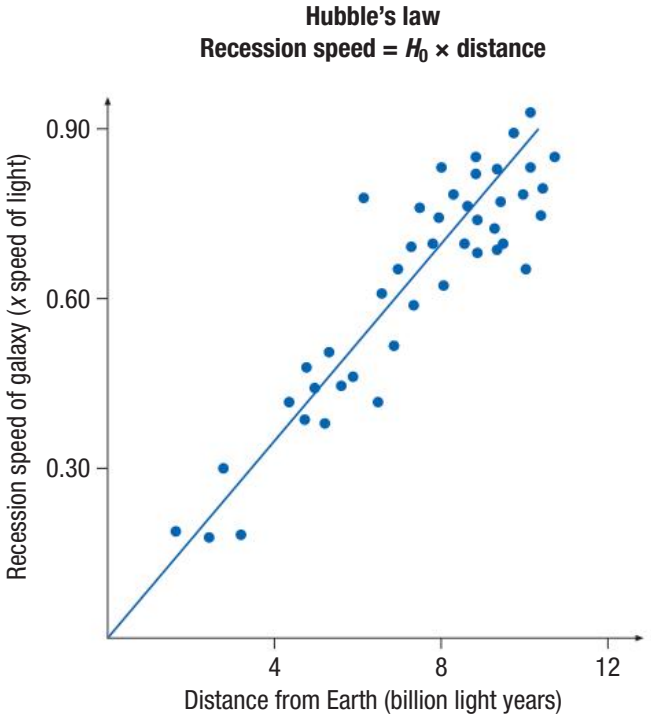


Figure 5.45 Hubble's law shows how the speed of a galaxy racing away from Earth varies with its distance from Earth.

You can find the distance to a far-distant galaxy by first working out its recession speed from redshift data. Using Hubble's constant, it is quite easy to put the numbers into the equation and rearrange it to find d.

ACTIVITY SHEET

Expanding universe

SCI10SIAS00137

glossary terms

cosmic redshift
relative to spectra produced on Earth, absorption spectral lines for galaxies far away are all shifted towards the red end of the spectrum

Doppler effect
the effect on observed frequency as a result of the relative motion of observer and source

frequency
the number of waves per second

Hubble's law
the law that states that the recession speed is proportional to the distance from the observer

stellar blueshift
relative to spectra produced on Earth, spectra from local stars moving towards Earth are shifted towards the blue end of the spectrum

stellar redshift
relative to spectra produced on Earth, spectra from local stars moving away from Earth are shifted towards the red end of the spectrum

ISBN 9780170189071

Age of the universe

We can now use Hubble's law to estimate the age of the universe. Hubble's law tells us that each galaxy is receding from each other galaxy at the same rate. This means that we can estimate how much time has elapsed since the galaxies were all together at the moment when space started to expand (Table 5.6).

Table 5.6 Calculating the age of the universe

Speed is the rate at which distance changes as time changes:	Compare this with Hubble's law, which can be rearranged as:
$v = \frac{d}{t}$	$v = H_0 d$
$t = \frac{d}{v}$	$H_0 = \frac{v}{d}$
	$\frac{1}{H_0} = \frac{d}{v}$
$t = \frac{1}{H_0}$	

Thus, we can find the time elapsed since the universe began expanding by measuring Hubble's constant and finding its inverse.

INTERACTIVE

The universe and its origin

SCI10SUIN00138

Accelerating universe

About five billion years ago the rate at which space was expanding started to increase. Rather than the rate being constant, it began to accelerate. Gravitational energy stops the universe expanding, and may even cause the universe to collapse back onto itself; however, dark energy exerts an outward drive to expand the universe. It seems that dark energy has therefore overcome gravitational energy and is accelerating the spread of space (Figure 5.46).

How do we know there was, and is, a 'new' phase of accelerating space? Astronomers discovered this in 1998. Using data from space probes and other observations, they were able to show this effect.

If at some time two stars are near each other, cosmic redshift data tells us that they will be further apart later on (Figure 5.47a). For an accelerating universe, these distances increase by more than the same amount every time (Figure 5.47b).

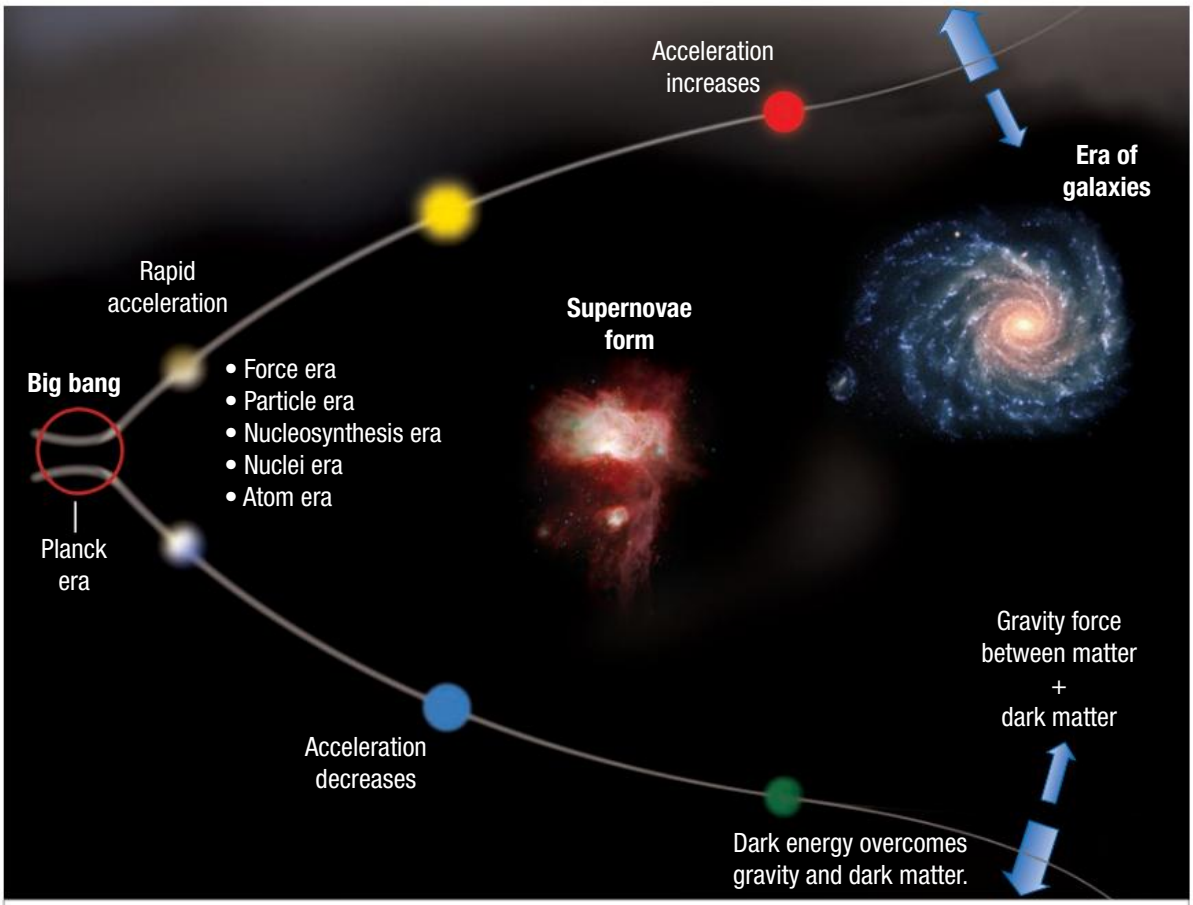


Figure 5.46 The expansion of the universe. Dark energy supplies a greater outward force than gravitation effects on matter and dark matter.

ISBN 9780170189071

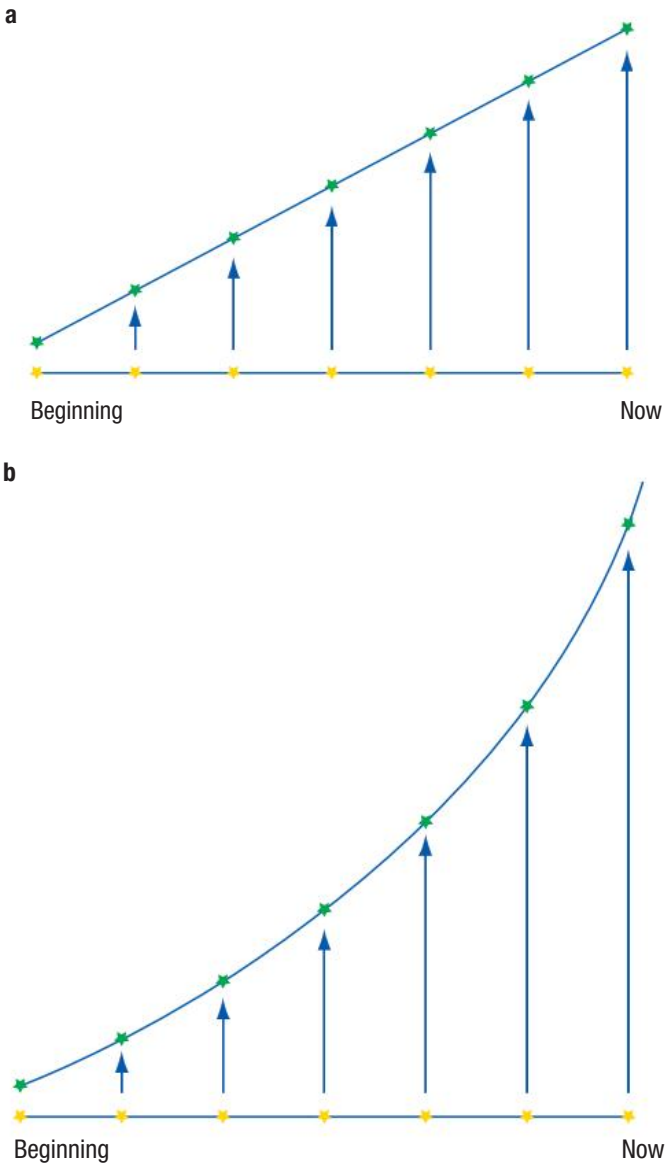


Figure 5.47 The expanding universe causes nearby stars to separate as the universe expands: **a** uniform expansion, **b** accelerating expansion

In 2011, these astronomers were awarded the Nobel Prize for their groundbreaking work; one of them, Brian Schmidt, worked in Canberra at the Australian National University. Schmidt is listed as Australia's eleventh Nobel Prize winner, the second in the field of physics.

WEBLINK
2011 Nobel Prize

ACTIVITY SHEET
Brian Schmidt: Nobel Prize winner
SCI10SHAS00139

Questions 5.6
What have you learnt?

WORKSPACE
What have you learnt? 5.6
SCI10SUWR00243

Understand

1 **a** What is an absorption spectrum?
b What is a continuous spectrum?

2 Draw a diagram to show the cosmic redshift associated with the spectra from far galaxies.

3 Define the Doppler effect.

Apply

4 Describe the sound from an ambulance siren as it travels:
a towards you
b away from you.

5 How does the Doppler effect explain stellar redshift and stellar blueshift?

Analyse

6 Explain how the Doppler effect works. How does this help to explain the cosmic redshift shown by galaxies?

7 Why do galaxies show only a cosmic redshift?

8 Compare a continuous spectrum with an absorption spectrum.

Synthesise

9 Construct a table that lists the various methods by which astronomers measure distances and the range of distances for which that method is most useful.

Reflect

10 How have you developed your understanding of the use of data in relation to theory?

ISBN 9780170189071

Fate of the universe

There are three possible fates for the universe:

1. The universe will expand forever.
2. The universe will continue on steadily forever.
3. The universe will expand and then contract until it returns to a single point.

Continuous expansion means that everything will move away from everything else until it becomes lonely out there (Figure 5.48a). Every object will be an infinite distance from every other object. Everywhere will be at absolute zero. All energy will have been transformed – there will be no stars to twinkle.

Steady state means that everything will expand for a while. The effect between gravitational force and other forces will then reach equilibrium. After that, the universe will continue forever (Figure 5.48b).

Expansion and then contraction means that the universe will do what it has been doing for a while – rushing away from itself. For a long time, it might even look like it is in a steady state. At some tip-over point, however, it will begin to collapse under its own mass. Furthest galaxies will become blueshifted as space contracts back to a single point (Figure 5.48c). The big crunch!

Will the universe rebound into a new version, possibly with different characteristics (Figure 5.48d)? The big bounce!

Activity 5.9
Reviewing the big bang

At the beginning of this unit you were asked for your opinion about the big bang theory. You were asked to compile your thoughts and ideas. Now that you have read this unit and completed a number of activities, has your opinion altered in any way? Explain any changes, or why you have not changed. Record your responses on your blog.

Extension

Choose 20 glossary terms from this unit and create a crossword puzzle. Upload your puzzle to the class wiki for others to download and complete.

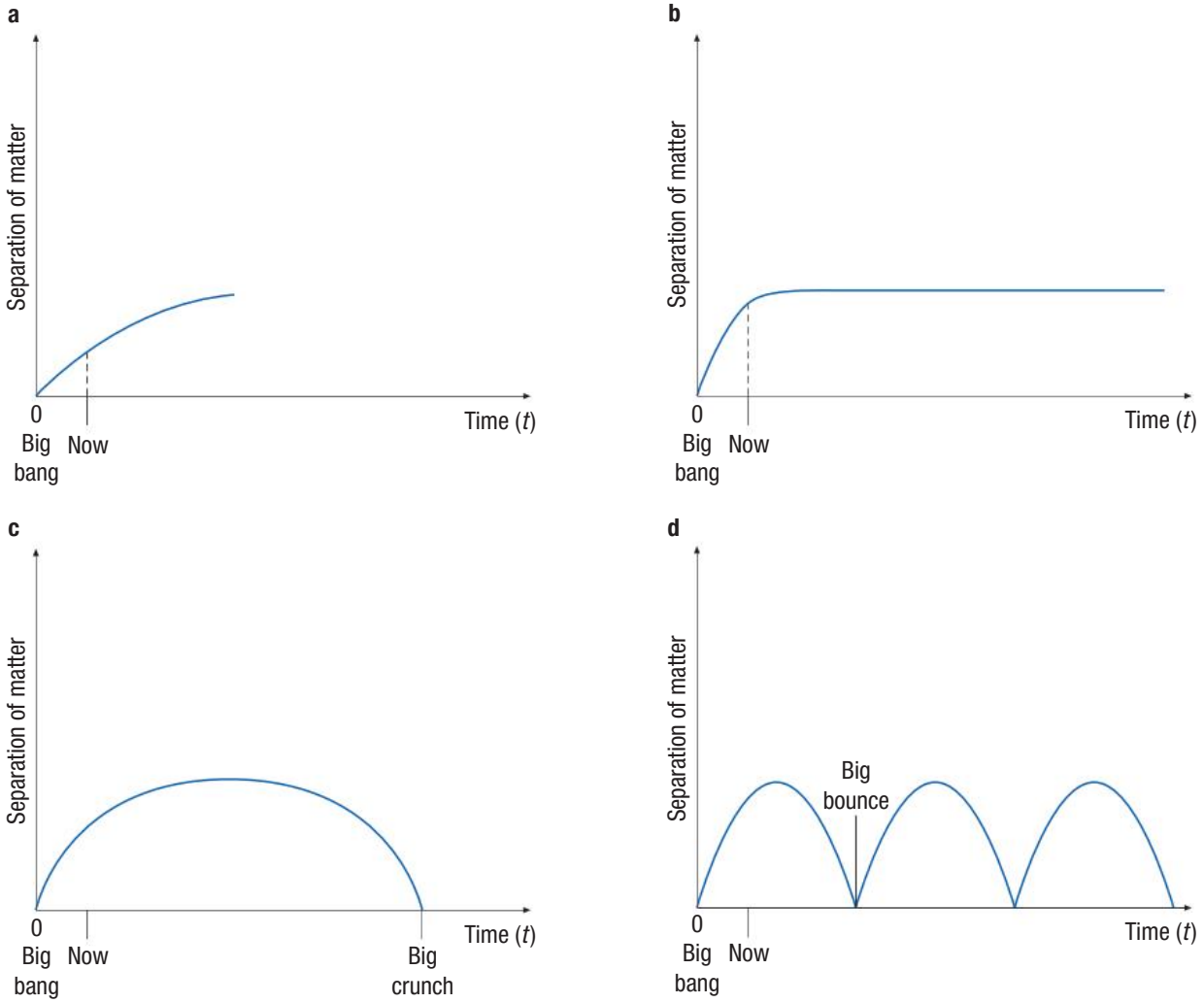


Figure 5.48 Possible fates of the universe: **a** continuous expansion, **b** steady state, **c** the big crunch and **d** the big bounce

ISBN 9780170189071

Unit review

ACTIVITY SHEET
Unit 5 checklist
SCI10SUAS00142

REVIEW QUIZ
Unit 5
SCI10SURQ00141

WORKSPACE
Unit 5 review
SCI10SUWR00143

Understand

1 What two main ideas have people used to explain what they see in the sky? Give an example of each.

2 What is the cosmological principle? How did Newton use it?

3 What does the big bang theory explain?

4 Define the term 'parallax'.

5 Sketch a Planck curve and state what it represents.

6 What is a main-sequence star?

7 Describe the difference between apparent magnitude and absolute magnitude.

8 How does cosmic background radiation occur?

Apply

9 Dark matter and gravitational matter affect the universe differently. Explain how.

10 Describe the first 3 minutes of the universe after cosmic inflation.

11 Show how deuterium ($^{2}_{1}H$) is produced by the fusion of a proton ($^{1}_{1}H$) and a neutron ($^{1}_{0}n$). Hence, show how ($^{4}_{2}He$) is formed.

12 A radar signal sent from Earth took 5.2 minutes to return from an object in space. How far away was the object?

13 An object has a parallax angle of 0.0006 arc second.

a Draw a diagram to represent this situation.

b State what the distance to the star is in:

i parsecs

ii light years.

14 A main-sequence star has an apparent magnitude of +2.5 and a surface temperature of 12000 K. How far away is it?

15 A Cepheid variable has a period of 3 days. Its apparent magnitude is +9.5. How far away is it?

16 What is a continuous spectrum from a star?

Analyse

17 Was there space before the big bang? Explain.

18 Why was it necessary for the temperature to fall before atoms could form?

ISBN 9780170189071

19 How are measurements of distances the same as, and different from, one another for main-sequence stars and Cepheid variables?

20 Why do 'local' stars show either a stellar redshift or a stellar blueshift? Why do far-away galaxies always show only a cosmic redshift?

21 Use the Doppler effect to explain redshift and blueshift.

Synthesise

22 Construct a timeline that shows the eras that occurred up until the formation of galaxies from the beginning of time.

23 On a diagram, show the range for which different measuring techniques can be used to find the distance to celestial objects.

Reflect

24 How has your understanding of the way the universe started and continues to expand changed?

25 What have you learnt about evidence and the big bang theory?

26 How has your understanding of the way measurements of astronomical distances are made changed?

ISBN 9780170189071

6

Global systems

How are modern humans affecting global systems?

Modern humans have been on the planet for at least the last 50 000 years. They have lived in increasingly larger groups and have been modifying their environment to sustain their increasingly complex lifestyle. Until the industrial revolution, most changes made were sustainable – the natural order of ecosystems was maintained and any disturbance was quickly absorbed, minimising long-term impact. So what has occurred in the last 200 years to tip the balance?

What do you already know about global systems?

Modern technological and medical advances have mostly impacted on population size. More people are able to survive and thrive and, in doing so, are encroaching more and more into the natural world. More forests are cleared, more industry is being established and more wastes are produced. One major area of concern is climate change. How much are the activities of humans responsible for the recent increase in the world's temperatures?

Activity 6.1
What do you already know about global systems?

WORKSPACE

What do you already know about global systems?

SCI10SUWR00144

For the table below, complete the first three columns now. The fourth column can be done at the end of the unit. Then complete the questions. (Hint: A value is something that a person believes is important.)

1 When the media reports on climate change, what five main values do you think they have in mind?

2 When scientists report on climate change, what five main values do you think they have in mind?

3 When you think about climate change, what five main values do you have in mind?

4 Create a bubble chart to represent the similarities and differences in the main values that different groups hold on the one issue.

5 Write a short paragraph explaining your bubble chart. Upload this to the class wiki.

WEB 2.0

You could create your bubble chart using Google Docs.

What I already know	What I want to know	How I can find out	What I have learnt

Culminating assessment task
Preparation for issue identification

This unit provides information on global systems, and the effects of human activities and natural cycles on these systems.

Your task is to gather information in the following areas:

- functioning and structure of the global spheres
- changes that have been observed in the global spheres over the last 100 years
- possible causes of these changes to the global spheres, such as:
  - natural
  - human-induced
- effects of these changes on:
  - natural systems, namely ecosystems
  - greenhouse emissions
  - biodiversity
  - your day-to-day living
- short-term impact of these changes:
  - effect on human activities
- long-term impact of these changes to:
  - biodiversity
  - human living and occupation of the planet

ISBN 9780170189071

- scientific evidence that supports the concept of global warming
- scientific evidence that does not support the concept of global warming.

With this information, work in a group of 2–3 students and prepare a letter, storyboard or a debate that outlines an agreed policy designed to limit the impact of any changes on global systems.

In addition, you will need to:

- research the name of your local member of parliament
- prepare your draft policy
- outline the process your draft policy needs to go through to reach discussion at the government level.

Your final presentation must be completed electronically. Discuss how you would like to do this with your teacher. Remember to reference all your work correctly.

WEB 2.0

For your presentation, you might choose to create a vodcast, animoto, movie, prezi or website.

ACTIVITY SHEET

Rubric: Preparation for issue identification

SCI10SUAS00145

Investigating how human activity affects global systems

When a butterfly flaps its wings in the forest on one side of the planet, catastrophic events can occur on the other side – or so the story goes. How much truth is there to this?

The Earth is a system with inputs, processing and outputs. It is a global system linking four different spheres of planet Earth together: lithosphere, biosphere, hydrosphere and atmosphere. Each sphere contributes to the overall functioning of the planet.

The lithosphere includes the Earth's crust (Figure 6.1). It is hard and brittle, and exposed to all climatic conditions. Beneath the crust lies the hot, liquid mantle and the solid and semi-solid core at the centre. The lithosphere includes all the rocks and solid structures on which life exists.

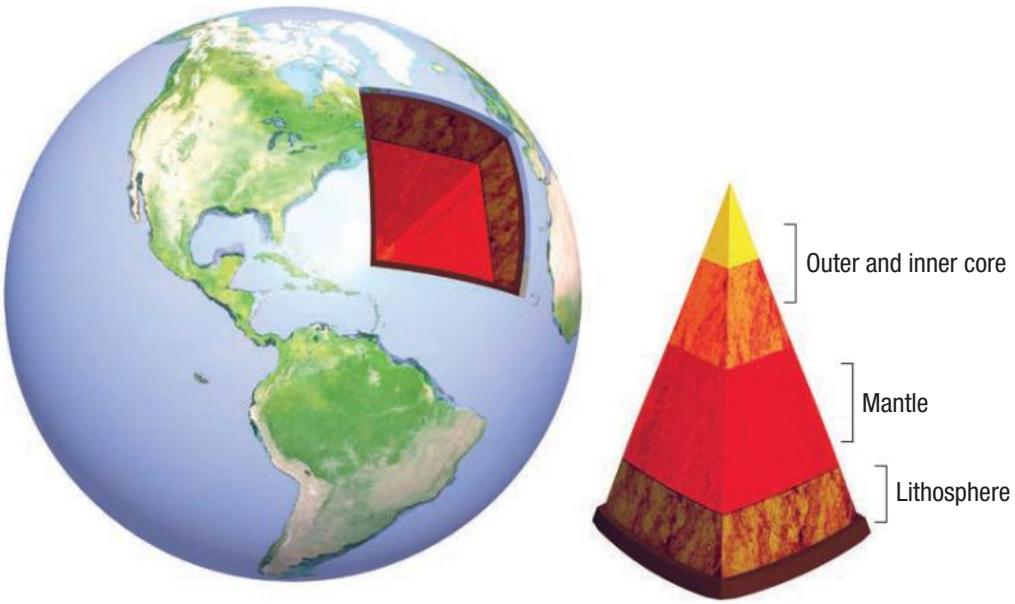


Figure 6.1 Cross-section through the Earth, with lithosphere as the outer layer and the mantle and core beneath

glossary term

lithosphere
the outer part of the Earth, consisting of the crust and upper mantle, approximately 100 km thick

ISBN 9780170189071

The biosphere contains all the planet's living organisms (Figure 6.2). From bacteria to the mountain ash forests of Australia, from plankton to the blue whale in the vast oceans of the planet – life is found in many environments.

The hydrosphere encompasses all forms of water: solid ice on the polar caps; liquid water in oceans, streams, rivers and lakes; and gaseous vapour in clouds and spewing from geysers into the atmosphere (Figure 6.3). The atmosphere contains all the gases that make up the Earth's air, which is used to maintain life. The biosphere overlaps into parts of both the hydrosphere and atmosphere.

Figure 6.2 The biosphere includes agricultural areas seen here, with surrounding atmosphere.

Activity 6.2
Mapping the global spheres

1 Use a visual means to show your understanding of how the four global spheres interlink. Compare your understanding with that of another student. What are the similarities and differences?

WEB 2.0

Using the Google Draw function of Google Docs, work with two others to prepare your visual presentation.

2 Create your own definition for each of the spheres that a primary-age student would understand.

An event in one of these spheres has the potential to impact on all the others. Natural disasters over the years have been clear demonstrations of this, such as the earthquake and tsunami that hit the east coast of Japan on 11 March 2011 (Figure 6.4). A shifting of the tectonic plates in the lithosphere resulted in the generation of the tsunami (hydrosphere) that devastated coastal regions and wiped out many human and natural habitats (biosphere). The location of the nuclear reactor near the coast led to the release of radioactive material into the atmosphere. Radioactive materials reached the upper layers of the atmosphere and circulated via the air movement; any material that entered waterways was spread into the hydrosphere, eventually reaching the oceans.

Figure 6.3 Freshwater aspects of the hydrosphere include features such as Niagara Falls, USA.

Figure 6.4 The tsunami inundating coastal Japan in March 2011

ISBN 9780170189071

The death toll from the Japanese disaster was high; however, without the advance warning of the impending tsunami, the toll could have been much greater. Warnings from meteorological bureaus and seismologists allowed governments across many nations to issue warnings that assisted with the evacuation of residents in many coastal towns and cities.

It does not have to always be a catastrophic event that links these spheres. Birds fly through the air and drink at a lake that has formed in a depression on an island. Oil spilt from a ship into the ocean greatly affects wildlife dependent on the sea and coastline for their survival (Figure 6.5). The clearing of forests in the Amazon Basin for the latest expansion of human settlement or to provide increased agricultural production also impacts on more than one sphere. All these examples show that the four spheres are linked.

Figure 6.5 A bird caught in an oil spill – the impact of an industrial accident in the hydrosphere impacting negatively on the biosphere

Activity 6.3
Advanced warnings

WORKSPACE

Advanced warnings

SCI10SIWR00146

In what ways are advanced warnings of disasters communicated to the public? What do you think is the best way to communicate advanced warnings quickly? Explain why.

Consider all the relevant factors when thinking about how you would communicate; for example, the purpose of the warning and what effect this might have on your warning system.

The carbon cycle

In Unit 9 of *Nelson iScience 7* you learnt about the water cycle. Its pathway through the various global spheres can be easily traced. The carbon cycle maps out the pathway of carbon through the spheres (Figure 6.6 on page 188). Its travel through the biosphere and atmosphere can be readily seen, but what about the lithosphere and hydrosphere?

glossary terms

atmosphere
the gaseous mass or 'envelope' surrounding the Earth and retained by the Earth's gravitational field

biosphere
the part of the Earth and its atmosphere in which living organisms exist or that is capable of supporting life

carbon cycle
the combined processes – including photosynthesis, decomposition and respiration – by which carbon as a component of various compounds cycles between its major reservoirs: the atmosphere, oceans and living organisms

earthquake
a sudden movement of the Earth's crust caused by the release of stress accumulated along geologic faults or by volcanic activity

hydrosphere
the waters of the Earth's surface in solid, liquid and gaseous forms

meteorological bureau
a government agency responsible for providing weather information to the community

nuclear reactor
any of several devices in which a chain reaction is initiated and controlled, with the resulting heat typically used for power generation

seismologist
a scientist who studies earthquakes

tsunami
a very large ocean wave caused by an underwater earthquake or volcanic eruption

water cycle
the cycle of evaporation and condensation that controls the distribution of the Earth's water as it evaporates from bodies of water and then condenses, precipitates and returns to those bodies of water

ISBN 9780170189071

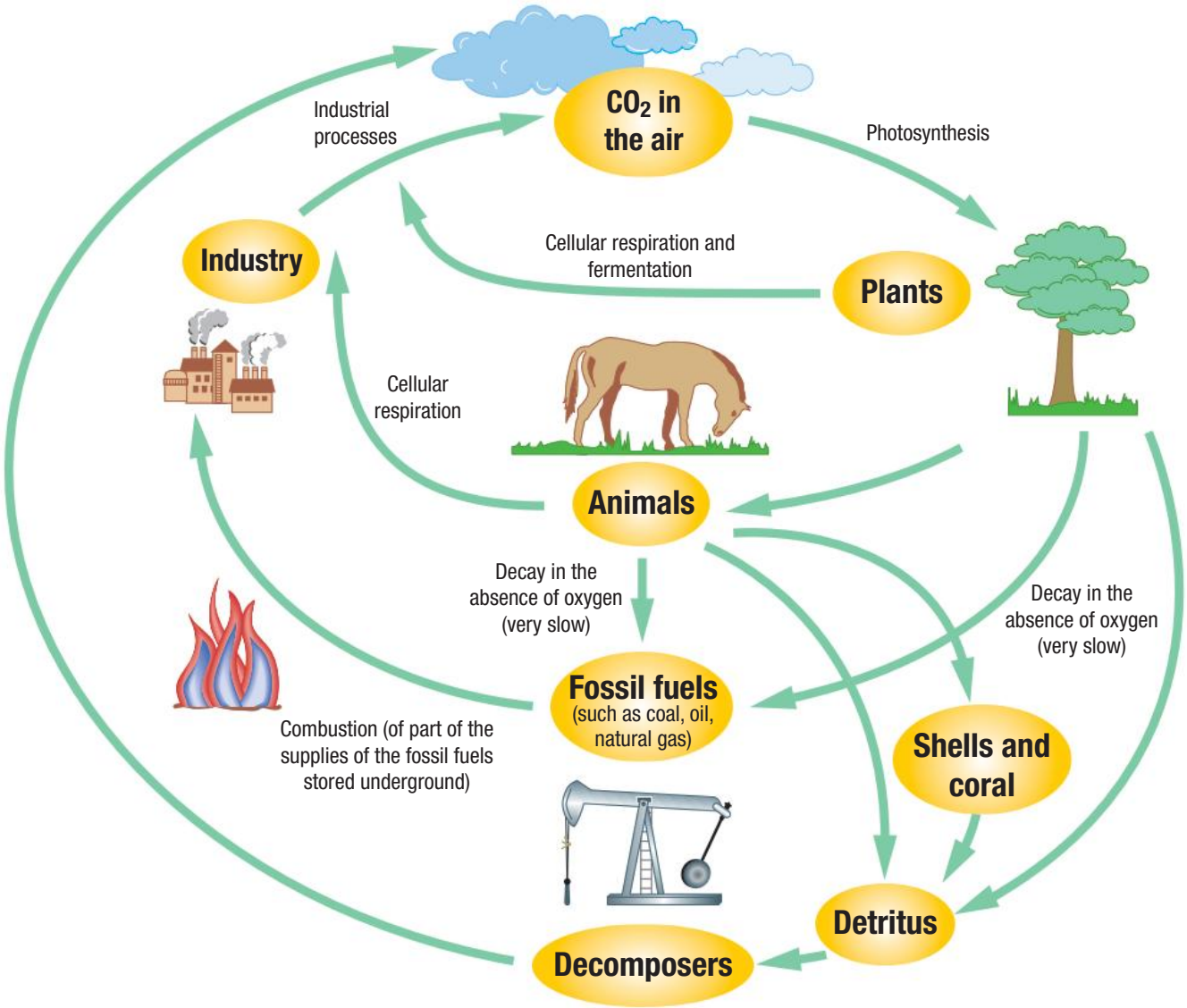


Figure 6.6 The carbon cycle

The largest source of carbon on Earth is the carbon dioxide (CO_2) in the atmosphere. It enters the biosphere through plants via the process of photosynthesis. The carbon-containing simple sugar glucose ($C_6H_{12}O_6$) is produced as a result. As plants are the primary producers in all food chains, carbon passes through and is incorporated into all the major biochemical groups, including carbohydrates, proteins, lipids and nucleic acids. All these groups make up various aspects of all living things, from the single-celled to complex multicellular, multisystem organisms.

In some situations, carbon stays within the organism briefly and is released back into the environment via cellular respiration. At other times, it is incorporated into a cell's structure, such as in the lipid membrane of a cell of a frog. Its time within the living system is extended for the life of the organism. Yet again, carbon can become incorporated into the structure of living organisms, such as a tree. In this case, the carbon is not released back into the atmosphere until the wood is used to light a fire or the tree dies and decomposes. Even longer still, the tree may become fossilised. The carbon is therefore taken out of circulation for millions of years and re-released into the atmosphere when fossil fuels undergo combustion.

WOW!

Storing carbon

The world's forests store 283 billion tonnes of carbon dioxide presently. Twenty per cent of all carbon dioxide emissions generated by humans are caused by deforestation. The current rate of global deforestation is about 13 million hectares a year, which is an area equal to the size of England. How long would it take to clear an area the size of Australia?

ISBN 9780170189071

Humans' breathing releases carbon dioxide into the atmosphere, and the digestive waste of cows releases methane (CH_4). As we burn fuel, whether in our individual bodies or in machines we use to move around, we contribute to the release of carbon dioxide into the atmosphere.

Before the great expansion in the human population following the industrial revolution, the recycling abilities of plants to absorb carbon dioxide and release oxygen back into the atmosphere kept the carbon in balance. As we find more ways to release carbon dioxide gas into the air, we are increasing the ratio. As the population expands, we need places to live and to streamline the production of our food. All of these factors require land space, which was once taken up by trees, forests and even swamps. The common trait shared by the forests and swamps is the abundance of plant life that recycles carbon dioxide back into the biosphere from the atmosphere.

What happens to all the carbon dioxide being released? Plants are highly efficient at photosynthesising when given all the right conditions, so why do they not recycle it all? Animals have always breathed out carbon dioxide, and we have always burned wood to cook and keep warm. What has changed?

ANIMATION
The carbon cycle
SCI10SUAN00147

VIDEO
Threat to Southern Ocean
SCI10SUVD00148

Generating electricity

The start of the industrial revolution in the 1790s saw the advent of the use of machinery in industry and agriculture, as well as an increase of carbon dioxide emissions into the environment (Figure 6.7). Fossil fuels were needed to drive the machinery and generate electricity, and so they added significantly to the amount of carbon dioxide entering the atmosphere. While the generation of electricity has been refined over the decades, the scale on which it has been produced has increased rapidly. Little attention was given to the wastes of industry and where they ended up. So how exactly does electricity contribute to the imbalance in the carbon cycle?

Figure 6.7 A coal-fired power station emitting carbon dioxide into the environment

glossary terms

carbohydrate
an organic compound that includes sugars, starches, celluloses and gums and that serves as a major energy source in the diet of animals; they are produced by photosynthetic plants and contain only carbon, hydrogen and oxygen

carbon dioxide
a colourless, odourless, incombustible gas (CO_2) formed during respiration, combustion and organic decomposition

cellular respiration
the process of cell metabolism in which cells release usable energy from stored nutrients

lipid
an organic compound – including fats, oils, waxes, sterols and triglycerides – that is insoluble in water, oily to the touch and constitutes the principal structural material of living cells

nucleic acid
a complex compound found in all living cells and viruses and, when in the form of DNA and RNA, controls cellular function and heredity

photosynthesis
the process in green plants and certain other organisms by which carbohydrates are synthesised from carbon dioxide and water using light as an energy source; most forms of photosynthesis release oxygen as a by-product

protein
a complex organic macromolecule that contains carbon, hydrogen, oxygen, nitrogen and usually sulfur, and is composed of one or more chains of amino acids; proteins are the fundamental components of all living cells

ISBN 9780170189071

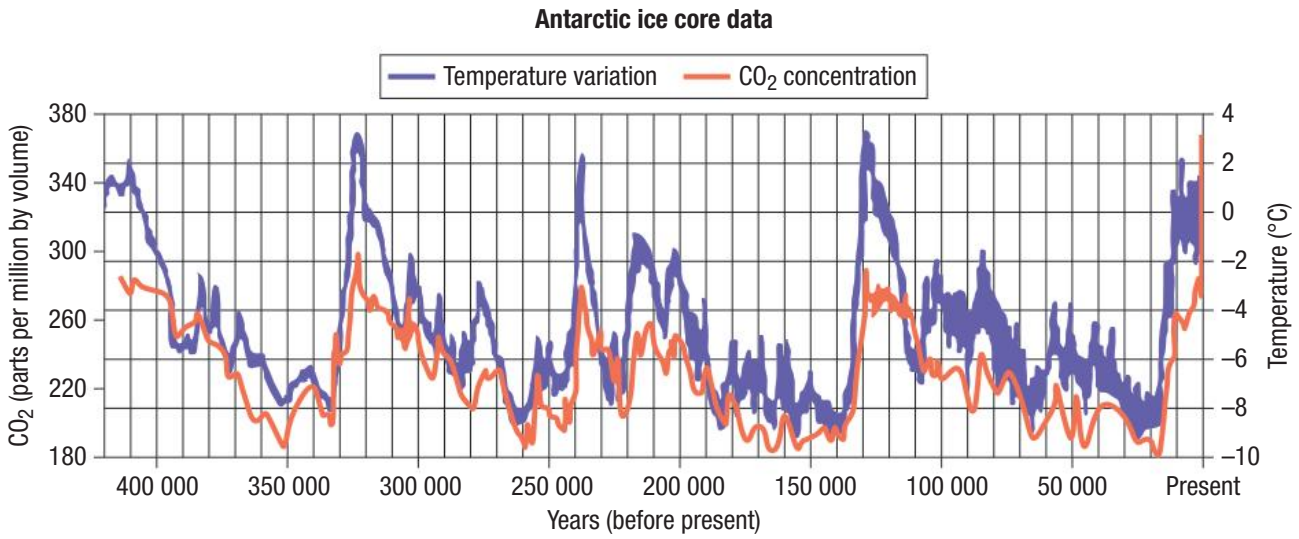


Figure 6.8 Carbon dioxide in ice cores from 400 000 years ago to the present, showing the relationship between carbon dioxide levels and temperature

There are various stages during electricity generation at a coal-fired power station in which a range of pollutants are released; the pollutants are mostly carbon-based. When coal is burnt to generate thermal energy that heats water to produce steam, carbon dioxide, soot and ash are released into the atmosphere. Cooling water releases heat into the atmosphere that cannot escape as the carbon dioxide builds up. As we clear land, the number of carbon-cycling trees is reduced. So as more carbon dioxide is released, less can be recycled through the natural process of photosynthesis.

Initially, the release of carbon dioxide into the atmosphere had little impact. The human population was smaller and industry was on a much smaller scale than modern levels. Even so, harm was done. It was not until the 1980s that damage to the Black Forest in Germany and the effects of acid rain were recorded (Figures 6.9 and 6.10). At the same time, other signs were reported when reduced reproduction in many tree species was observed across the United States and Europe. The water pollution of the Yarra River in Melbourne in the form of solid waste, heated water or chemical spillage was investigated and attempts to rectify it were undertaken in the late 1980s.

Carbon capture

Figure 6.8 shows the concentrations of carbon dioxide in ice cores from 400 000 years ago to the present. A relationship is evident between increasing temperatures and carbon-dioxide concentrations – that is, when one increases, so does the other. The ice cores and their carbon dioxide concentrations therefore represent a snapshot of conditions throughout geological time.

Activity 6.4
Think, pair, share

WORKSPACE
Think, pair, share
SCI10SUWR00149

1 On your own, **think** of as many ways as possible that electricity contributes to the imbalance in the carbon cycle.

2 **Pair** up with a classmate, combine your lists and add new ideas.

3 **Share** your combined list with another pair of students and combine your lists. Upload the combined list to the class wiki.

Figure 6.9 The defoliation (loss of leaves) caused by acid rain leads to the death of trees as they are no longer able to photosynthesise.

ISBN 9780170189071

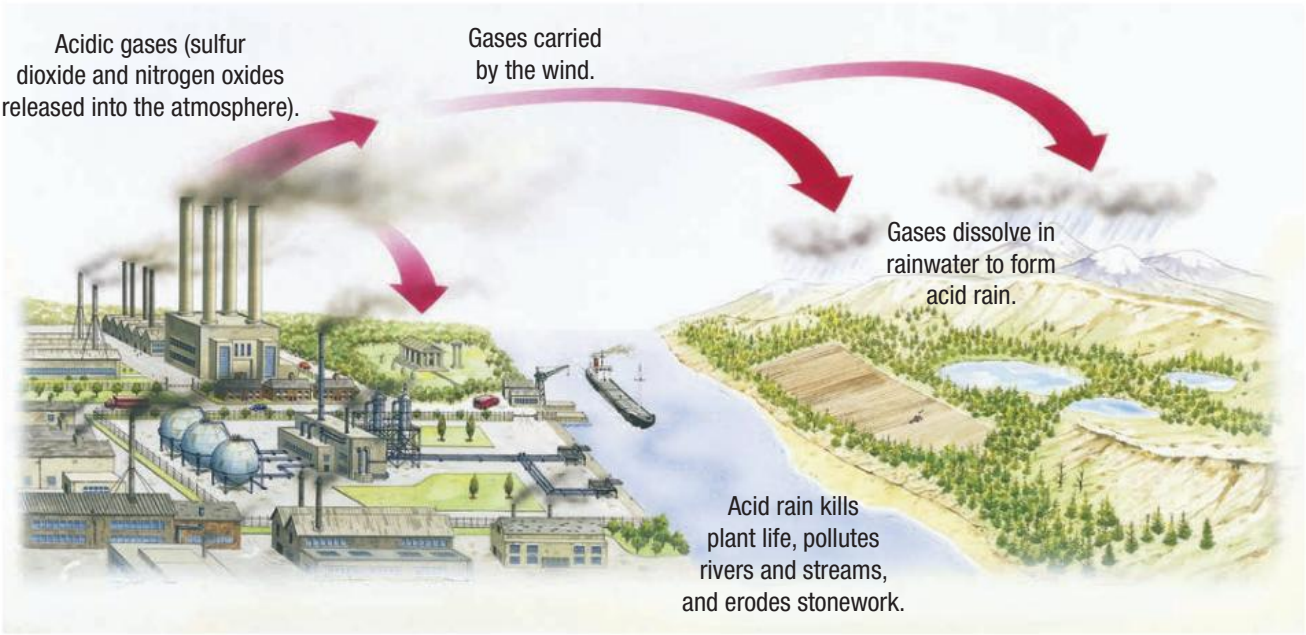


Figure 6.10 The release of pollutants into the atmosphere gives rise to acid rain, which then impacts on living organisms. Acid gases (sulfur dioxide and nitrogen oxides) are released into the atmosphere.

WOW!

Burning ban

King Edward I of England banned the burning of sea coal by proclamation in London in 1272 after its smoke had become a problem.

A number of measures have been considered to reduce the release of carbon dioxide and other pollutants into the atmosphere. It is not the burning of wood (which is carbon neutral) that adds carbon dioxide to the atmosphere, but the burning of fossil fuels that have stored carbon for millions of years. Its reintroduction into the carbon cycle leads to the atmospheric imbalance. Therefore, the removal of excess amounts would seem an appropriate measure. One such method is described as carbon capture. This involves trapping the carbon at its emission point, containing it and transporting it to a long-term storage facility underground.

Currently, most carbon-capture technology is focused on fossil-fuel-driven power stations. Power stations burn fuel, such as coal or gas, to provide the energy to convert water into steam. The steam ultimately turns a turbine that is connected to a generator to produce electricity. These power stations are one of the largest sources of carbon released into the atmosphere. Essentially, the process involves the removal of carbon dioxide from the power plants' waste before it is released into the atmosphere. The carbon needs to be captured either before the fossil fuel is burned or after.

In pre-combustion carbon capture, carbon dioxide is trapped before the fossil fuel is burned (Figure 6.11 on page 192). The process consists of three stages:

1. The fuel (methane or coal) is converted into hydrogen and carbon monoxide to form a gas.
2. The carbon monoxide reacts with water to produce carbon dioxide.
3. The carbon dioxide is separated from the hydrogen (which is combusted cleanly), compressed into a liquid and transported to a storage site.

Pre-combustion capture has an 80–90% success rate. This procedure is currently employed to remove carbon dioxide from natural gas.

glossary terms

carbon capture
the process of capturing carbon dioxide from large point sources, such as fossil-fuel power plants, and storing it in such a way that it does not enter the atmosphere

pollutant
any contaminant introduced into a natural environment that causes instability, disorder, harm or discomfort to the ecosystem – that is, to physical systems or living organisms

pre-combustion carbon capture
the process in which carbon dioxide is trapped before the fossil fuel is burned

ISBN 9780170189071

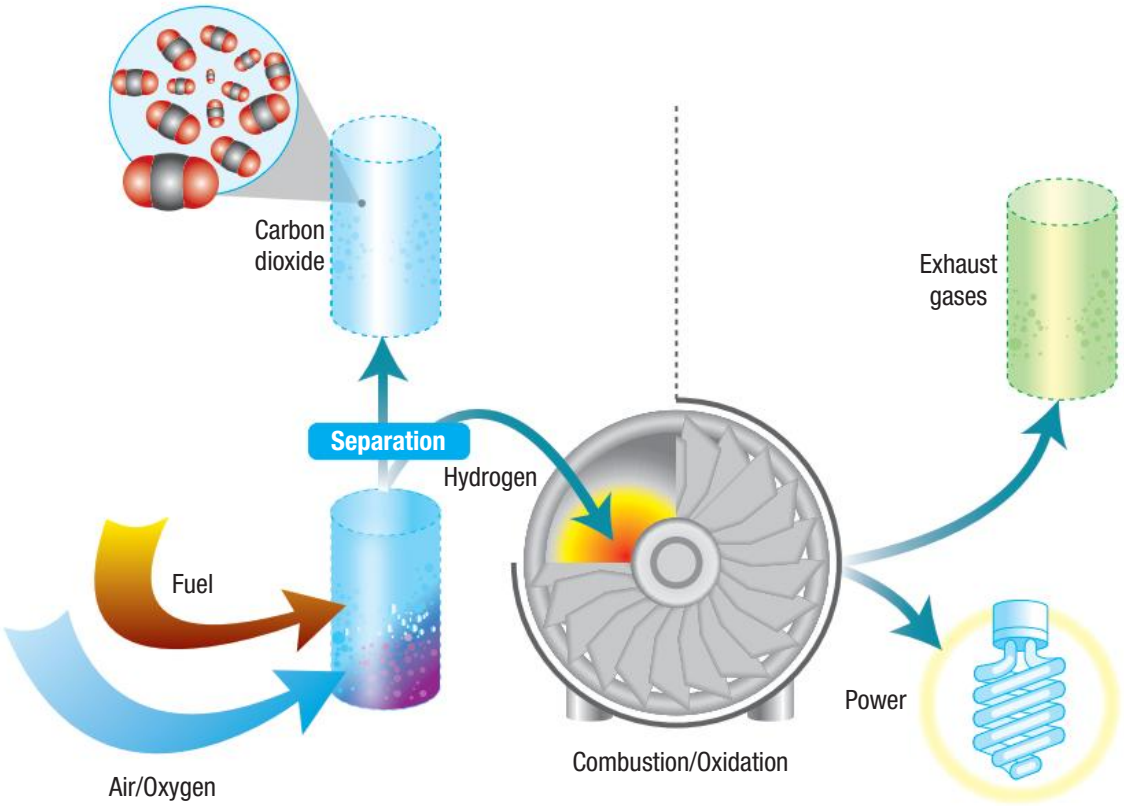


Figure 6.11 Pre-combustion carbon capture – the removal of carbon (as carbon dioxide) from fuel prior to combustion in the power plant, to leave hydrogen, which is burnt to produce power

Activity 6.5
Catalytic converters

WORKSPACE
Catalytic converters
SCI10SHWR00150

Find out what a catalytic converter is. Why were they introduced into the automotive industry? When did they first appear in cars? Which pollutants does an engine produce, and how does the catalytic converter deal with each of these to help reduce vehicle emissions?

ANIMATION
Carbon capture
SCI10SUAN00151

Investigation 6.1
What is your carbon footprint?

Use the Internet to complete the following.

1 Define 'carbon footprint'.
2 Calculate your own and your family's carbon footprint.
3 Find ways to reduce your footprint over one week and compare them with those of your classmates.
4 Present your findings as a digital poster using Glogster.

WEB 2.0

Create a short movie or create a voki that could be run as an advertisement to raise awareness of six things that every household could do to reduce their carbon footprint. Share this with the rest of the class on the class wiki.

In post-combustion carbon capture, the carbon dioxide is separated via a filter from other waste products of the combustion process as it travels up the smoke stack (Figure 6.12). The filter is a solvent that absorbs the carbon dioxide. The process can also prevent 80–90% of the emissions reaching the atmosphere; however, it is costly to then compact and prepare the carbon dioxide for storage. The advantage of this process is that the filter can be fitted to older power plants with a very good success rate.

In effect, power plants that employ post-combustion carbon capture are attempting to reduce their carbon footprint.

ISBN 9780170189071

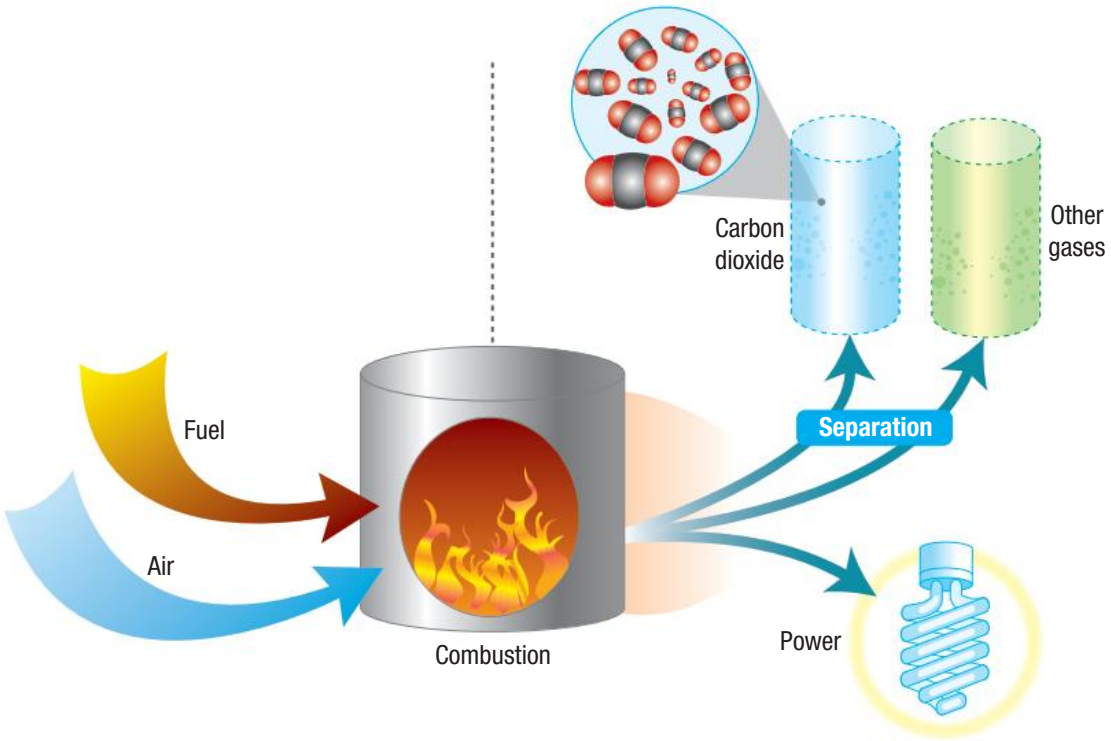


Figure 6.12 Post-combustion carbon capture – the combustion of fuel produces waste products, including carbon. The carbon is removed from the waste.

Questions 6.1
What have you learnt?

WORKSPACE
What have you learnt? 6.1
SCI10SUWR00152

Understand

1 List the four spheres that make up the Earth. What comprises each sphere?

Apply

2 Into which of the spheres do the following belong?
- **a** Clouds over the Pacific Ocean
- **b** Rabbit burrows in Victorian farmland
- **c** Ord River Dam in Western Australia
- **d** Blue Lake, Mount Gambier

3 Explain how the carbon cycle is able to be identified in each of the four spheres listed in Question **1**.

4 How does photosynthesis fit into the carbon cycle? Why is this so important to the living organisms of the planet?

5 What are the advantages of each carbon-capture technique?

Analyse

6 Complete a five whys with the starting question: 'Why would a butterfly flapping its wings on one side of the planet influence a catastrophic event on the other side?'

glossary terms

carbon footprint
the amount of carbon dioxide emitted by a person, organisation or event

post-combustion carbon capture
the process in which carbon dioxide is separated from other waste products of the combustion process before they are released into the environment

ISBN 9780170189071

Synthesise

7 Use a graphic organiser of your choice to organise the content that you have learnt so far. Revisit this organiser throughout the unit to add, edit and connect information as you gain more knowledge.

Reflect

8 What is something that you do each year that would have an effect on the spheres? Record this on your blog.

9 How do you think the carbon cycle can be influenced by the carbon-capture strategies described in the unit?

Greenhouse effect: causes and effects

The term 'greenhouse effect' has been part of our vocabulary for many years. What exactly is it? The answer is not as straightforward as you might think.

Activity 6.6
The greenhouse effect

Work in a group to brainstorm all your thoughts about what the greenhouse effect is. Use SmartDraw to create a cluster diagram. Store this on the class wiki and add or remove from it as you read on.

INTERACTIVE
Greenhouse effect self-check quiz
SCI10SUIN00153

The greenhouse effect has been around for as long as life on Earth. High-energy short-wave radiation emitted by the Sun passes through the atmosphere. About 50% of this radiation hits the Earth's surface and heats it. About 50% of this radiation is reflected back into space, mainly off clouds. A blanket of greenhouse gases around the Earth absorbs and emits this radiation, ensuring the planet stays at a regular temperature. If there was no carbon dioxide, the Earth's surface temperature would be around –30°C, which is too cold to sustain life.

Gases that absorb heat in the atmosphere are known as greenhouse gases. Apart from atmospheric water vapour, four main gases act in this way: carbon dioxide, methane, nitrous oxide and fluorinated gases. Water vapour is often disregarded as a greenhouse gas, but it is one of the most important; ozone is also considered to be a minor greenhouse gas.

Three of the four gases are directly derived from the burning of fossil fuels; there are also other sources, however. For example, livestock and the decay of organic matter generate methane. Nitrous oxide is emitted as a result of agricultural practices. The fluorinated gases are produced as a result of industrial practices and are used in place of ozone-depleting gases, such as chlorofluorocarbons (CFCs) and halons.

INTERACTIVE
Greenhouse effect
SCI10SUIN00153

Activity 6.7
Greenhouse effect in a jar

WORKSPACE
Greenhouse effect in a jar
SCI10SIWR00154

With a partner, complete the following practical exercise. Present your findings as a formal scientific report (see appendix, page 283). After reading through this activity:

- Write an aim and hypothesis.
- Identify the dependent and independent variables and the control.
- Predict what you think the results will be.

Materials

- 2 thermometers, or data logger and probes
- stopwatch
- 2 L plastic drink bottle with the bottom cut out so that it sits flat

Method

1 Go outside and place the two thermometers directly in sunlight for 5 minutes. Let the temperatures stabilise.

ISBN 9780170189071

2 Cover the first thermometer with the plastic bottle and start recording the temperatures from both thermometers every minute for 20 minutes.

Results

1 Graph the results on the one set of axes.

2 Did your results agree with your prediction?

Discussion

3 How do you explain your results? You may need to convert your results into percentages so that they can be compared more easily.

4 How did this model compare with the greenhouse effect in our atmosphere?

5 Were there any sources of error in your data or data collection techniques? How could you improve on your method?

Conclusion

6 Refer back to the aim. Write a conclusion to this activity. Was your hypothesis supported or disproved?

Extension

7 Research the role of high- and low-energy radiation in the greenhouse effect.

How do gases trap heat in the atmosphere?

Scientists describe two types of greenhouse effect. The first is the 'natural' greenhouse effect that ensures the temperature of the Earth is such that living things can survive. The second looks at the effect humans have had on this natural warming of the Earth's surface through various activities that have been undertaken over the last century.

To understand the greenhouse effect, we must first look at radiation from the Sun (Figure 6.13). Energy from the Sun

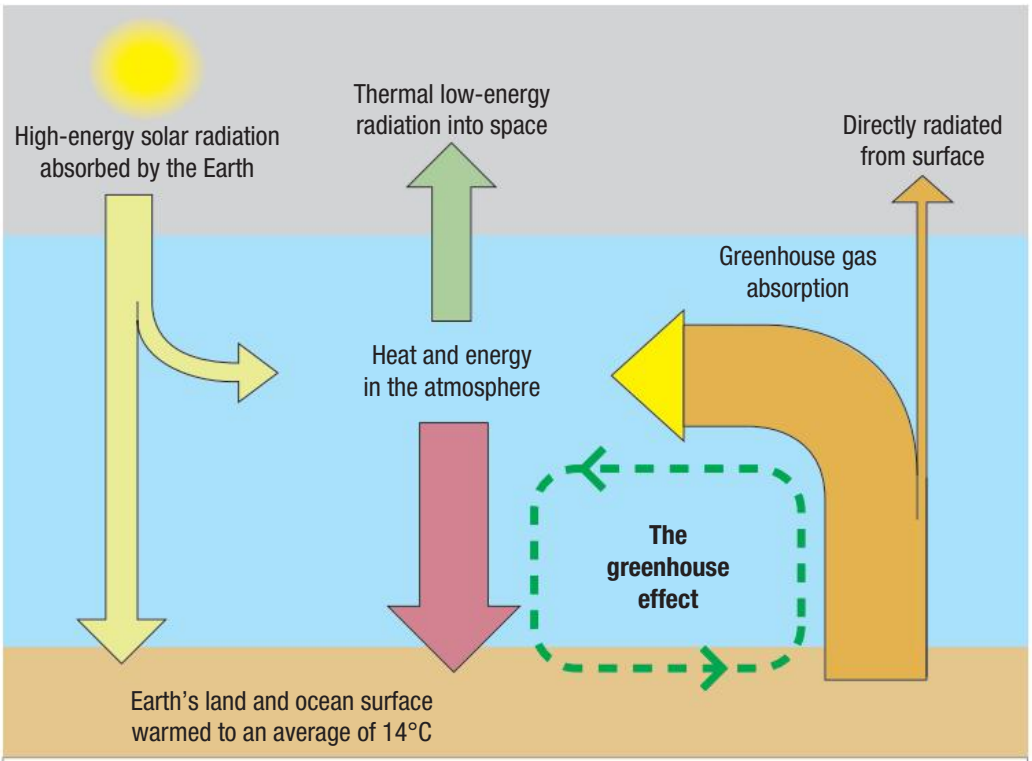


Figure 6.13 How the greenhouse effect is generated: high-energy solar radiation reaches the Earth's surface and is absorbed and re-radiated as low-energy radiation that is unable to penetrate the atmosphere, leading to increased surface temperatures.

glossary terms

chlorofluorocarbon
an organic compound that only contains carbon, chlorine, fluorine and hydrogen; formerly used as a refrigerant and as a propellant in aerosol cans, the chlorine in CFCs causes depletion of atmospheric ozone

greenhouse gas
an atmospheric gas that contributes to the greenhouse effect by absorbing infrared radiation produced by solar warming of the Earth's surface

ISBN 9780170189071

enters the Earth's atmosphere as high-energy radiation – that is, short wavelength, high frequency. It is absorbed by the Earth's surface and then re-radiated as thermal energy. Thermal energy is described as low-energy radiation – long wavelength, low frequency – and has difficulty penetrating the Earth's atmosphere. It is not radiated away from the surface easily, and most is reflected back to the surface.

The atmosphere forms a blanket around the Earth that limits the escape of the thermal energy. Certain gases that make up the lower atmosphere restrict the exit of this thermal energy further. This results in a rise in the temperature of the Earth's surface, creating a greenhouse effect. Greenhouse gases are generated by many living things – increasingly, over the last 50 years, by human activities. This phenomenon is now known as global warming. We will look at the impact of this temperature increase in detail later in this unit.

Depletion of the ozone layer

Some people confuse the greenhouse effect with the ozone hole as if they are the same thing – they are not. Ozone is one of several gases found in the Earth's atmosphere at 15–30 km above the Earth's surface (Figure 6.14). It is also found at ground level, where it is a component of smog. The major role of ozone is to absorb UVB radiation before it enters the Earth's atmosphere. Human activity is causing depletion to the protective layer of ozone. Studies have shown that UVB radiation has many harmful effects, especially to mammals; for example, it is a major cause of skin cancer. Even though the ozone layer is about 50 km thick, significant depletion has been measured.

That's not very thick!

If the ozone layer was compressed by sea-level pressures, it would only be about 3 mm thick.

Ozone is a highly reactive chemical. It reacts with synthetic substances that contain chlorine, fluorine, bromine, carbon and hydrogen. As substances containing these elements are released into the atmosphere, they break down atmospheric ozone, depleting the layer.

As mentioned previously, compounds with chlorine, fluorine and carbon are called CFCs, which were once mainly used as refrigerants and aerosol propellants. The discovery of their relationship to the destruction of the ozone layer led to the Nobel Prize in Chemistry for Paul J. Crutzen (Netherlands), Mario J. Molina (Mexico) and F. Sherwood Rowland (USA) in 1995 and a worldwide ban on their use.

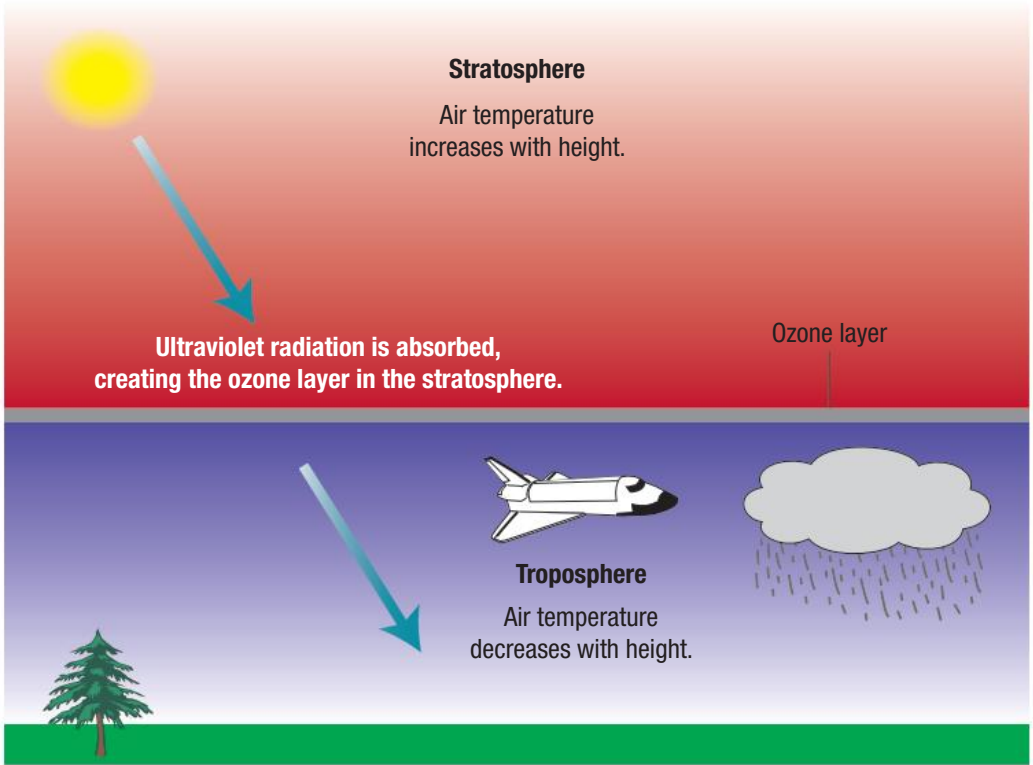


Figure 6.14 The upper atmosphere (the stratosphere) is separated from the lower atmosphere (the troposphere) by the ozone layer.

ISBN 9780170189071

CONNECTION
Literacy: Nobel Prize
SCI10SHCN00155

Depletion of the ozone layer over Antarctica has been detected. Figure 6.15 shows the increasing size of the ozone hole from 1981 to 1999. Measurements of the ozone layer begun in 1956 by the CSIRO, in collaboration with the Bureau of Meteorology, in Melbourne; however, this work was transferred entirely to the bureau in 1982. The largest measurements were recorded in the late 1980s and early 1990s. The latest readings indicate that the size of the ozone hole is 26 million square kilometres, which is three times the area of Australia.

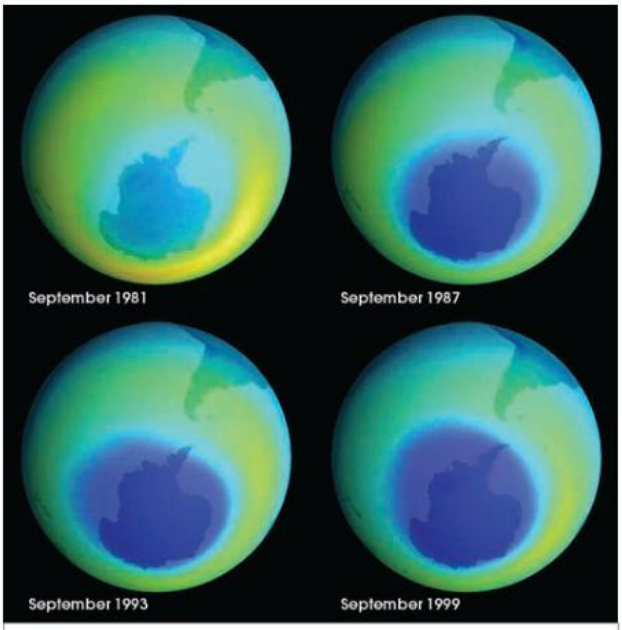


Figure 6.15 These images show the increasing size of the ozone hole over Antarctica from 1981 to 1999.

Fortunately, the size of the ozone hole has stabilised due in some part to the reduction in the use of CFCs across many nations. As more information comes to light regarding the role of the ozone layer, the stabilisation of the size of the ozone hole goes some way in ensuring the protection of the biosphere inhabitants from the effects of UVB radiation.

Student research task
Where to live in Australia

1 Use a variety of sources to create a list of Australian locations at which you would be exposed to high levels of UVB radiation due to ozone depletion during the months of:
   - March
   - June
   - September
   - December.

   Show these locations using Google Earth.

2 Explain your choices, and present your findings using a digital presentation of your choice.

WEBLINK
Ozone depletion

WEBLINK
Bureau of Meteorology

WEBLINK
Ozone layer on the mend

WEBLINK
An Olympic-sized ozone hole

glossary terms

global warming
an increase in the average temperature of the Earth's atmosphere, especially a sustained increase sufficient to cause climatic change

ozone
an unstable form of oxygen (O_3) that is formed naturally in the ozone layer from atmospheric oxygen by electrical discharge or exposure to ultraviolet radiation; it is also produced in the lower atmosphere by the photochemical reaction of certain pollutants

smog
fog that has become mixed and polluted with smoke

UVB radiation
ultraviolet light, or the ultraviolet part of the electromagnetic spectrum

ISBN 9780170189071

Questions 6.2

What have you learnt?

WORKSPACE

What have you learnt? 6.2

SCI10SUWR00156

Understand

1 Explain the greenhouse effect.

2 What are the most common greenhouse gases? What are their sources?

3 **a** Explain how the hole in the ozone layer occurred.

b How is the hole affecting life on Earth?

Apply

4 Some people confuse the greenhouse effect with the ozone hole. What would you say to these people to clear up this confusion? Are the two related?

5 Use diagrams to explain why the greenhouse effect occurs. Why is it important to life on Earth?

6 State whether the following are greenhouse gases or not. Justify each answer.

a Steam from a shower

b Exhaust fumes from a car

c Steam and odour from a compost heap

d Smoke out of a chimney from an open fireplace

Synthesise

7 Create a pamphlet to alert people to which of their activities increase greenhouse gases in the atmosphere. Explain the consequences of their actions and provide alternative activities that they could undertake.

8 Revisit your organiser to add, edit and connect information.

Reflect

9 Justify or refute this statement: 'Australians need to be concerned about ozone depletion.'

What is climate change?

Climate is defined as the season-to-season or year-to-year variability in temperature and precipitation over a region for a period of 30 years. Day-to-day changes are described as weather.

According to the Australian Government Bureau of Meteorology:

> Australia and the globe are experiencing rapid climate change. Since the middle of the 20th century, Australian temperatures have, on average, risen by about 1°C with an increase in the frequency of heatwaves and a decrease in the numbers of frosts and cold days. Rainfall patterns have also changed – the northwest has seen an increase in rainfall over the last 50 years while much of eastern Australia and the far southwest have experienced a decline.

© Copyright Commonwealth of Australia 2011, Bureau of Meteorology (ABN 92 637 533 532).

ACTIVITY SHEET

Indicators of global warming

SCI10SUAS00157

Scientists predict that, over the next two to three decades, climate change due to global warming will see higher death rates from heatwaves, floods and droughts. Diseases such as malaria and dengue fever, which are traditionally found in human populations in tropical areas such as equatorial African countries, will spread to Europe. Temperature rises of 4–5°C are expected to lead to increases in other health problems, such as malnutrition, diarrhoea and cardio-respiratory and infectious diseases. As the precipitation rate decreases in dry areas, farming productivity will drop, resulting in crop failures, food shortages and famines in India, South-East Asia and Africa.

Climate is one factor that determines what species live where; furthermore, it plays a key role in where plants and animals live, feed and reproduce. If climatic conditions change, the needs of some organisms will no longer be met. They will either move from that location or eventually face extinction.

Another significant aspect of climate change – and this is included in some definitions – is that its cause may be from natural processes, such as the greenhouse effect. The natural greenhouse effect sustains life on Earth. However, human increases to the greenhouse gases upset the fine-tuned balance and can affect the whole system, leading to climate change. Human activities have led to increased greenhouse gases, which have in turn led to an increase in

ISBN 9780170189071

the thickness of the atmospheric blanket that retains this additional heat energy. The predominant human activity is the burning of fossil fuels.

To develop a global and consistent body of information regarding global warming, an Intergovernmental Panel on Climate Change (IPCC) was established in 1988. It gathered information from many scientific bodies and drew conclusions about the state of the Earth's warming. In 2007, these conclusions were:

- Warming of the climate is occurring.
- Most of the observed increases in temperatures since the mid-20th century result from human activities increasing the emission of greenhouse gases.
- Human-related warming and sea-level rises will continue for centuries.
- The chances of this warming occurring as a result of natural processes are less than 5%.
- There is a greater chance that there will be an increase in heatwaves, warm spells and heavy rainfall, as well as drought, cyclones and extreme high tides.

These conclusions have encouraged many nations to adopt programs to reduce greenhouse-gas emissions and sign the Kyoto Protocol. Essentially, countries that signed the protocol agreed to reduce their greenhouse-gas emissions by 5% between 2008 and 2012.

The Kyoto Protocol

Arising out of the work of the United Nations Framework Convention on Climate Change, held in Rio de Janeiro in June 1992, the Kyoto Protocol came into force on 16 February 2005. The main distinction between the convention and the protocol is that the convention encourages industrialised countries to reduce their greenhouse-gas emissions, whereas the protocol sets binding targets for the signatories. The signatories currently stand at 37 countries, including Australia, and the European Community.

There are some scientists, however, who dispute that this current global warming is any different from what has occurred previously in Earth's history. They argue that the Earth undergoes such cycles naturally. For example, Ian Plimer, currently professor of mining geology at the University of Adelaide, stated in 2002:

> Natural climate changes occur unrelated to carbon dioxide contents. We've had many, many times in the recent past where we've rapidly gone into a greenhouse and the carbon dioxide content has been far, far lower than the current carbon dioxide content. It was only 1100 years ago where Greenland was populated. It was called Greenland because it was green. There were crops, there were cattle there … we've only got to have one burp from a volcano and we've totally changed the atmospheric composition … It looks as if carbon dioxide actually follows climate change rather than drives it.

© 2003 Lateline. Australian Broadcasting Group (www.abc.net.au/lateline/stories/s650126.htm).

Another scientist who studies ancient climates, Tim Patterson, a palaeoclimatologist and Professor of Geology at Carleton University, in Canada, stated in 2005:

> There is no meaningful correlation between CO_2 levels and Earth's temperature over this [geological] time frame. In fact, when CO_2 levels were over ten times higher than they are now, about 450 million years ago, the planet was in the depths of the absolute coldest period in the last half billion years. On the basis of this evidence, how could anyone still believe that the recent relatively small increase in CO_2 levels would be the major cause of the past century's modest warming?

Tom Harris, 'Scientists respond to Gore's warnings of climate catastrophe', Canada Free Press, 12 June 2006 (www.canadafreepress.com/2006/harris061206.htm).

glossary terms

climate
the meteorological conditions, including temperature, precipitation and wind, that characteristically prevail in a particular region over an extended period of time

palaeoclimatologist
a scientist who studies climatic conditions, and their causes and effects, in the geological past, using evidence found in glacial deposits, fossils and sediments

weather
the state of the atmosphere at a given time and place, with respect to variables such as temperature, moisture, wind velocity and barometric pressure

ISBN 9780170189071

Activity 6.8
Looking at the evidence

WORKSPACE
Looking at the evidence
SCI10SIWR00158

VIDEO
Big melt 3: viewing the evidence
SCI10SUVD00159

View the video 'Big melt 3: viewing the evidence' and read the quotes from Professors Ian Plimer and Tim Patterson on page 199. Then complete the following questions.

1 What is your opinion about global warming? What evidence do you have to back up your opinion?

2 Pair up with someone in your class who holds the opposite viewpoint to you. What evidence does he or she use?

3 Use both sets of evidence to write a persuasive text on the following topic: 'Global warming is a natural occurrence.' Use Blabberize to present your text. Upload the link to the class wiki.

CONNECTION
English: How to write a persuasive essay
SCI10SICN00160

Climate change and biodiversity

The impact of any change to climatic conditions may best be described when looking at climate change's impact on biodiversity.

Biodiversity is the sum of all living organisms – plants, animals and micro-organisms – and all their genetic variations and connections within complex ecosystems. It exists everywhere: natural environments, such as forests, lakes, mountains and deserts; human settings, such as houses, backyards, parks, cities and farms; and in and around our bodies, such as on the skin and in internal organs.

Biodiversity does not just include the organisms we can see, but also the myriad microscopic fauna and flora, such as algae, fungi, bacteria and viruses. Most of Earth's biodiversity consists of invertebrates, fungi, bacteria and non-flowering plants. The organisms we see probably only make up about 1% of the planet's biodiversity.

The complexity of relationships between organisms is clearly demonstrated when looking at the effect of removing or altering one factor within an environment and then following the effect. Two examples to be discussed below are the seagrass meadows off warm coastal waters, such as off the coast of Queensland, and rising sea levels, such as in the Maldives, coral atolls in the Indian Ocean.

Seagrass meadows

Seagrasses are a group of about 60 species of marine flowering plants that grow most commonly in shallow, soft-bottomed coastal margins and estuaries on all continents, except Antarctica (Figure 6.16). They are not seaweed, like kelp. Seagrasses obtain their energy from the Sun using the process of photosynthesis, similar to most terrestrial plants. They not only represent the primary food source for many larger marine animals, such as dugongs, sea turtles and manatees, but also provide sheltered habitats for many more sea creatures, their larvae and/or young and other plants.

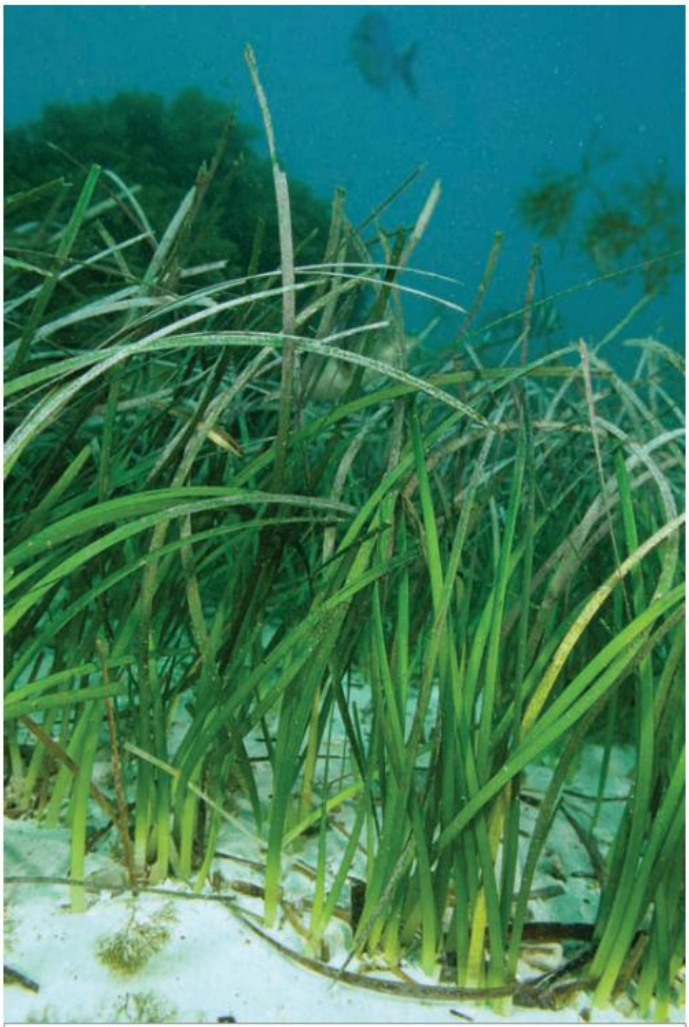


Figure 6.16 Seagrass species can grow into dense patches that provide food and shelter for many other species.

ISBN 9780170189071

Seagrass meadows are commonly made up of one, or many, species of seagrass plants. Each community, however, supports a great diversity of marine life, ranging from invertebrate species such as corals and anemones to sea turtles, dugongs and dolphins. The depth of the seagrass growth is determined by the penetration of light required for photosynthesis. Some species of seagrass can grow at depths of up to 10 m, though their photosynthetic processes occur closer to the water's surface and support the deeper growths.

As plants, they have complex root systems that stabilise sand and mud banks, collecting sediment and therefore leaving the water clear. This is important for the penetration of light and therefore enables photosynthesis to be carried out by the plants.

Seagrasses are one of the most important marine ecosystems for humans as they play a vital part in the fishing industry. For example, a drop in the number of baby tiger prawns off the coast of Queensland in the1980s prompted the study (by Queensland's Department of Primary Industries and Fisheries) into the seagrass meadows of northern Queensland. It was discovered that the seagrass meadows absorbed nutrients from coastal runoff and stabilised the sediments in estuaries.

Many drastic weather events, including torrential rains and cyclones such as those experienced along the north-eastern coast of Australia over the summer periods of 2010–2011 and 2011–2012, have impacted on the growth of seagrasses. Extreme rainfall over land has led to the runoff of vast volumes of water into the estuarine and coastal meadows. This increase in runoff results, in part, from the deforestation of the mountain hundreds of kilometres inland. With these rains come large volumes of silt and sediment, which create turbid water conditions when they reach the coast. The turbidity reduces the light reaching the plants and therefore photosynthesis. If these events continue for extended periods of time, the seagrass will perish, as will the many organisms reliant on it for food and shelter.

The impact of global warming is felt indirectly by the seagrass environments. We need to look to the polar regions for an explanation. As the ice caps melt (particularly over each hemisphere's summer) and therefore the volume of water held in storage shrinks, this water needs to go somewhere. It is measured as an increase in the level of water reaching the coastal fringes of the continents. As the sea level rises at these margins, the seagrass meadows are under greater depths of water, reducing their access to the necessary light. As they are plants, moving further inland is not an alternative. The meadows eventually die out.

Scientists have observed over time that a change to sea levels can impact on the distribution of seagrass. Since the collection of data on sea levels across Australia began in 1880 by the CSIRO, an overall increase to sea levels of 200 mm has been measured. Information is based on high tide recordings and, more recently, satellite data. The effects of rising sea levels have been most significant in coastal regions where the erosion of the coastline has been evident. Salt water has inundated low-lying coastal areas, as well as entered aquifers and low-lying freshwater bodies. Some smaller islands – especially coral atolls, such as the Maldives – are under greater threat of inundation. Here, not only human settlements are threatened but also wetlands and estuarine environments. These habitats are the home to many diverse and often threatened marine species.

Activity 6.9
Endangered dugongs

WORKSPACE
Endangered dugongs
SCI10SHWR00162

Read the article in the weblink 'Protecting the dugong' and then complete the questions that follow.

WEBLINK
Protecting the dugong

1. What climatic event prompted this article to be written?
2. What environmental problems resulted from this event?
3. What ethical decision has resulted from these environmental problems? Who made this choice?
4. List the actions that occurred as a result of the choice identified in Question **3**.
5. How reliable is the reported number of dugong deaths? Explain.
6. What is your reaction to this article?

glossary terms

seagrass meadow
the only flowering plants that can live underwater; seagrasses live in the coastal waters of most of the world's continents

turbidity
a measure of water clarity or murkiness

ISBN 9780170189071

Activity 6.10

Seagrass food web

WORKSPACE

Seagrass food web

SCI10SIWR00163

1 Working in groups of 3–4 students, collect a list of 15–20 organisms that are found to inhabit the seagrass meadows off the Australian coast. Use the weblinks to start your search.

WEBLINK

Seagrasses

WEBLINK

Seagrass meadows

2 Arrange the organisms into a food web.

3 Choose one organism and remove it from your food web. What impact would this have on the organisms remaining in the food web?

4 Create a digital presentation that clearly illustrates the feeding relationships between these organisms. Include pictures and/or videos in your presentation.

Rising sea levels

Are the Maldives going to disappear under the waves? Will Tuvalu have a similar fate? Will a tropical nation such as Kiribati vanish? Such issues have made headlines over the last decade.

As the sea level rises, where and who will be most at risk? In the Pacific and Indian Oceans, groups of islands, including the Maldives, are only 30 cm or so above sea level. Built from coral reefs and now forming a sliver of land in the vast oceans, cyclonic conditions are known to devastate the dwellings of the inhabitants, both human and otherwise. However, flora and fauna are able to survive these catastrophes as they are once-in-20-year events. In time, the natural conditions of local climate and water salinity are returned to ranges in which most organisms survive.

WOW!

Greenland

The last measured volume of the Greenland icesheet was 2.85 million cubic kilometres. If the icesheet was to melt, the global sea level would rise by 7.2 m. This would flood most coastal cities and submerge several small island countries, such as Tuvalu and the Maldives.

Habitat loss from these catastrophic events has far-reaching impacts on many species. As interactions between species are quite complex within any given environment, any changes will affect many organisms. As you have discovered in previous years when studying food webs, remove one species and others feel the effect. If the most-affected organism is a plant, animals that rely on the plant for food and shelter are affected. The reduction in the number of organisms means that decomposers and other recyclers of the habitat have less to process. This leads to fewer nutrients in the soil, which in turn has an effect on the growth of plants. This may be seen in devastated rainforest areas. The larger trees provide nutrients and shelter for animals and other plants and fungi, such as parrots, lianas and toadstools, respectively.

What is the impact on seagrass beds? The seagrass meadows are already submerged; however, they are able to survive in intertidal and estuarine environments where the water level varies as the tide rises and falls. As plants, the seagrass requires light to photosynthesise. As the sea level rises, they are deeper in the water and photosynthesis becomes less efficient; they therefore begin to die out. As the meadows die out, the number and variety of species are drastically reduced.

Seagrass survival is also dependent on the action of mangroves, which are truly estuarine plants. Mangroves are able to effectively trap the extreme sediment loading and associated turbidity that would severely impact on the seagrass' ability to photosynthesise. Mangroves also have a wide tolerance of altering water and salinity levels; therefore, in collaboration with the seagrass, they reduce the sediment loading. This results in the loading washing out onto reefs; otherwise the sediment would have smothered the coral.

These idyllic pit stops in the ocean provide valuable nesting sites and habitats for many organisms. Living things that may only nest in these tiny specks in the vast waters of the Pacific Ocean may soon be looking for other places to breed or else they will perish. Seabirds such as boobies and frigate birds return to the same islands where they were born to breed. The loss of shelter and food at these Pacific islands will result in population decline.

The major threat to the world's biodiversity is the loss of habitat. In the past, we have worried about the destruction of this habitat as a direct consequence of human activity, such as the clearing of rainforests and the reclaiming of wetlands and swamps for building. Now, our indirect actions that contribute to global warming are impacting on the most fragile of habitats along the edges of the major continents. For example, at the Great Barrier Reef, increasing runoff is smothering the coral; as a result, the habitats for many fish and marine invertebrate species are limited or lost.

ISBN 9780170189071

The wetland and estuarine ecosystems offer some of the most diverse communities of living things; for example, the nesting sites for many species of sea turtle (Figure 6.17), including leatherback, hawksbill and green sea turtles. All these require sandy beaches on which to lay their eggs. The rising sea levels work to erode away coastlines and remove these nesting sites.

Figure 6.17 A sea turtle arriving on the beach to lay eggs

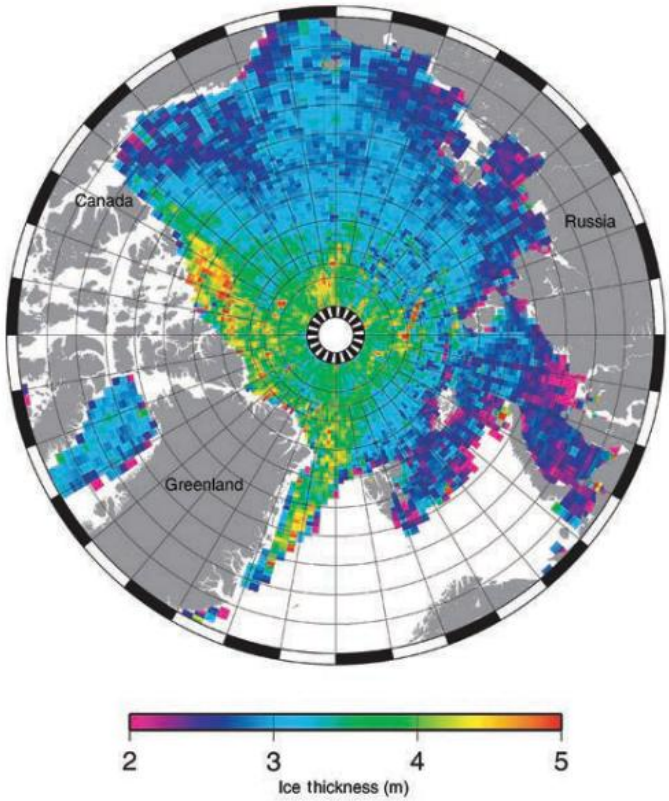


Figure 6.18 Sea-ice thickness in the Arctic Ocean between January and February 2011

Global warming and sea ice

Evidence over the last 30–40 years has pointed towards a decrease in the amount of sea ice, particularly in the Arctic Circle. Dissimilar to the Antarctic ice cap, which is frozen water over a continental land mass, no such land mass is under the Arctic polar cap. In addition to the reduction of Arctic sea ice, the age and thickness of the ice are also decreasing (Figure 6.18). Less ice means less surface area to reflect light and heat. This leads to more rapid melting.

Scientists have become increasingly concerned over the last 15 years about the reduced size of the polar ice caps and their ability to sustain the organisms that rely on them. For example, certain algae live on the underside of the ice; other species rely on them via the relationships established through food webs, including invertebrates, birds, fish and marine mammals. More specifically, North American caribou travel 5000 km through Alaska and Canada into the Arctic Circle on their annual migrations; currently, they take nearly one-third of each year to complete their journey. Remove the icesheets and this journey would be much longer. Of more concern, however, is the impact of the retreating icesheet on the permafrost.

Permafrost is any soil or rock that remains frozen – that is, at or below 0°C – throughout the year. It can be found in the climates of polar and alpine regions, where the mean average temperature is below the freezing point of water. In some areas, only the top layers of the soil may thaw, allowing for the growth of some plants in summer months, while the depths remain frozen. The frozen layer acts as a barrier to the movement of water into deeper layers. The unfrozen soil becomes quite soggy with poor drainage. Given the cool soil temperature in permafrost areas, plant growth and decomposition are slow.

As the sea ice of the Arctic area decreases in area, thickness and age, air temperatures over the oceans begin to rise. These warmer air masses move inland, increasing the land temperatures. Therefore, rapid sea-ice

glossary terms

ice cap
extensive sheets of ice; technically, they cover an area that is smaller than 50 000 km²

permafrost
permanently frozen ground; soil, sediment or rock that remains at or below 0°C for at least two years

sea ice
ice that forms at the ocean surface once the surface temperature drops to the freezing point during autumn and winter; the freezing point for salty ocean water is about –2°C, which is slightly colder than it is for fresh water at 0°C

ISBN 9780170189071

loss leads to warmer inland temperatures, particularly in autumn; and, in turn, increased loss of permafrost. The frozen ground of the Arctic also stores up to 30% of carbon stored in soils worldwide. As the permafrost thaws, the release of carbon dioxide into the atmosphere adds to the greenhouse effect. The global carbon balance is disturbed and results in increased atmospheric carbon levels. As carbon dioxide is a greenhouse gas, this adds to the global-warming effect.

Scientists from the University Corporation for Atmospheric Research – a non-profit consortium of research universities based in Boulder, Colorado, in the United States – have been able to develop computer simulations that show that when Arctic sea ice is in decline, land temperatures can increase to triple the predicted rate of other global-warming models (Figure 6.19). Though most of the warming occurs over the oceans, this temperature increase is known to penetrate at least 1500 km inland.

VIDEO
Disappearing villages
SCI10SUVD00164

Global warming and deep ocean currents

Oceans and surface water make up 70% of the Earth's surface. Ocean currents are the vertical and horizontal movement of both surface and deep water throughout the world's oceans. The currents move in a specific direction, and impact on the Earth's atmospheric moisture content and therefore on climatic conditions.

Surface currents refer to water movement in the upper 400 m of the ocean; they make up 10% of the water in the oceans. They result mainly from wind and form small whirlpools in the water. In the northern hemisphere these whirlpools move in a clockwise direction. In the southern hemisphere, they move anticlockwise. The speed of the ocean current is greatest at the surface of the water.

Deep ocean currents are caused by changes in both water temperature and salinity and occur below a depth of 400 m; they affect 90% of the oceans. Differences in temperature and salinity bring about density differences in the water. Warm water holds less salt than cold water and is therefore less dense. It rises towards the surface. In contrast, cold salty water sinks to the lower depths of the oceans. As the warm water rises, the cold water is forced to move into the gap left by the warm water, creating an upwelling. This upwelling brings nutrients and other matter to the surface, allowing for more feeding for the top-dwelling marine organisms (Figure 6.20).

WEBLINK
Amazing feeding frenzy

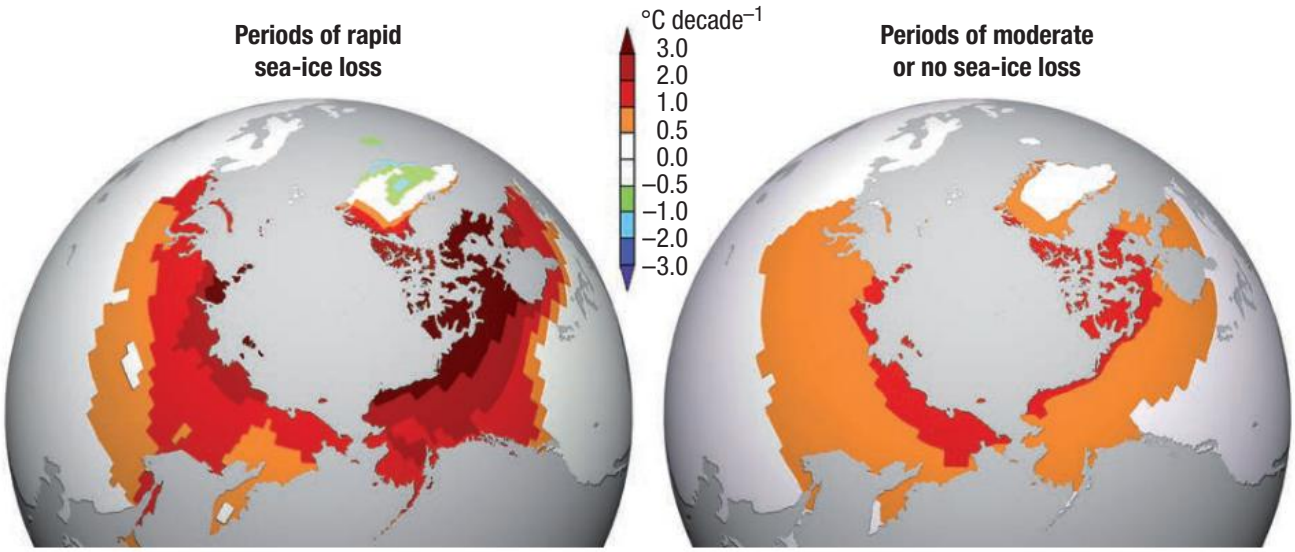


Figure 6.19 A computer simulation showing that when Arctic sea ice is in decline (left), land temperatures can increase compared with times of no sea-ice loss (right).

ISBN 9780170189071

Figure 6.20 Shark feeding frenzies are most common where the deep-sea upwelling of nutrients occurs.

Investigation 6.2
Simulating deep ocean currents

The aim of this investigation is to formulate and test a hypothesis about the effect of temperature or salinity changes on the oceans currents. What do you predict will be the results?

You need

- kitchen spoon
- salt
- food colouring
- large drinking glasses
- thermometer or data logger
- digital camera

This might help

1. Remember to devise a fair test. Identify your independent and dependent variable, as well as your control.
2. How are you going to record your results?
3. How does your prediction compare with the results?
4. What can you conclude from your investigation?

WEB 2.0

If you have made a movie of your discovery, upload this to the class wiki.

The global ocean circulation between deep colder waters and warmer surface waters strongly influences world climates. Scientists think that melting Arctic sea ice and increased precipitation will deposit enough fresh water into the North Atlantic to interfere with ocean currents. As this fresh water hits the currents, the water becomes more buoyant and travels across the surface. The usual course of events is cold water from the melting ice will sink to the bottom and flow towards the equator in the deep ocean currents. The warmer water from the equator will flow across the surface towards the poles. The upwelling occurs at the point where the cold water warms near the equator and rises to the surface, providing nutrition for many marine species. The currents also move many species around the oceans for either breeding or feeding purposes.

Because the currents move water worldwide, they have a significant impact on the weather. For example, the Gulf Stream originates in the warm waters of the Gulf of Mexico and moves northwards, warming Europe more than other places at similar latitudes. The Humboldt Current, a cold current off the coast of Chile and Peru, creates productive waters but keeps the coast of Chile quite cool and arid.

When the Humbolt Current is warmed, the resulting climatic changes are known as El Niño. It is seen as an extended period of warmer oceanic waters in the central and eastern tropical Pacific Ocean, which leads to drier terrestrial conditions on the western edge of the Pacific, including Australia. The cycle lasts from three to five years and explains the drought experienced by Australia during the 2000s. La Niña is a period of cooler-than-average sea surface temperatures in the same part of the Pacific.

glossary terms

deep ocean current
the water movement caused by changes in both water temperature and salinity; deep ocean currents occur below a depth of 400 m

El Niño
a period of extensive warming of the central and eastern Pacific Ocean that leads to a major shift in weather patterns across the Pacific

Gulf Stream
a relatively warm ocean current flowing north-eastwards off the Atlantic coast of the United States from the Gulf of Mexico

Humboldt Current
a cold ocean current of the South Pacific, flowing north along the western coast of South America

La Niña
a period of cooler-than-average sea surface temperatures in the central and eastern tropical Pacific Ocean

surface current
the water movement in the upper 400 m of the ocean

upwelling
the movement of deeper colder waters to shallower depths

ISBN 9780170189071

In recent years, El Niño has seen the drying up of marine plants in the Galapagos Islands as the water temperature increase did not suit their growing habits. This led to the decimation of the marine iguana population on the islands' fringes as the iguanas relied on the marine vegetation for food (Figure 6.21). As the iguanas died off, the other wildlife associated with them also moved or died out. There was a great drop in the number of seabirds nesting on the islands; however, the land birds thrived and lived exclusively on seeds and nuts.

Closer to home, the East Australian Current brings warm surface waters to the east coast and travels as far south as Tasmania. The surface waters are warmed in the tropical waters of the Coral Sea and then travel south along the east coast of Australia, bringing with them many species such as tuna and sea turtles as far as Bass Strait.

Figure 6.21 The number of Galapagos marine iguanas has decreased as marine vegetation has died out due to El Niño.

Questions 6.3
What have you learnt?

WORKSPACE
What have you learnt? 6.3
SCI10SUWR00165

Understand

1 How do climate and weather differ?

2 Global warming is a popular catchcry. What exactly does it mean?

3 What do scientists predict will be the effect of global warming on our weather? How will these changes affect the health of humans?

4 What is biodiversity?

5 How does climate change impact on biodiversity?

Apply

6 Seagrasses are located in warmer areas of the oceans.
- **a** Why are seagrasses so important?
- **b** What do they tell us about the state of the sea level?
- **c** What can they tell us about the state of the land?

7 The Arctic ice cap does not have a land mass underneath it, whereas the Antarctic ice cap does. Why is this significant?

Analyse

8 Which hemisphere of the planet is most affected by reduced sea ice? Why?

9 Explain why biodiversity is affected by melting permafrost.

Synthesise

10 Draw a flowchart outlining the key events that link the melting sea ice to the dying seagrass meadows. Include at least five links and explain how they are connected.

11 Revisit your graphic organiser and add, edit or connect information.

Reflect

12 What are the arguments that are put forward to deny human-induced climate change? What do you think?

ISBN 9780170189071

Long-term effects of biodiversity loss

The study of global systems has shown that a change in one area will impact on many other areas. The most obvious is noticed in the biosphere. Whether we are looking at the impact of the greenhouse effect on the growth of organisms or on sea levels, we are really looking at the effect on the variety of organisms inhabiting a range of environments.

Greenhouse gases generated through human activity can, to a certain extent, be recycled by plants, especially in areas where plants are found in their greatest numbers – that is, forests and swamps. However, human activity is directly impacting on these areas as land is cleared and reclaimed for building and other activities (Figure 6.22).

Figure 6.22 The clearing of Australian native forests reduces the amount of carbon dioxide that can be recycled.

When areas are replanted, not all organisms are able to make immediate use of new habitats; the diversity of organisms is therefore reduced. What is the lasting effect of this loss? Fewer species are able to occupy specific niches of the environment. For example, in an area where once five or six decomposers survived and thrived, the number is now reduced to one or two, which do not decompose all available material. The amount of work required of this limited number can be overwhelming. Some materials may not be recycled as the organisms are unable to process all of the materials that come their way.

Further up the food web, fewer producers reclaim these nutrients and therefore support fewer higher-order consumers. The number of producers limits the ability of the biosphere to recycle the greenhouse gases via photosynthesis. We are back where we started with the natural ecosystems unable to recycle all wastes produced.

Flooding following monsoonal rains in India's Maharashtra state in 1994 and 2005 may be directly attributed to logging and deforestation in the higher altitudes of India and Pakistan (Figure 6.23). The forests that slow the flow of torrential rain and induce infiltration into the soil have been removed. This leads to gushing rivers of water over vast areas that swamp lower lying areas very quickly.

Figure 6.23 Flooding in India's Maharashtra state following monsoonal rains in 2005 can be linked to logging.

Species such as amphibians and butterflies that are susceptible to the deterioration of ecosystems are decreasing in numbers. Amphibians are most susceptible to changes in water quality; butterflies, to changes in air quality. As these species decrease, ecosystem health also decreases, which leads indirectly to unhealthy human populations.

glossary term

East Australian Current
an oceanic current that carries a stream of warm water from the Coral Sea into the cool waters of the Tasman Sea; it is the largest ocean current around Australia

ISBN 9780170189071

Activity 6.11

What do the media say?

WORKSPACE

What do the media say?

SCI10SIWR00166

In groups of three or four, collect two days' worth of newspaper articles on the environment.

1 Categorise the articles under the following headings.
   - Climate change
   - Global warming
   - Greenhouse effect
   - Ozone depletion
   - Melting ice caps
   - Any other category

2 From your knowledge of all these areas, how accurate is the information in each article? How much of the article is expressing the opinions of:
   a scientists
   b politicians
   c the general public?

3 Choose one article and extract any information that you think is incorrect. How would you rewrite it to make it more scientifically correct?

4 Why do you think information from the media is not always accurate?

Questions 6.4

What have you learnt?

WORKSPACE

What have you learnt? 6.4

SCI10SUWR00167

Understand

1 We started this unit with the statement: 'When a butterfly flaps its wings in the forest on one side of the planet, catastrophic events can occur on the other side.' Give an example of what this saying means.

2 Look back at your answer to Question **6** in 'What have you learnt? 6.1' on page 193. What was your final answer to the five whys? In what ways would you change this now based on all that you have learnt in this unit?

Synthesise

3 Using the information you collated when constructing the seagrass food web and your knowledge of rising sea levels and melting sea ice, create a chart that lists the differences and similarities between the three areas.

Reflect

4 Do you believe everything you read in the newspaper? Explain your answer.

ISBN 9780170189071

Unit review

ACTIVITY SHEET
Unit 6 checklist
SCI10SUAS00169

REVIEW QUIZ
Unit 6
SCI10SURQ00168

WORKSPACE
Unit 6 review
SCI10SUWR00170

Understand

1 The global system consists of four spheres. Into which of the four do the following belong?
   - **a** Snow on Mt Everest
   - **b** Lagoon in the Maldives
   - **c** Spider monkey in the Amazonian jungle
   - **d** Lava from Mt Etna

2 'The greenhouse effect enables life to survive on Earth.' Explain this statement, giving an example you have studied in this unit.

3 Contrast ozone depletion with the greenhouse effect. Why do you think some people get them confused?

4 Complete this sentence: 'Biodiversity is a term used to describe ...'

5 Climate change has been attributed to human activities. List five human activities from the industrial revolution onwards, and describe their impact on the climate.

6 Pre-combustion and post-combustion carbon-capture techniques have been implemented in coal-burning power stations to reduce carbon emissions. Describe how each carbon-capture technique works.

7 How are polar bears affected by the thinning of the sea ice on the Arctic Ocean?

8 Name the current that:
   - **a** affects the climate of Europe
   - **b** keeps the coast of Chile cool and arid
   - **c** brings warm surface waters to the east coast of Australia.

Apply

9 Explain how increasing sea levels impact on the biodiversity in oceanic habitats. Use a flowchart to illustrate your answer.

10 Construct a food web of a seagrass meadow community with the dugong as the top-order consumer. How many levels exist within the food web? What impact does removing the seagrass have on your food web?

11 Carbon-capture techniques ensure less carbon dioxide is released into the atmosphere from the combustion of fossil fuels. Draw a diagram to explain the impact on the carbon cycle if carbon capture did not occur.

12 Deforestation affects the carbon cycle. Redraw the diagram from Question **11** to incorporate the effect of deforestation.

13 El Niño and La Niña effects occur when the temperature of the Pacific Ocean changes. Construct a table that shows the name of the current, and the temperature of the water required to produce each effect.

ISBN 9780170189071

Analyse

14 Use the data shown in Figure 6.24 to answer the following questions.

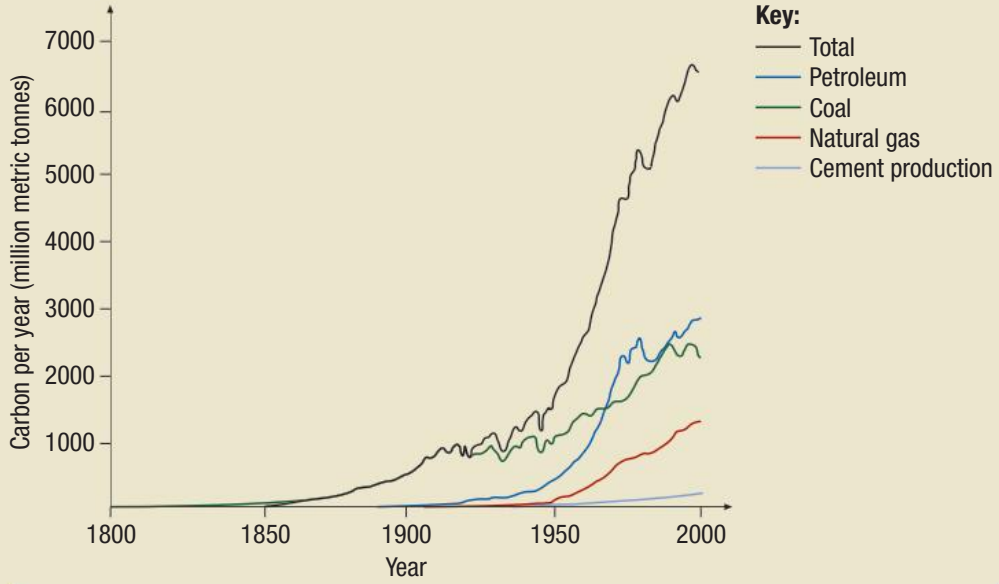


Figure 6.24 Global fossil carbon emissions

- **a** Explain why the black 'Total' line did not start rising until 1850.
- **b** Locate the period of the Second World War. What occurred to the green 'Coal' line during this time? How can you explain this?
- **c** There is a decrease in the blue 'Petroleum' line in the 1980s. How can you explain this?
- **d** Give one reason to explain why there are different starting times for the different fossil fuel emissions.
- **e** Predict the total emissions in 2100.

15 It takes less energy to produce a motor car than it does to use and operate it during its lifetime. How does the use of a car impact on all four spheres of the global system? How does it contribute to loss of biodiversity?

Synthesise

16 Produce a flowchart that links the four spheres of the global system with the carbon cycle. In a different colour, include the effects of global warming with explanatory notes along the links.

17 Seagrass meadows are damaged after torrential rains on land. Draw a diagram or flowchart that outlines the process that leads to this damage.

Evaluate

18 Melting sea ice has a devastating impact on biodiversity in the northern hemisphere. What are the best actions you can recommend for populated areas in Europe to slow the rate at which sea ice melts?

19 Design a power-generating plant that uses fossil fuels and has a reduced carbon footprint. What measures would you put in place to ensure that the carbon output is minimal? List these on your plan.

20 Over the short term, how effective do you think the Kyoto Protocol was? Justify your response with scientific information.

21 'Think globally, act locally' is a common catchphrase of the environmentally aware public. Do you think that this catchphrase has captured people's imagination? Come up with an improved or different catchphrase.

Reflect

22 How does your behaviour influence what is happening on Earth? List 10 ways you could change your behaviour to decrease your carbon footprint. Implement two of these. How does it make you feel to be able to take action in this way?

ISBN 9780170189071

7

Force to go

How do we describe motion and understand its causes?

How do we know that something is moving? How will we compare fast and slow, and speeding up and slowing down? For thousands of years, humans have considered motion and its causes. At the basis of our experience of motion lies two fundamental observations: position and time. Australian hurdler Sally Pearson wins races because she can get from position A to position B in the shortest possible time. In the process, she applies forces to the track and the track applies forces to her. In this way, she is able to accelerate and run faster than other elite athletes.

What do you already know about motion and its causes?

You may be already learning to drive a car in preparation for getting your driver's licence. If you are, you will know that driving takes a lot of concentration. You need to be able to react to different road conditions and to the actions of other drivers. Do you know what your reaction time is? Do you know how your reaction time affects your ability to brake or to swerve to avoid an accident? Do you know how distraction affects your ability to drive safely?

Driving a car involves a lot of physics. An understanding of physics will help you become a better and safer driver.

Activity 7.1
What do you already know about motion?

WORKSPACE
What do you already know about motion?
SCI10SUWR00171

1. Record 10 words you associate with motion.
2. Search on the Internet for images that demonstrate each of your words.
3. Annotate each image to show what it means. Sometimes, you might find an image that demonstrates two or more words, so you will need to annotate the image accordingly.

WEB 2.0

This activity can be completed using Google Docs. Invite two other people to contribute to your Google Doc by adding words and phrases that you have not added yourself.

This Google Doc can be added to continuously throughout the unit, and will provide a useful resource for revision and recording thoughts, ideas and key learnings.

WEBLINK
Google Docs

Culminating assessment task
Motion performances

Select one or more motion situations, such as a sporting event, vehicle testing or animal speeds. Use published data to describe and compare performances in your chosen situation. You may choose to compare the performances, for example, of animals with humans. Report on speeds, accelerations and forces involved in achieving these performances. Produce an electronic presentation that includes data tables, graphs and calculations to show position, speed, acceleration and average net force required to achieve these performances.

Your report will include the following sections:

- introduction
- definitions and equations
- data
- data analysis
- conclusions
- relevant diagrams, including the use of force arrows and naming conventions for forces, as well as appropriate visual representations of comparative data
- a bibliography of all resources you consulted and acknowledgement of any assistance you received.

ACTIVITY SHEET
Rubric: Motion performances
SCI10SUAS00173

Analysing motion

The peregrine falcon is the fastest animal on Earth (Figure 7.1). It can travel at speeds of close to 400 km/h, which is about 10 times faster than an elite athlete can sprint. Some sharks are 6 times as fast as the fastest sprint swimmer. They would finish a 50 m swim-off in about 3 seconds – if they didn't finish off the swimmer first! Accurate measurements of distance and time are used in sports events, such as athletics and horse racing. Millions of dollars can be riding on such measurements (Figure 7.2)

ISBN 9780170189071

Figure 7.1 A peregrine falcon stoops (dives vertically) at up to 400 km/h.

WEBLINK
High-velocity falcon

Figure 7.2 The finish of the Melbourne Cup in 2011. The difference between first and second prize was $2.7 million!

Describing motion

When we observe things moving, we are aware of two things that occur simultaneously. First, things change their positions. We travel from home to school. We go from the fridge to the table. We run from start to finish. In each of these cases, we have a start and a finish position. The start is called the origin, or reference position. The change of position is the distance.

Second, distance travelled always occurs during a time interval. It takes time to get to school from home, or from the fridge to the table. The fastest runners take about 10 seconds to run a 100 m race from start to finish. A time interval must have a start and finish. It is therefore the difference between the start and finish time, such as the time from start to finish of a running race (Figure 7.3 on page 214).

If we want to compare these movements, we need to compare the rate at which the change of position takes place. The rate of change of position is called speed. To measure speed, we need to see how the position changes during the time interval.

VIDEO
Watch your speed
SCI10SUVD00174

Speed itself changes too. Cyclists speed up and slow down. The rate at which something changes speed is called acceleration (Figure 7.4 on page 214). A 100 m sprinter accelerates out of the blocks for about the first 60 m to the fastest speed possible, and then tries to run at this speed to the finish line. To measure acceleration, we need to see how the speed changes during a time interval.

INTERACTIVE
Accelerate
SCI10SUIN00175

glossary terms

acceleration
the rate of change of speed

distance
the difference between two position measurements

origin
the start; a reference point

position
the place relative to an agreed origin

speed
the rate of change of position

time interval
the difference between two time measurements

ISBN 9780170189071

Figure 7.3 In a race, the winner takes the least time for the distance covered from origin to finish position.

Figure 7.4 An accelerating cyclist whizzes past a slower-moving pedestrian.

Activity 7.2
Measuring speed

WORKSPACE

Measuring speed

SCI10SIWR00176

1 Brainstorm as many different things that have their speed measured as you can. Then record the devices that measure the speed of the things on your list.

2 Create a table with three columns. In the first column, name the device, such as a speedometer. In the second column, describe what the device looks like; you could also insert an image. In the third column, describe where you would find the device, such as on the dashboard of a car.

3 Choose one of the devices in your table – for example, a speedometer in a car – and improve it by making something on it bigger or smaller, and adding something and removing something.

4 Share your improved device on the class wiki.

WEB 2.0

You could complete this activity using your Google Doc. Share your doc with two other students.

ISBN 9780170189071

Measuring motion

If we want to talk about and compare the motion of things, we need to be able to say something about how position is changing as time changes. This means we need to establish an agreed origin for positions. We can then measure distances from that agreed position. The difference between two positions is the distance travelled or distance interval, *d* (Figure 7.5).

Similarly, we use a timing device, such as a clock or stopwatch, to measure the passage of time (Figure 7.6). The difference between two times is called the time interval, *t*.

Notice that we have used lower-case letters to represent distance and time. In science, *d* is a different symbol from *D*; likewise, *t* and *T* represent different quantities.

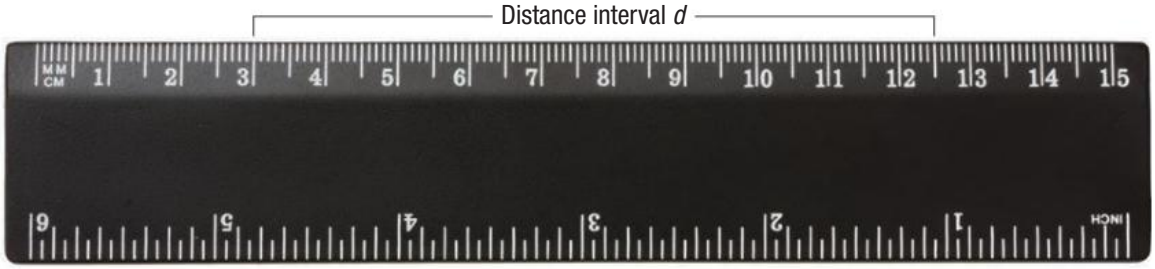


Figure 7.5 A ruler measures distance. The difference between two positions is the distance interval, *d*. This ruler is measuring the difference between 12.5 cm and 3 cm.

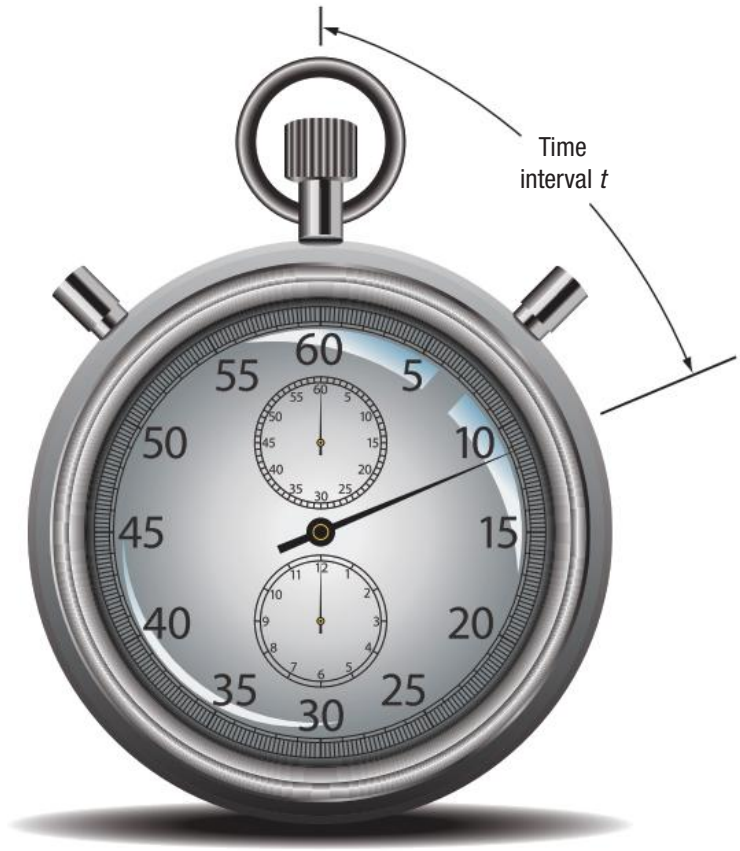


Figure 7.6 A clock measures time. The difference between two times is the time interval, *t*. This clock is measuring the difference between 11.2 seconds and 0 second.

ISBN 9780170189071

Position–time graphs

Because Australia is such a large continent, there are many long, straight sections of road. For example, the Gunbarrel Highway, a remote road in Western Australia, is named because it is thought to be as straight as a gun barrel (Figure 7.7).

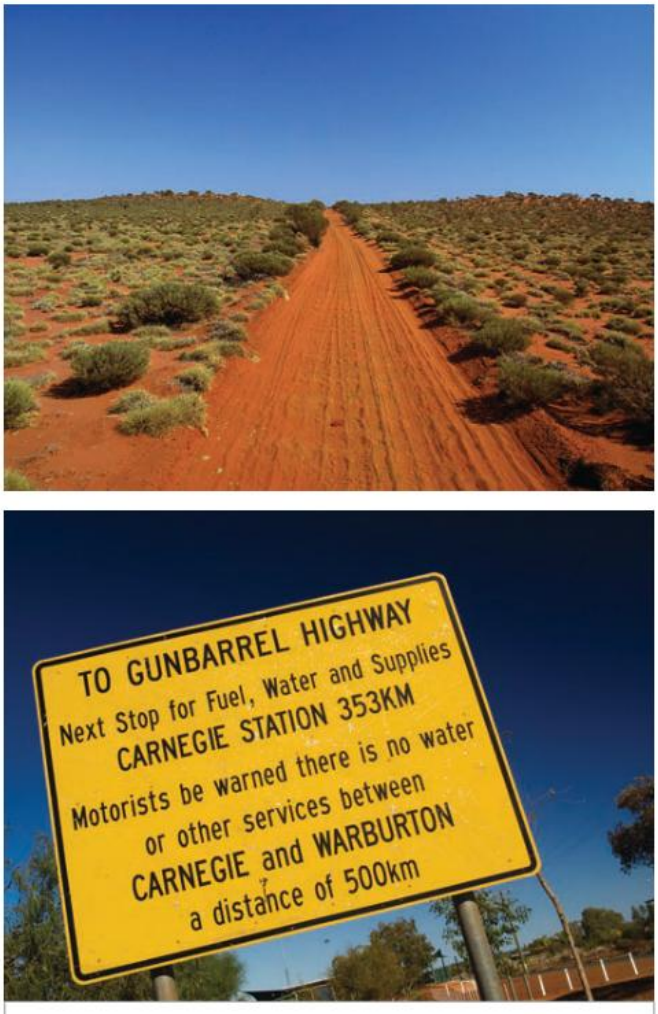


Figure 7.7 The Gunbarrel Highway

However, the longest, straightest section of road in Australia is part of the Eyre Highway, in Western Australia (Figure 7.8). This 146.6 km section starts near Balladonia in the west and finishes near Caiguna in the east. It is known as the 90 Mile Straight. The Eyre Highway will be used here as an example of a position–time graph, as shown in Figure 7.10.

A group of people get into a car at place P, 5 km east of Balladonia. They travel towards the east for 120 km along the Eyre Highway, before stopping two hours later. Everyone then gets out to explore and look for native plants and animals, such as the bluebonnet parrot (Figure 7.9). After an hour, they all get back in and return, going past P and arriving in Balladonia. The return trip takes 1.5 hours.

The trip described above can be represented in a number of ways. Two of these are shown in Figure 7.10. The reference point in the graph is P. The eastward direction has been taken as positive; thus, the stopping point is positive 120 km (that is, +120 km). Any position to the west of P is negative; therefore, Balladonia is negative 5 km from the reference point (−5 km). During the time the car was stopped, it stayed at the same position; however, time continued to be counted, so the graph line is horizontal.

ANIMATION
Trip along the highway
SCI10SIAN00177

Activity 7.3
Where is it?

1. Use Google Maps to locate the Eyre Highway.
2. Locate Balladonia and Caiguna using Google Earth.
3. How far is it from Caiguna to Balladonia?
4. Beginning at Balladonia, if you travel in an easterly direction along the Eyre Highway for 125 km, where will you stop? Use Google Maps to locate your position. Upload a screenshot of your location to the class wiki.
5. Did everyone have the same screenshot? Why or why not? Share how you resolved any differences with a classmate.

ISBN 9780170189071

Average speed

The outward trip of 120 km from P along the Eyre Highway took 2 hours. Therefore, on average, the car travelled a distance of 60 km during each hour:

$$v_{av} = \frac{120\text{ km}}{2\text{ h}} = 60\text{ km/h}$$

From this we can see that the average speed (v_{av}) is calculated by dividing the distance travelled d by the time taken t:

$$\text{Average speed } (v_{av}) = \frac{\text{distance travelled } (d)}{\text{time taken } (t)}$$

$$v_{av} = \frac{d}{t}$$

What was the average speed of the car on the return journey? The distance travelled was 120 km back to P and another 5 km to Balladonia, so the distance was 125 km.

$$\text{Average speed } (v_{av}) = \frac{\text{distance travelled } (d)}{\text{time taken } (t)}$$

$$v_{av} = \frac{125\text{ km}}{1.5\text{ h}}$$

$$= 83\text{ km/h}$$

Activity 7.4
How fast?

Calculate the average speed that you travel to school. Upload this to the class wiki, including the distance travelled and the mode of travel. Look at the data of your classmates. What questions do you have? What conclusions can you draw?

Figure 7.8 Australia's straightest section of road, the 90 Mile Straight, is on the Eyre Highway in Western Australia.

Figure 7.9 Bluebonnet parrots

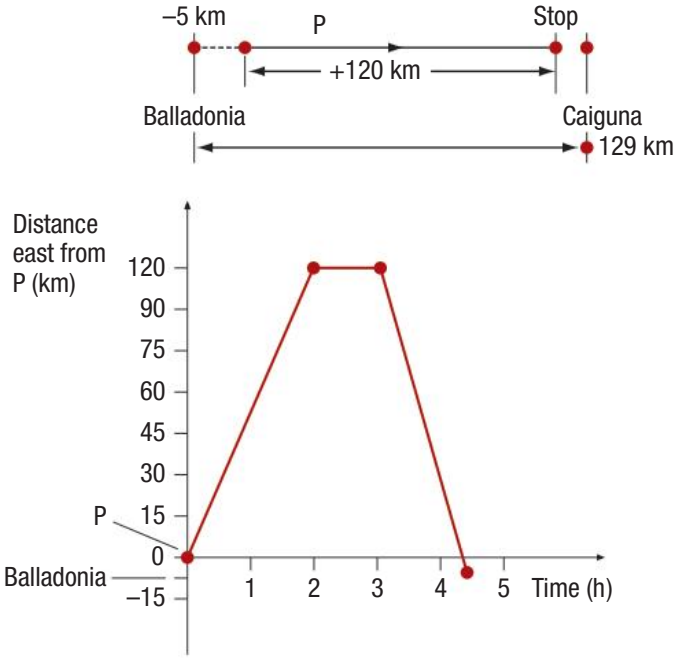


Figure 7.10 A graph representing a journey along Australia's straightest stretch of road

glossary term

average speed
a single value for speed that best represents the motion of an object; speed change divided by time interval

ISBN 9780170189071

Velocity

So far we have calculated the average speed, without taking direction into account. In the trip along the Eyre Highway, there was an average speed when travelling to the east (60 km/h, east) and another when travelling to the west (83 km/h, west). Speed and velocity are very similar because they both refer to how fast we are going; however, velocity also includes the direction in which we are travelling. For example, one car travelling west at 60 km/h and another travelling north at 60 km/h have the same speed, but their velocities are different because they are travelling in different directions. Their velocities are 60 km/h west and 60 km/h north, respectively.

To specify velocity properly, we therefore need a numerical value and a direction. Speed is an example of a scalar quantity because it has only a size (or magnitude). In contrast, velocity is an example of a vector quantity because it has a magnitude and a direction. Notice that distance is also a scalar quantity. The term displacement is used when referring to the distance travelled in a particular direction, so displacement is a vector quantity (Figure 7.11).

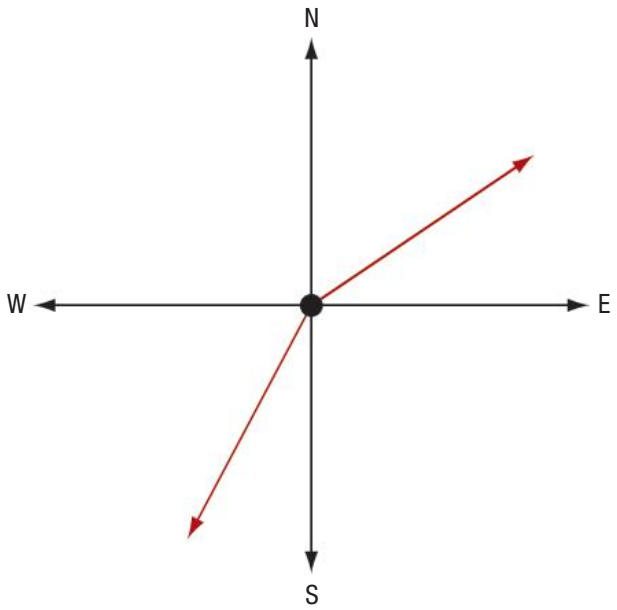


Figure 7.11 Two displacement vectors. They show the same scalar distances, but their vector directions are different.

Investigation 7.1
Measuring time interval and distance

Time and distance are measured in a variety of ways, such as multiple flash photography, video analysis and radar gun. In school laboratories, stopwatches, rulers, measuring tapes, trundle wheels, data loggers, flip cameras and even ticker timers are frequently available.

What to do

1 Devise a way to measure time intervals and distances for several different motions; for example:

- running
- jumping
- performing a ballet movement
- throwing a ball
- pushing a trolley.

For each motion, select a different measurement strategy.

2 Produce a digital report on the different measurement techniques used to measure time intervals and distances.

WEB 2.0

To create your report, you can use Animoto, Photostory, a wikispace, blog, poster, pamphlet or slide show.

WEBLINK
Animoto

ACTIVITY SHEET
Using ticker timers
SCI10SIAS00178

ISBN 9780170189071

Speed from a position–time graph

Remember the trip along the Eyre Highway from P towards Caiguna and back to Balladonia? Did you notice that the average speed calculations were the same as working out the gradient of the position–time graph? You work out the gradient of a graph by calculating the rise-to-run ratio:

$$\text{Gradient} = \frac{\text{rise}}{\text{run}}$$

In each case, the rise on the graph is the same as the distance, *d*, and the run is the same as the time interval, *t*. A positive gradient occurred for this trip when the car was moving towards the east. When the car was moving towards the west, the gradient was negative. Notice that, when the car was stopped, the change in distance travelled was zero, so the average speed was zero.

Figure 7.12 shows the position of a horse and rider on a trip north from one point and the return journey south to another point.

To find the average speed of the horse and rider, use the equation:

$$\text{Average speed } (v_{av}) = \frac{\text{distance travelled}}{\text{time taken}} = \frac{d}{t}$$

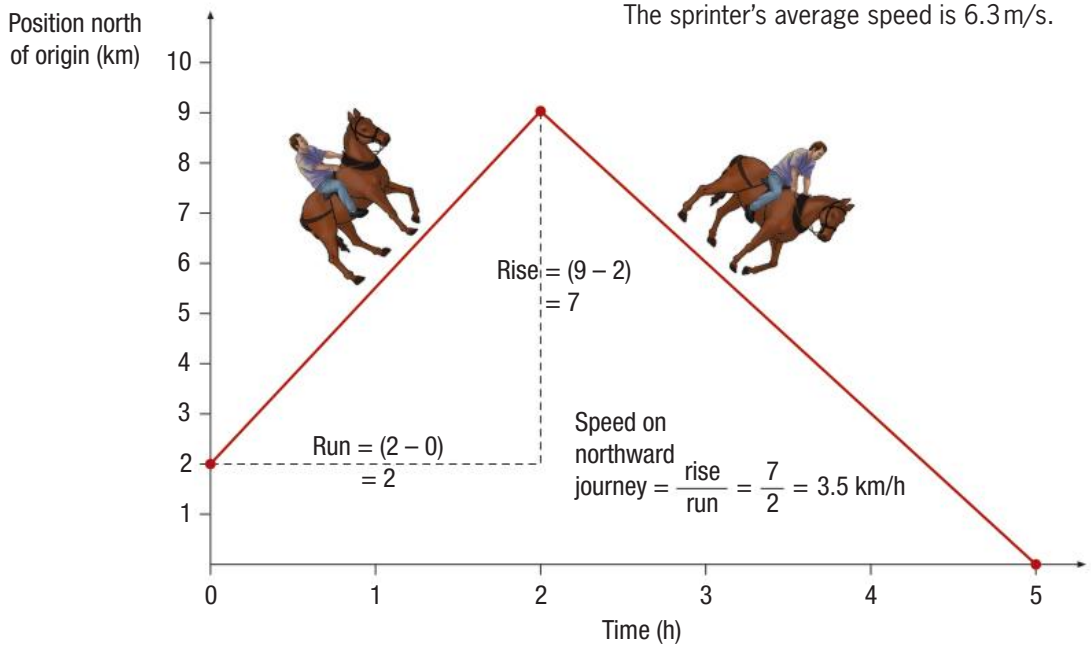


Figure 7.12 Finding average speed from a position–time graph for a trip by a horse and rider

This equation has three variables: v_{av}, *d and t*. It is therefore possible to find any one of these different quantities. In each case, we use the same equation, substitute the numbers we are given and then complete the necessary algebra to find the value of the quantity. However, first we need to list the variables and the values we are given in the question.

Example 1: find average speed v_{av}

A sprinter takes 16 seconds to complete a 100 m race. What is the sprinter's average speed?

Solution

1 List the variables.

v_{av}	*d*	*t*
?	100 m	16 s

2 Write the equation: $v_{av} = \frac{d}{t}$.

3 Substitute the values and perform the calculation:

$$v_{av} = \frac{100}{16}$$
$$= 6.3 \text{ m/s}$$

The sprinter's average speed is 6.3 m/s.

glossary terms

displacement
final position relative to a starting position, taking direction and magnitude into account

magnitude
size

scalar
a quantity without reference to direction, such as speed, distance and time

vector
a quantity that includes direction, such as displacement, velocity and force

velocity
speed in a particular direction

ISBN 9780170189071

Example 2: find distance *d*

A very fast train travels at an average speed of 250 km/h for 3 hours. How far did the train travel?

Solution

1 List the variables.

v_{av}	d	t
250 km/h	?	3 h

2 Write the equation: $v_{av} = \frac{d}{t}$.

3 Substitute the values to make *d* the subject (this requires one step: multiply both sides by 3) and then do the calculation:

$$250 = \frac{d}{3}$$
$$d = 250 \times 3$$
$$= 750\,\text{km}$$

The train travelled 750 km.

Example 3: find the time interval *t*

A motorcyclist travels 600 km at an average speed of 75 km/h. How long did it take to make the trip?

Solution

1 List the variables.

v_{av}	d	t
75 km/h	600 km	?

2 Write the equation: $v_{av} = \frac{d}{t}$.

3 Substitute the values to make *t* the subject (this takes two steps: multiply by *t* and then divide by 75), and then do the calculation:

$$75 = \frac{600}{t}$$
$$75 \times t = 600$$
$$t = \frac{600}{75}$$
$$= 8\,\text{h}$$

It took 8 hours to make the trip.

ANIMATION
Doing the calculations
SCI10SIAN00179

Activity 7.5
Why?

Why is it useful to know information about distance, speed and time? List five reasons why you personally would need to calculate and consider time to travel, speeds and distance. Upload your lists to the class wiki.

Units for speed and velocity

Everything we measure in motion relates back to two variables: distance and time. In the internationally accepted system of units, known in French as the *Système international d'unités* (SI units), distance is measured in metres (m) and time is measured in seconds (s). From these, we can develop units for other motion quantities. For example, speed and velocity are calculated by dividing distance by time, so the unit of speed and velocity is metres divided by time (m/s).

You can convert between speed values given in kilometres per hour (km/h) and metres per second (m/s). Remember that there are:

- 1000 m in a kilometre
- 60 seconds in a minute.

Example 1: converting from km/h into m/s

Convert 90 km/h into m/s.

Solution

$$90\,\text{km} = 90\,000\,\text{m}$$
$$1\,\text{h} = 3600\,\text{s}$$
$$\text{Altogether: } 90\,\frac{\text{km}}{\text{h}} = \frac{90\,000\,\text{m}}{3600\,\text{s}}$$
$$= 25\,\text{m/s}$$

Example 2: converting from m/s into km/h

Convert 20 m/s into km/h.

Solution

$$20\,\text{m} = \frac{20}{1000}\,\text{km} = 0.020\,\text{km}$$
$$1\,\text{s} = \frac{1}{3600}\,\text{h}$$
$$\text{Altogether: } 20\,\frac{\text{m}}{\text{s}} = \frac{0.020\,\text{km}}{\frac{1}{3600}\,\text{h}}$$
$$= 0.020 \times 3600$$
$$= 72\,\text{km/h}$$

ISBN 9780170189071

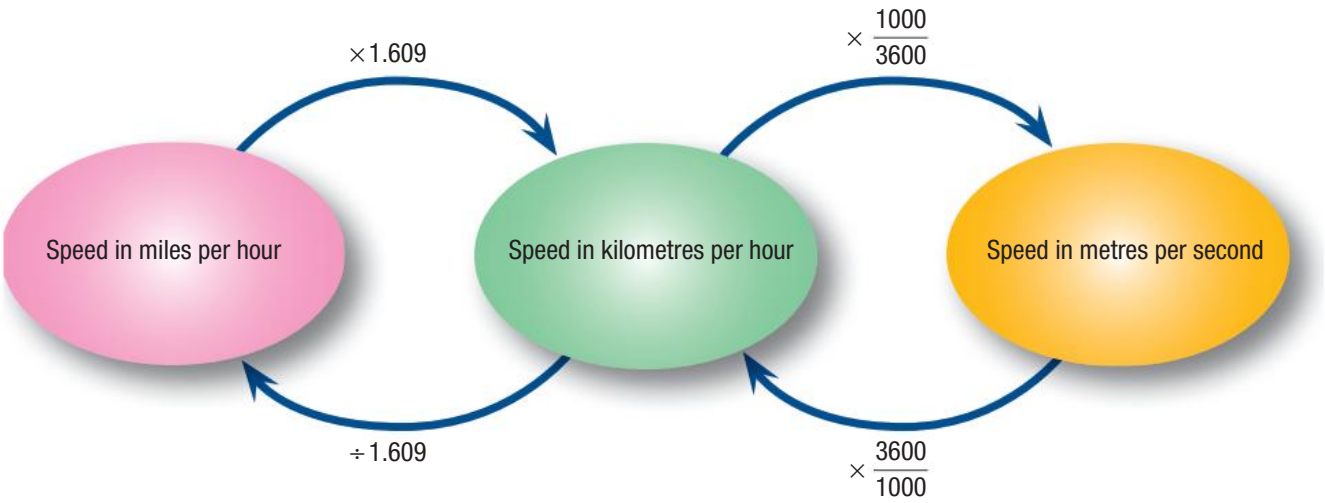


Figure 7.13 Converting between units for speed and velocity.

Figure 7.13 gives a simple summary of the conversion factors. It also includes the conversion between speed given in the British Imperial System (miles per hour) because the United Kingdom and the United States still use these units.

CONNECTION

Numeracy: Converting between units

SCI10SICN00180

Acceleration

The fastest land mammal is the cheetah. It reaches speeds of around 140 km/h. It can change speed from 0 to 100 km/h over short time intervals. It accelerates very quickly! If you wanted to find out how quickly the cheetah's speed changes, you would need to work out, for a particular time interval, the difference between the starting and final speeds:

Speed change = final speed – starting speed

Acceleration is measured in metres per second per second (m/s^2).

WEBLINK

Cheetah – fastest running animal

Car performance

One of the performance measures for cars is acceleration time. This is the time it takes from a standing start ($t = 0$) for a car to reach 100 km/h. A typical speed versus time graph can be drawn to show this (Figure 7.14).

Activity 7.6

British Imperial System

What if the United Kingdom and the United States no longer used the British Imperial System? Complete a consequences and sequence chart to show the short-term, medium-term and long-term effects that this would have. Determine the time frame for which you are listing the consequences, and consider the requirements. For example, will you look at the consequences locally or globally?

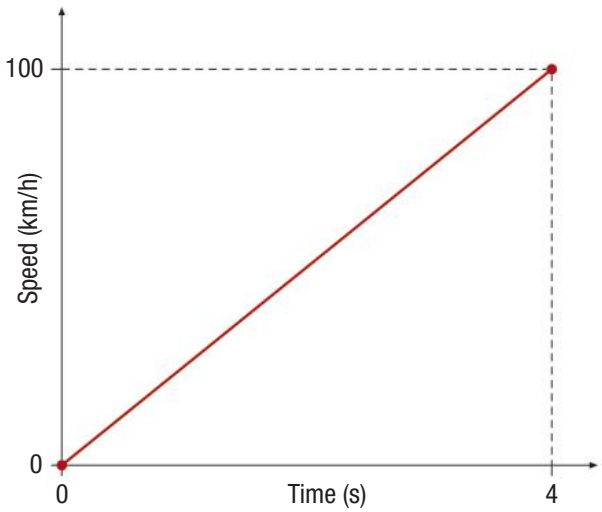


Figure 7.14 Typical car speed versus time graph from standing start to 100 km/h

glossary term

SI units
a set of units agreed on by all nations

ISBN 9780170189071

Any change of speed occurs in a time interval. This is called acceleration. Average acceleration (a_{av}) is then:

$$a_{av} = \frac{\text{speed change}}{\text{time taken } (t)}$$

where speed change = (final speed) – (starting speed).
If the speed increases, a_{av} is positive and the acceleration is positive. If the speed decreases, a_{av} is negative and the acceleration is negative. This is called deceleration.

WEBLINK
Acceleration times

Finding average acceleration

The equation for average acceleration has three variables: a_{av}, speed change and t. Similar to examples involving distance, time and speed, questions can be asked about any one of these different quantities. So we use the same steps.

1 List the variables in a table to make sure you do not miss anything.

a_{av}	Speed change	t

2 Write the equation: $a_{av} = \frac{\text{speed change}}{\text{time taken } (t)}$.
3 Substitute the values in the equation.
4 Tidy up the algebra to make the unknown variable the subject of the equation.
5 Calculate your answer.

Example 1: find the speed chang

A car accelerates uniformly at a rate of 5.0 m/s² for 4.0 seconds. What is the change in its speed?

Solution

1 List the variables.

a_{av}	Speed change	t
5.0 m/s²	?	4.0 s

2 Write the equation: $a_{av} = \frac{\text{speed change}}{\text{time taken } (t)}$.
3 Substitute the values and do the calculation:

$$5.0 = \frac{\text{speed change}}{4.0}$$

$$\text{Speed change} = 5.0 \times 4.0$$

$$= 20 \text{ m/s}$$

Example 2: find a new speed chang

Sometimes, you are asked to do a little more thinking. For example, if the car was travelling at 15 m/s when the acceleration was applied, what would be the new speed of the car after 4.0 seconds at this acceleration?

Solution

1 List the variables.

Speed change	Final change	Start speed
20 m/s	?	15 m/s

2 Write the equation:

Speed change = final speed – starting speed

3 Substitute the values, tidy up the algebra (one step needed) and then do the calculation:

$$20 = \text{final speed} - 15$$

$$\text{Final speed} = 20 + 15$$

$$= 35 \text{ m/s}$$

Activity 7.7
Car performance

1 Collect data about the time it takes for five different cars to accelerate from 0 to 100 km/h. Select the cars from the weblink 'Acceleration times'.

WEBLINK
Acceleration times

2 Compare the cars by plotting the data on a graph of speed versus time.

Extension

3 If there were no boundaries, what car would you most like to own? What are its performance specifications? How does your chosen car compare with the five cars above? Complete a plus/delta for your chosen car.

ISBN 9780170189071

Questions 7.1

What have you learnt?

WORKSPACE

What have you learnt? 7.1

SCI10SUWR00181

Understand

1 a Which two basic quantities are used to measure speed and acceleration?

b Describe how these variables are used to measure speed and acceleration.

2 Giving an example for each, state the difference between:

a speed and velocity

b a scalar and a vector quantity.

3 Use the definition of speed to calculate the average speed of an ant that travels 1.2 m in 7.2 seconds.

Apply

4 Complete the following table.

v_{av} (m/s)	d (m)	t (s)
45	?	0.3
16	0.2	?

5 Complete the following table.

a_{av} (m/s^2)	Speed change (m/s)	t (s)
?	40	8.0
10.0	?	5.0

Synthesise

6 Redraw Figure 7.10 on page 217 using Balladonia as the origin.

7 a Explain why the gradient of a position versus time graph is used to measure the average speed of an object.

b Explain why the gradient of a speed versus time graph is used to measure the average acceleration of an object.

8 Create a position versus time graph to show the time you left home to go to school and the time you arrived back home after school.

9 Create a speed versus time graph for a ball that is thrown vertically upwards and then returns to the place from which it was thrown. Show the part of the graph that represents deceleration and the part that shows a positive acceleration.

Reflect

10 Refer to your original list of motion words in Activity 7.1 on page 212. Add new words, ideas and thoughts. Update any of the annotations in light of what you have learnt so far.

glossary terms

average acceleration
a single value for acceleration that best represents how the speed of an object changes

deceleration
negative acceleration, usually associated with braking

ISBN 9780170189071

Road safety science

A car is a dangerous thing. We all need to make sure we understand our own reactions in dangerous situations. That is why drivers are taught to drive defensively. This means being alert so that they can react quickly. They also need to anticipate and be ready to anticipate when things might go wrong so that they can take early action, such as slowing down. It is also why we should try to keep to the 2-second rule: always travel 2 seconds behind the car in front. Never tailgate.

Reacting to an emergency

One of the reasons for speed limits of 40 km/h near schools, when children are arriving and leaving, is that drivers need to be alert to the impulsive behaviour of children. The slower the cars travel, the greater the chance they have of stopping before tragedy results.

How quickly can you react to a dangerous situation? Until you react, the car continues to travel at speed until you start to brake. The car also continues forwards until it comes to a stop. If you are travelling at 54 km/h (15 m/s) and your reaction time is 0.2 second, you will continue on for 3.0 m before you start to brake. Typically, braking accelerations are about –5.0 m/s^2 (the negative sign means the speed gets smaller, which is a deceleration). An acceleration of –5.0 m/s^2 means that the car's speed gets smaller by 5 m/s every second. Thus, the car will take 3.0 seconds to reduce speed from 15 m/s to zero. In all, you will take 3.2 seconds (which is 60% longer than the 2-second rule) to come to a stop after noticing the dangerous situation (Figure 7.15).

In general, we can calculate the total stopping time by adding reaction time to braking time:

Stopping time = reaction time + braking time

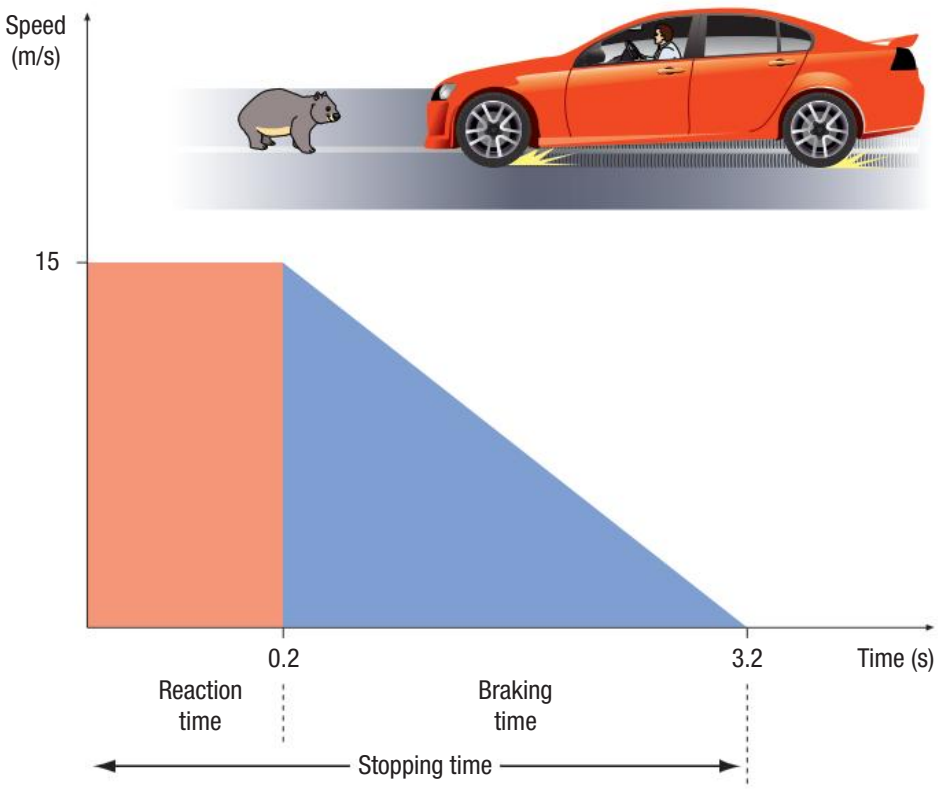


Figure 7.15 A car stops in an emergency. The reaction time was 0.2 second and the braking time was 3.0 seconds. In all, the stopping time was 3.2 seconds.

INTERACTIVE

Give me a brake

SCI10SUIN00175

ISBN 9780170189071

Reaction time

If you drop a ruler between the thumb and forefinger of a classmate, you can find out how far the ruler falls before your classmate reacts (Figure 7.16). Set up your experiment so that it tests the reaction time fairly. For example, how will you take into account the 'practice effect'?

Use the graph in Figure 7.17 to work out your classmate's reaction time. Perform the test several times and find an average that best represents the reaction time.

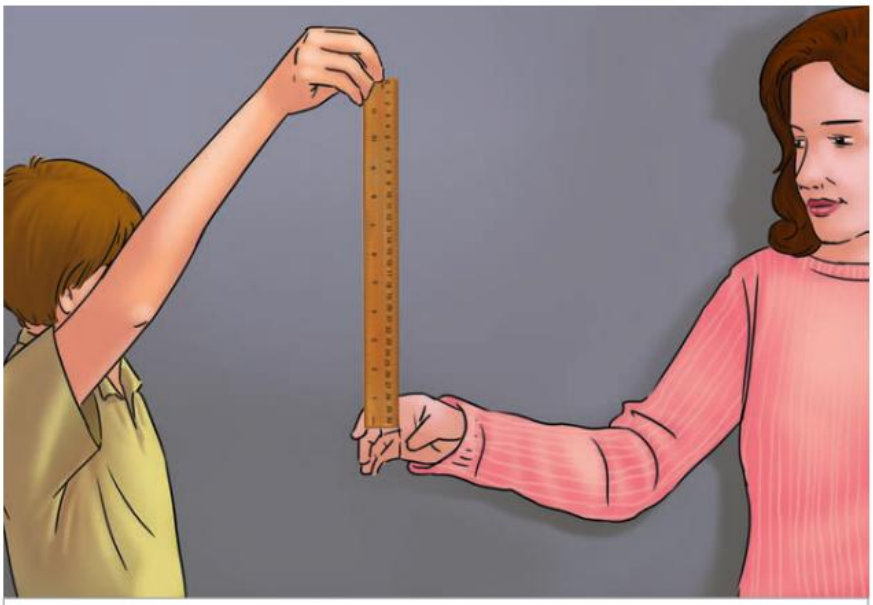


Figure 7.16 Finding your reaction time by dropping a ruler

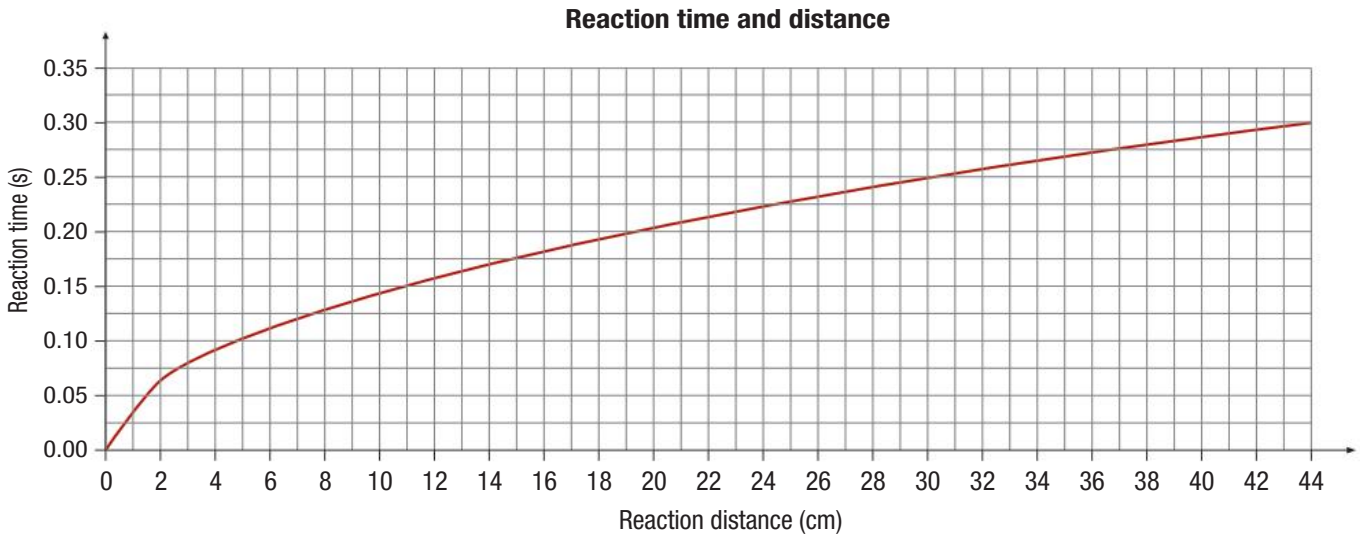


Figure 7.17 Distance versus time graph for a free-falling object, such as a ruler

glossary terms

braking time
the time over which a negative acceleration applies

reaction time
the time between observing a need to act and acting

stopping time
the total time to come to a stop after observing the need to react

ISBN 9780170189071

Factors affecting braking

Four main factors are involved in bringing a car to a stop in a dangerous situation: the visibility, the driver, the car and the road surface. Drivers need to anticipate the possibility of dangerous situations, so alertness and visibility are both involved. An alert driver is neither tired nor distracted while driving. A well-designed car is able to brake quickly and safely. The friction between road and tyres helps achieve the required performance. If the road is slippery, the car cannot brake as effectively as it can under normal, dry conditions (Table 7.1).

Table 7.1 Effect of road conditions on reaction time and braking time

Road conditions	Reaction time	Braking time
Fog	Not affected, but visibility is reduced, so it is hard to identify problems early enough to anticipate braking	Normal, except if the fog has made the road wet
Icy road	Not affected, unless visibility is reduced	Significantly increased
Rain	Not affected, unless visibility is reduced	Increased
Alcohol-affected driver	Increased because driver is slower to react	Increased (worse on wet or icy roads)
Tired driver	Increased because driver is slower to react	Increased (worse on wet or icy roads)

Activity 7.8
Road signs

Which road signs warn drivers of road conditions? Find images of these road signs and upload them to your blog. Include an explanation of what they mean and where, in your local area, you are likely to find them.

Stopping distance

We have seen that stopping time is the sum of the reaction time and the braking time. Similarly, the stopping distance is the sum of the distance travelled during the reaction time (the reaction distance) and the braking distance:

Stopping distance = reaction distance + braking distance

During the reaction time, the car travels at constant speed. Using the equation $v_{av} = \frac{\text{distance}}{\text{time taken}}$, the reaction distance can be calculated.

Example 1: finding the distance travelle

In Figure 7.15 on page 224, the speed was 15 m/s and the reaction time was 0.2 second.

Solution

1 List the variables.

v_{av}	Distance travelled	Time taken
15 m/s	?	0.2 s

2 Write the equation: $v_{av} = \frac{\text{distance}}{\text{time taken}}$.

3 Substitute the values and do the calculation:

$$v_{av} = \frac{\text{distance}}{\text{time taken}}$$

$$15 = \frac{\text{distance}}{0.2}$$

$$\text{Distance} = 15 \times 0.2$$

$$= 3.0\,\text{m}$$

We have shown this on Figure 7.15 on page 224 as the pink shaded area under the graph.

Example 2: finding the braking and stopping distances

In general, the area under a speed versus time graph can be used to calculate the distance travelled, even when the speed is not constant. This means we can calculate the braking distance since this is just the area of the triangle shown on Figure 7.15 as the blue area.

$$\text{Area of triangle} = \tfrac{1}{2}\,\text{base} \times \text{height}$$

$$= \tfrac{1}{2} \times 3.0 \times 15$$

$$\text{Braking distance} = 22.5\,\text{m}$$

For the scenario in Figure 7.15, the total stopping distance is:

$$\text{Stopping distance} = \text{reaction distance} + \text{braking distance}$$

$$= 3.0 + 22.5$$

$$= 25.5\,\text{m}$$

Driver concentration

It is dangerous to drive while distracted. People have been booked for applying make-up or eating and drinking while driving. One woman in the United States was arrested for driving while not only holding a cigarette and a drink can,

ISBN 9780170189071

but also attending to 27 dogs jumping around inside the car! In Australia, the United States and United Kingdom, bicyclists have been injured or killed by drivers who were texting and driving simultaneously. Laws have therefore been enacted to restrict mobile phone usage while in charge of a vehicle. Police now routinely check mobile phone records to see whether a person involved in an accident was talking or texting at the time. Here is one account:

> I was following an 18-year-old lady on the Northern Beaches when the vehicle, for no reason, crossed to the wrong side of the road and collided head-on with a truck. She was killed instantly and we believe at the time she was using a mobile phone to text or talk to somebody … It only takes that one moment of lack of concentration.

Source: Gemma Jones, 'Mobile phones "road death devices" – police', the *Australian*, 1 September 2008 (www.theaustralian.com.au/australian-it-old/mobile-phones-road-death-devices-nsw-police/story-e6frgan6-1111117358650).

People who study motor vehicle safety and the factors that contribute to road use accidents include mechanical engineers, design engineers, physicists, mathematicians, sociologists, behavioural psychologists and neuropsychologists. It is rare for scientists to work alone in such a complex field. For example, physicists work with neuroscientists to observe and explain why the brain gets injured at several points when a person's head crashes into a windscreen. (It has to do with waves sloshing around in the head!) Design engineers work with mechanical engineers to plan and build vehicles that can safely withstand crashes. Physicists examine the accelerations and forces associated with crashes, while neuroscientists examine the effects on the brain of crashes, including acquired brain injuries. Other scientists, such as psychologists and neuropsychologists, work with physicists, mathematicians, design engineers and sociologists to understand human beliefs, behaviours and reactions to situations, and then plan for systems that reduce the risk of crashes. Some of the work of multidisciplinary teams involved in accident analysis and prevention can be seen at the Monash University Accident Research Centre (MUARC).

WEBLINK
MUARC

Activity 7.9
Careers in road safety

Choose one of the careers just mentioned, or another that your teacher selects or approves. Create a voki to represent your chosen career. The voki is to tell the name of the career, the years of study to attain the qualification and where the study can be done. List five positive things about the career. Upload the voki to the class wiki.

WEBLINK
Voki

Activity 7.10
Distraction and stopping distance

WORKSPACE
Distraction and stopping distance
SCI10SIWR00182

A driver must be alert and ready to respond to any emergency. While driving, you have your foot on the accelerator. When you respond to a situation, you take your foot off the accelerator and place it on the brake.

In this activity, you will simulate the distraction of talking on a mobile phone while driving. Your foot will be placed on an 'accelerator simulator', which is a 1 m ruler to which an elastic material is attached (Figure 7.18 on page 228).

When you are required to respond, you take your foot off the 'accelerator' and then return it as though braking. At this point, the accelerator becomes the 'brake'. When you

glossary terms

braking distance
the distance travelled while applying the brakes until coming to a stop

reaction distance
the distance travelled before responding to the need to act

stopping distance
the total distance to come to a stop after observing the need to react

ISBN 9780170189071

Figure 7.18 A student places a foot on an accelerator simulator (1 m ruler attached to elastic material). Braking is simulated by raising the foot and quickly returning it to the ruler.

take your foot off the accelerator, the elastic moves the ruler. When you put your foot back down to brake, the ruler stops moving. The distance the ruler moves from release to return is your reaction distance.

Aim

1 Write down the aim of this activity.

2 Write an appropriate hypothesis based on your aim statement.

3 What do you predict will be the result of your investigation?

Materials

Per group of 3 people:

- 1 m ruler
- 60–80 cm length of elastic material
- chair
- rigid support, such as a bench or table leg
- masking tape
- reversible STOP and GO signs (you could use digital STOP/GO signs if you have access to an interactive whiteboard or computer)

Method

1 Attach one end of the elastic material securely to the ruler.

2 Attach the other end of the elastic material firmly to the base of the rigid support.

3 Lay the ruler on the floor so that the elastic material is stretched by about one-third of its length.

4 Place a piece of masking tape on the floor at the end of the ruler.

5 Seat the 'driver' on the chair with his or her foot comfortably placed on the end of the ruler nearest the elastic material, as shown in Figure 7.18.

Part A: reaction distance when concentrating

6 Assign the following tasks: driver, recorder and signaller (in charge of the STOP/GO signs).

7 Partners are to do this as quietly as possible – no distractions!

8 The signaller stands directly in front of the driver with the GO sign facing the driver and then quickly flips it to STOP.

9 When STOP appears, the driver takes their foot off the ruler and then quickly returns it.

10 The recorder notes down the distance the ruler moved while the driver's foot was off the ruler.

11 Return the ruler to its original position.

12 Repeat steps 8–11 five times, each time making the switch from GO to STOP unpredictable.

13 Give each partner a chance to be driver, recorder and signaller.

Part B: reaction distance when distracted

14 Assign the following tasks: driver, signaller/recorder and distractor.

15 Locate the distractor where he or she can talk to the driver, but can see neither the driver nor the signaller. (You could have a real mobile phone conversation with the driver.)

16 Start the conversation.

17 The signaller flips from GO to STOP.

18 The driver reacts by raising and lowering his or her foot.

19 Repeat steps 16–18 five times, each time making the switch from GO to STOP unpredictable.

ISBN 9780170189071

20 Give each partner a chance to be driver, signaller/recorder and distractor.

Results

1 Complete the data table below.

2 Identify one thing that could have affected the accuracy of the data in:

a part A

b part B.

Discussion

3 How did this activity model the real situation?

4 Does this model allow you to measure the time taken for a person to begin to react to a dangerous situation? What response is the model actually measuring?

5 Identify three more factors that are likely to affect a driver's reaction time.

Conclusion

6 How did your prediction relate to the data that you collected?

7 Relate your data to the purpose of this activity.

Extension

8 How could you improve this activity to measure the reaction time more accurately? You might consider using video analysis or an electronic circuit.

9 Look at the research behind determining the 40 km/h speed in school zones and the 50 km/h speed limit in residential areas. What factors led to these speed-limit decisions? Using your knowledge of speed, distance, reaction time, acceleration, braking time and braking distance, justify or refute this statement: '40 km/h is too fast in school zones'.

Partner's name	Part A: no distraction Reaction distance (cm)		Part B: distraction Reaction distance (cm)		Difference (cm)
	Trials	Average	Trials	Average	Part B – part A

Questions 7.2
What have you learnt?

WORKSPACE
What have you learnt? 7.2
SCI10SUWR00183

Understand

1 What is the difference between acceleration and deceleration?

2 a Define:

i reaction distance, *R*

ii braking distance, *B*

iii stopping distance, *S*.

b Hence, write an equation that links *R*, *B* and *S*.

3 How do you convert km/h into m/s?

Apply

4 a A car accelerates from 0 to 100 km/h in 4.0 seconds. Draw a correctly constructed graph with appropriate axes to show this information.

b Work out the acceleration of the car in:

i km/h/s

ii m/s^2.

c Is the answer to part **b** a positive or a negative acceleration? Explain.

d On the graph, show how the acceleration can be calculated from the graph line.

ISBN 9780170189071

5 Complete the following table.

a_{av} (m/s²)	Speed change (m/s)	Time interval (s)
?	12	4.0
28	?	4.2
6.3	25	?

Analyse

6 A wombat waddles onto the road as a car approaches, travelling at 72 km/h (20 m/s). The driver takes 0.2 second to recognise the danger before applying the brakes. It then takes a further 3.0 seconds before the car comes to a stop. Fortunately, the car just pulls up short of the wombat.

- **a** Draw to scale a speed versus time graph to show this situation, starting from the time the driver first notices the wombat.
- **b** What is the stopping time?
- **c** How far does the car travel before the driver starts to brake?
- **d** What is the acceleration of the car while it is braking?
- **e** How far does the car travel while it is braking?
- **f** What is the stopping distance?
- **g** How far was the wombat from the car when the driver spotted it?
- **h** Calculate the average speed of the car during:
  - **i** the braking distance
  - **ii** the stopping distance.

7 Identical cars travel at 72 km/h and 90 km/h respectively. Both drivers have reaction times of 0.2 second. The cars brake at the same rate. Draw an accurate speed versus time graph for each car on the same set of axes. Use your graph to answer these questions.

- **a** How much further does the faster car travel before the brakes are applied?
- **b** If the braking time for the slower car is 2.8 seconds, what is the braking time for the faster car?

Reflect

8 Which is more important: acceleration time to 110 km/h, or deceleration time from 100 km/h? Give reasons for your answer. Discuss your answer with others to help with your culminating assessment task.

9 What safety measures do you think could be introduced to reduce:

- **a** driver reaction times
- **b** stopping distances?

Causes of motion

We have learnt how to describe motion using data related to position and time. But what causes things to change position? Ideas developed more than 2500 years ago still influence our thinking today, even though they are no longer used in science. We will look at these early ideas and compare them with our current way of understanding motion.

Early Greek ideas about motion

Our current ideas about motion have developed through a long line of careful thought, observation and measurement. These ideas have been significantly influenced by the wonderfully vibrant classical Greek culture that blossomed from the fifth century BCE. Plato's student Aristotle (384–322 BCE) is the most well known of the Greek philosophers who discussed motion (Figure 7.19). His enormously influential works were taught in the schools and universities of late antiquity and the middle ages. For nearly 1800 years,

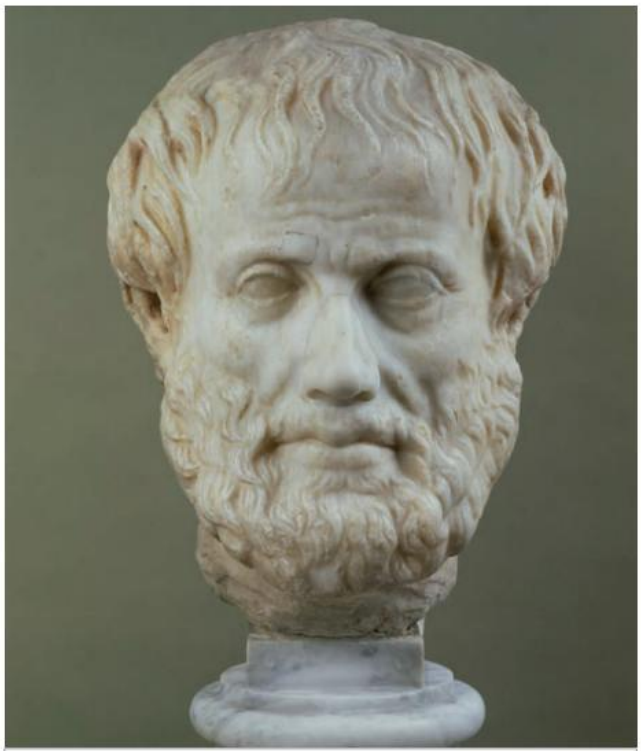


Figure 7.19 Bust of Aristotle

ISBN 9780170189071

a generally Aristotelian physics was accepted as true by most educated people. Philosophers and commentators on Aristotle's works – for example, Greek Christian–Platonist John Philoponus (490–570 CE) – sometimes disagreed with his conclusions, but Aristotle's thought was central to their understanding of how the world works.

From the 15th to the 17th centuries, Aristotle's views were further challenged by people such as Nicolaus Copernicus, Johannes Kepler, René Descartes and Isaac Newton. Even Newton's major work on motion sounds remarkably Aristotelian in parts. Ultimately, this led to a change in the way we understand motion.

Activity 7.11
Motion timeline

Create a timeline of significant developments in the understanding of motion.

What were Aristotle's ideas?

Aristotle's ideas on motion are complex. We shall simplify them considerably here. First, Aristotle separated the motion on Earth from the motion in the heavens, by which he meant beyond the Moon. On Earth, the natural motion of everything was not to move at all. If things were moving, it was natural for them to move in a straight line, either up or down with respect to the centre of the Earth. Heavy things naturally go down and light things naturally go up. For Aristotle, this made sense because the nature of a thing explains how it moves. That is, things move according to their natural motion unless forced to do otherwise. Air will go up (because it is lightweight) unless it is contained in a box. Therefore, Aristotle thought that some external force is needed to make things move horizontally – he called this the efficient cause. Violent force pushed things off their straight line, natural course. For example, violent force made things on Earth move in circles (Figure 7.20).

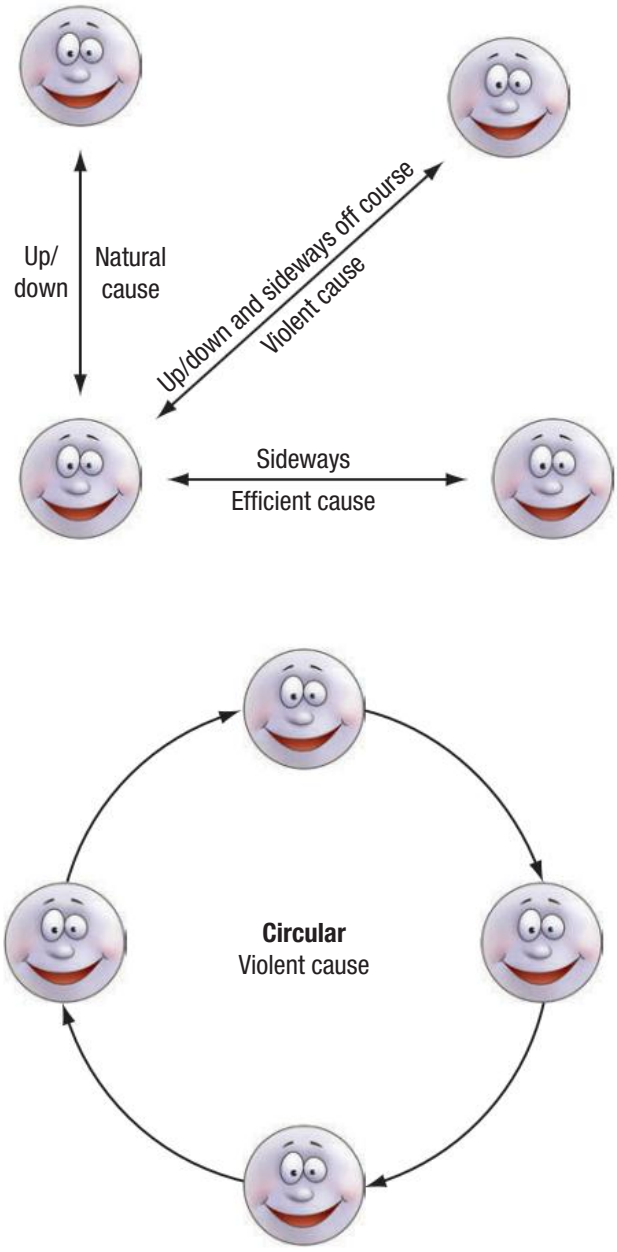


Figure 7.20 Aristotle's ideas about motion. Some things naturally go up, others naturally go down. Efficient force makes things move horizontally. Violent force causes things to move in circles. Beyond the Moon, things were different. These ideas are no longer considered to be correct.

glossary terms

Aristotelian
adhering to the ideas of Greek philosopher Aristotle

efficient cause
for Aristotle, the force needed to make things move horizontally or change direction

natural motion
what things do, of themselves

the heavens
for Aristotle, the region beyond the Moon

violent force
for Aristotle, the force that made things go off course, such as circular motion

ISBN 9780170189071

Aristotle's idea was that if you pushed an object, such as a cart, in one direction and there was a smaller resistance force pushing in the other direction, the object would travel at a constant speed. That is, Aristotle said that if there is a constant net force pushing on an object, the object will move at constant speed (Figure 7.21).

It is perhaps surprising that Aristotle did not think about how objects start moving. If you are stopped and a force is applied to you, you start to move and your speed increases – that is, you accelerate. What is equally surprising is that many people today still use Aristotle's idea to explain how things move, even though, with just a little thought, they would realise that it is obviously incorrect.

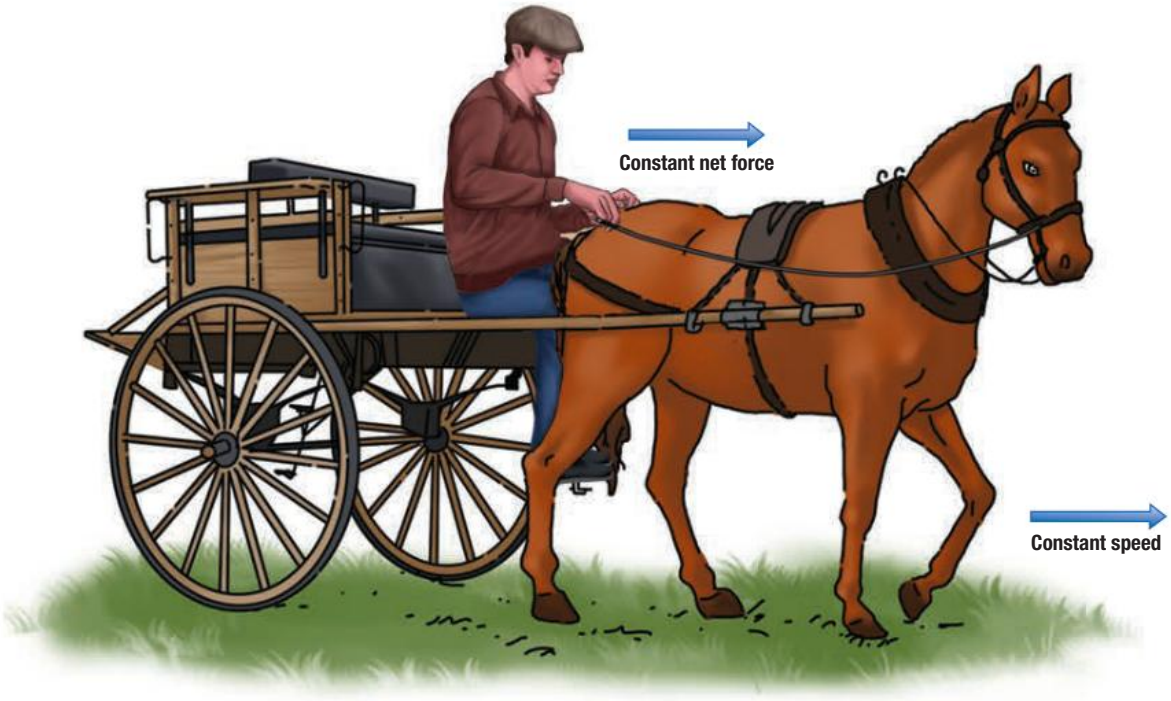


Figure 7.21 Aristotle's idea: net force causes constant speed. This idea is no longer considered to be correct.

WOW!

Force and motion

Beyond the Moon, Aristotle said that motion obeyed different principles. For Aristotle, the heavens were eternal and unchanging – he could see that the Moon was subject to change. When he spoke about the heavens, he meant the stars and planets. Like us, Aristotle observed that the Sun, stars and planets moved in circles around the Earth. He believed that this was because of the naturally circular motion of the element in the heavens, an element not found on Earth. Aristotle thought all things on Earth were made up of mixtures of fire, earth, air and water. A fifth pure element, the aether, was only found in the heavens. The existence of the aether was controversial from antiquity to the early 20th century, when it was finally rejected.

You can find out more about Aristotle's ideas by going to the weblink 'Aristotle's ideas'.

WEBLINK
Aristotle's ideas

CONNECTION
Literacy and history: Aristotle
SCI10SHCN00184

ISBN 9780170189071

Questions 7.3
What have you learnt?

WORKSPACE
What have you learnt? 7.3
SCI10SUWR00185

Understand

1 According to Aristotle:
   - **a** What was the natural motion for things on Earth?
   - **b** Why did things move vertically in straight lines?
   - **c** What happened beyond the Moon?
   - **d** What was the effect of a constant net force on the motion of an object?

Apply

2 When you ride a bicycle, you pedal with a constant effort to maintain a constant speed. How would Aristotle explain this?

Analyse

3 Aristotle said that horizontal motion needed an efficient cause, but vertical motion did not. Explain.

A new physics of motion

By the beginning of the 17th century, Aristotle's ideas about motion came under renewed scrutiny. They were shown to have several major problems. A new physics of motion began to be developed. It used force in a new way. In this new physics, which is still part of the physics we use today, forces acted externally on objects, no matter whether the object was on Earth or in the heavens. They were not contained in, or somehow natural to, objects. Forces caused things to move upwards, downwards and sideways. And non-zero net forces caused accelerations, not constant speed.

We shall now look at forces as we understand them today.

Forces act in pairs

Suppose you touch a vase. The vase touches you at the same time. Could you sneak up on the vase and touch it before it touched you? Of course not!

You cannot apply a force to an object without that object applying a force back on you. Each object always applies the same force back on the other object (Figure 7.22).

Forces: agent and receiver

A working definition of a force is that it is a push or a pull. Forces act from outside things – that is, a push or a pull is applied by something to something else. We shall refer

Figure 7.22 You cannot touch something without it touching you at exactly the same time. You cannot kiss someone without being kissed. You cannot push on someone without them pushing right back the same.

glossary terms

aether
for Aristotle, a heavenly substance

force
a push or pull applied by agent A on receiver B

net force
the addition of two or more forces applied to a single thing

resistance force
the force applied to an object in the direction opposite to its motion

ISBN 9780170189071

to the thing doing the forcing – the 'doer' of a force – as the agent:

F(by agent on receiver)

The girl in Figure 7.23 is the agent of the force applied to the wall. She is doing the forcing on the wall. The force applied by the girl to the wall would therefore be written as:

F(by girl on wall)

We shall refer to the thing to which the force is being applied as the receiver. The wall receives the force applied by the girl to the wall; hence, the force 'by girl on wall' in the symbol above. Equally, however, we could write this the other way around: if we think of the wall as the agent and the girl as the receiver. The force by the wall on the girl is written as:

F(by wall on girl)

We can see therefore that forces always act in pairs. These two forces are always equal in size and act in opposite directions. They act on different things: one force acts on the wall; the other, on the girl.

We shall see that this distinction becomes very important later on, when we are looking at the forces applied to one thing to affect its motion.

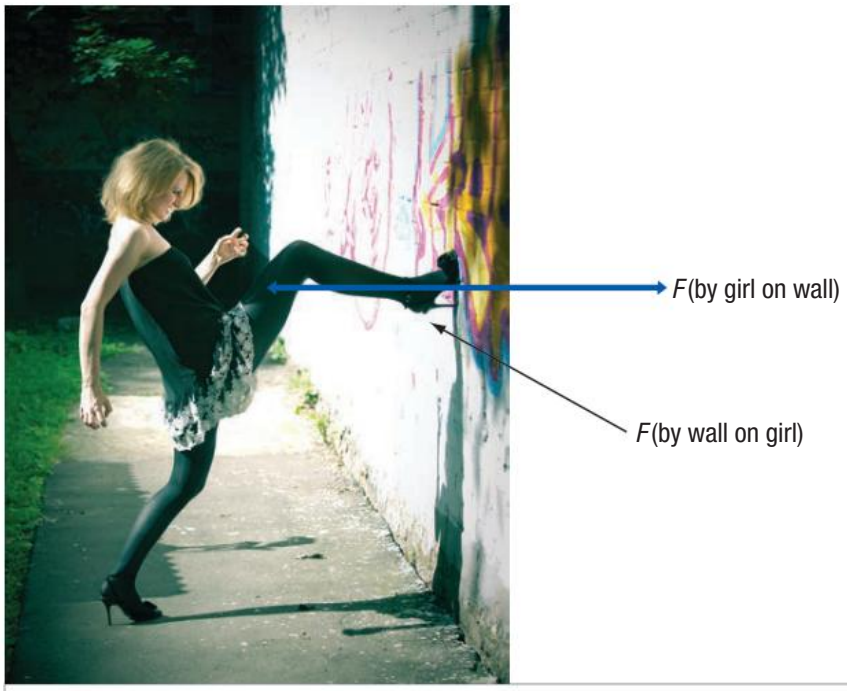


Figure 7.23 The girl kicks the wall and the wall pushes right back. The two forces are always equal, opposite in direction, but act on different things. What is the agent and receiver for the foot pushing down on the ground?

Activity 7.12
Agent and receiver

WORKSPACE
Agent and receiver
SCI10SIWR00186

Something or someone that exerts a force is called the agent of the force. The receiver is the thing or person on which the force is applied. An object cannot exert a force on itself. It must always interact with another thing.

In this activity you are to take photos of 10 different interactions in which a force is applied and received. Make sure you use some contact and some non-contact situations.

1 For each photo, identify the agent, the receiver and the effect on the receiver.

2 Count the number of objects involved in each situation. For example, if you use a finger to turn off a light switch, the finger is the agent, the light switch is the receiver and there are two objects involved: finger and switch. We write this as *F*(by finger on switch) (Figure 7.24).

ISBN 9780170189071

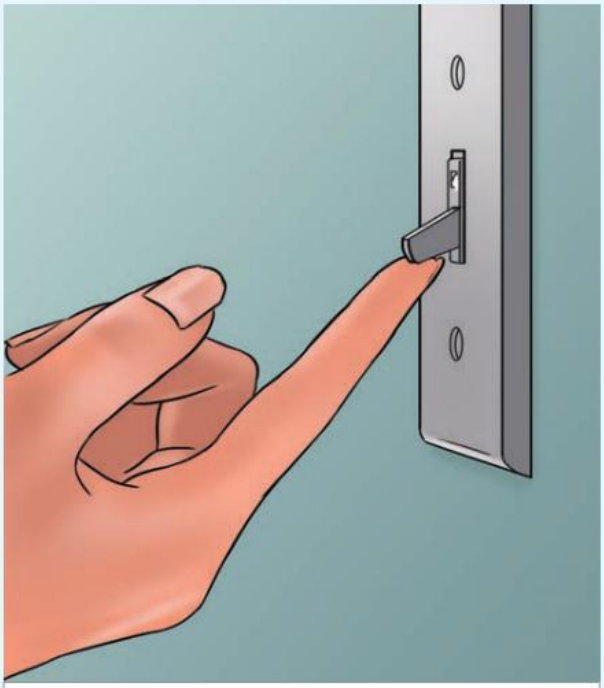


Figure 7.24 Two objects – finger and switch – are involved in turning on the light. The finger applies an external, contact force to the switch, *F*(by finger on switch). At the same time, the switch applies a force to the finger, *F*(by switch on finger).

3 For each photo, identify and name the force applied, from the point of view of the opposite pair.
Forces always act in pairs; thus, agents can be receivers. For example, from the point of view of the switch, the switch applies a force to the finger (Figure 7.24).

4 Set out your results in the data table below.

5 Complete this activity by creating a poster from one of the situations you analysed to represent the idea that forces act in pairs.

WEB 2.0

Choose six of these photos and create a photocube. Upload this to the class wiki.

WEBLINK
Photocube

Force in one direction				Paired force in opposite direction			
Object applying the force (agent)	**Object experiencing the force (receiver)**	**Effect of force**	**Name of force** ***F*(by A on B)**	**Name of the paired force** ***F*(by B on A)**	**Object applying the force (agent)**	**Object experiencing the force (receiver)**	**Effect of force**
Finger	Switch	Switch moves	*F*(by finger on switch)	*F*(by switch on finger)	Switch	Finger	Finger slows

glossary terms

agent
the thing applying the force to another thing (receiver)

receiver
the thing being forced on by another thing (agent)

ISBN 9780170189071

Representing forces

We can represent a force with an arrow. We start the arrow at the point where the force is applied. The head points away from the point of action. The lengths of arrows in a diagram indicate the relative sizes of the forces. In Figure 7.23, the forces both start where the foot and the wall are in contact. The arrows point in different directions. The lengths are the same because the forces are equal in size.

ACTIVITY SHEET

Newton: force arrows and sports

SCI10SIAS00187

Driving a car

You are a driver, sitting in a car seat about to set off. You will go directly forwards. For the moment, we will consider only the forces that are applied horizontally to your back. You touch the back of the seat. If you push on the back of the seat, it must automatically push back on you. The force by the seat on you is the same size as the force you exert on the seat. However, before you start off, you are only touching the back of the seat, but not pushing into it. As you are not pushing into the back of the seat, the back of the seat is not pushing into you.

Now, you start to move the car. As your speed increases, you feel the back of the seat pushing on your back. It is this force that pushes you forwards. It is this force that causes you to accelerate. At the same time, you push backwards into the back of the seat with the same amount of force. However, this force is applied to the back of the seat, not on you, so it has no effect on your motion. The seat does not go back because it is attached to the car body. The force you apply on the seat is trying to push the whole car backwards. Your effect on the whole car is small compared with the effect of the seat on your relatively small mass.

So why doesn't the force by the back of the seat on you cause you to go forwards into the windscreen? The reason is because you, the back of the seat and all of the rest of the car are accelerating at the same rate, so there is no relative motion between you, the seat and the car.

Other horizontal forces are being applied to you that oppose the force applied to you by the back of the seat. These include the force by the floor of the car on your feet. Another force on the driver is the force by the steering wheel on the driver – that is, F(by steering wheel on driver). Notice that the force by the driver on the back of the seat does not affect the driver; it only affects the seat. The sum of all the forces acting on one thing – the object or receiver – is called the net force: F(net, on receiver).

In Figure 7.25 the net force on the driver in the horizontal direction is:

$$F(\text{net, on driver}) = F(\text{by seat on driver}) - F(\text{by floor on driver}) - F(\text{by steering wheel on driver})$$

Figure 7.25 The driver (agent) forces on the back of the seat (receiver) with exactly the same size of force as the back of the seat (agent) forces on the driver (receiver).

ISBN 9780170189071

Notice that when you are working out the net force, the receiver must always be the same. In the equation on page 236, the receiver is the driver for each of the forces.

Let us now consider what happens if the car were to slow down quickly, such as in emergency braking. You continue to go forwards – there is no force on you to stop you – but the seat behind you slows down. So does the windscreen because both the windscreen and the seat are effectively attached to the car through the car body. No longer are you touching the seat, so the seat cannot push on you. You may not have the strength to push effectively on the steering wheel or the floor, so you will now continue on towards the windscreen.

This is of course the physics behind seatbelt legislation. If you are effectively tied into the car, you will come to a stop with the car. The seatbelt applies a force to you to slow you at the same rate as the car: F(by seatbelt on driver). This way, you, the seat and the windscreen keep the same distances apart (Figure 7.26).

Forces summary

Going back through our discussion, we can summarise the main points about forces.

1. Everything we have said relates to the basic notion that forces are actions, such as pushes and pulls. They are applied externally to things. There is an external agent that applies a force to an object, which we called the receiver. Of course, agent and receiver can swap places, depending on our point of view.
2. If no force is applied to an object, the object will continue to do what it has been doing. If stopped, it will continue to be stopped. If moving, it will continue to move at that speed. It will not change direction either.
3. The sum forces, or net, acts on a single receiver. The forces that add up to make a net force all act on the same receiver.
4. Forces act in pairs. The force by an agent on a receiver is the same size as the force by the receiver on the agent. Therefore, they are acting in opposite directions. They are also acting on *different* objects!
5. Although every pair of forces are equal and opposite, they cannot add up to make a net force because they affect different objects – the receivers are different.

Activity 7.13
Seatbelts

WORKSPACE
Seatbelts
SCI10SIWR00188

1. Research seatbelt laws in your state or territory. When did they come into effect? What led to this law? Compare Australian seatbelt laws with those of four other countries. What is the same or different between the countries? Why do you think there are differences globally?
2. Justify or refute one of the following.
   a. Seatbelts should be compulsory in all countries in the world.
   b. Seatbelts should be compulsory on all public transport in Australia.
3. Create an advertising campaign to heighten awareness of the importance of wearing seatbelts for a country that does not have these laws. Remember to be culturally aware when developing your campaign.

Figure 7.26 A seatbelt applies a force to the driver to slow the driver with the car. This keeps the driver from carrying on towards the windscreen when the car slows down.

ISBN 9780170189071

Questions 7.4

What have you learnt?

WORKSPACE

What have you learnt? 7.4

SCI10SUWR00189

Understand

1 For each of the terms below, write one definition suitable for a five year old and another for an adult.
   - **a** Force
   - **b** Agent
   - **c** Receiver
   - **d** Net force

2 Write down the rules for representing forces with arrows.

Apply

3 Sketch the following situation: 'When a net force is applied to a book, it starts to move across a table.' On your sketch, draw force arrows to show the horizontal forces applied to the book. Label the arrows.

Analyse

4 When you push on the floor, the floor pushes back. On a diagram, show how you can be both agent and receiver.

5 Forces act in pairs that are equal in size and opposite in direction. Does this mean the net force is always zero? Explain.

Reflect

6 Why do you think that many people today still think, incorrectly, that a constant force causes things to move at constant speed?

7 Words and ideas such as 'agent', 'receiver' and 'net force' might be new to you. Think about these and other words and ideas that are not yet on your illustrated and annotated list from Activity 7.1. Add anything new, with an appropriate image and annotation.

8 Complete a five whys on the following: 'Why is it important to have historical perspectives on how things develop?'

Net force

Several agents can apply forces to a single receiver. Forces applied to one receiver can be added up. What is the effect of a net force on an object?

We shall first consider things moving in a straight line. This is the simplest form of motion. Along a straight line, forces may be positive if pointing to the right, or negative if pointing to the left (Figure 7.27).

Forces can change the direction of the object's motion; however, we will only consider straight-line motion at the moment.

- If the force acting on an object in one direction is greater than that from the other direction, a change to the motion occurs. The object goes faster or slower.
- If the forces on the object are equal, but pointing in opposite directions, the object simply continues to sit there or continues on at its speed at the time the two equal forces were applied.

Net force causes acceleration

You are about to drive off down the street. At the start, your speed is zero – you are not moving. However, with the engine going and the car in drive gear, you increase your speed evenly up to 60 km/h – that is, you accelerate uniformly to 60 km/h in 10 seconds. You maintain this speed for 20 seconds and then you slow uniformly to a stop over 15 seconds (Figure 7.28).

A car is forced forwards by the driving force and slowed by resistance forces:

$$F(\text{net, on car}) = F(\text{by driving force on car}) - F(\text{by resistance force on car})$$

It is the net force that causes the car to accelerate (0–10 seconds) and to come to a stop (30–45 seconds). When the net force is zero, the car travels at constant speed (10–30 seconds).

1 If the driving force on the car is greater than the resistance force on the car, the car accelerates (positive acceleration).

Figure 7.27 Forces along a straight line: positive forces point to the right, and negative forces point to the left.

ISBN 9780170189071

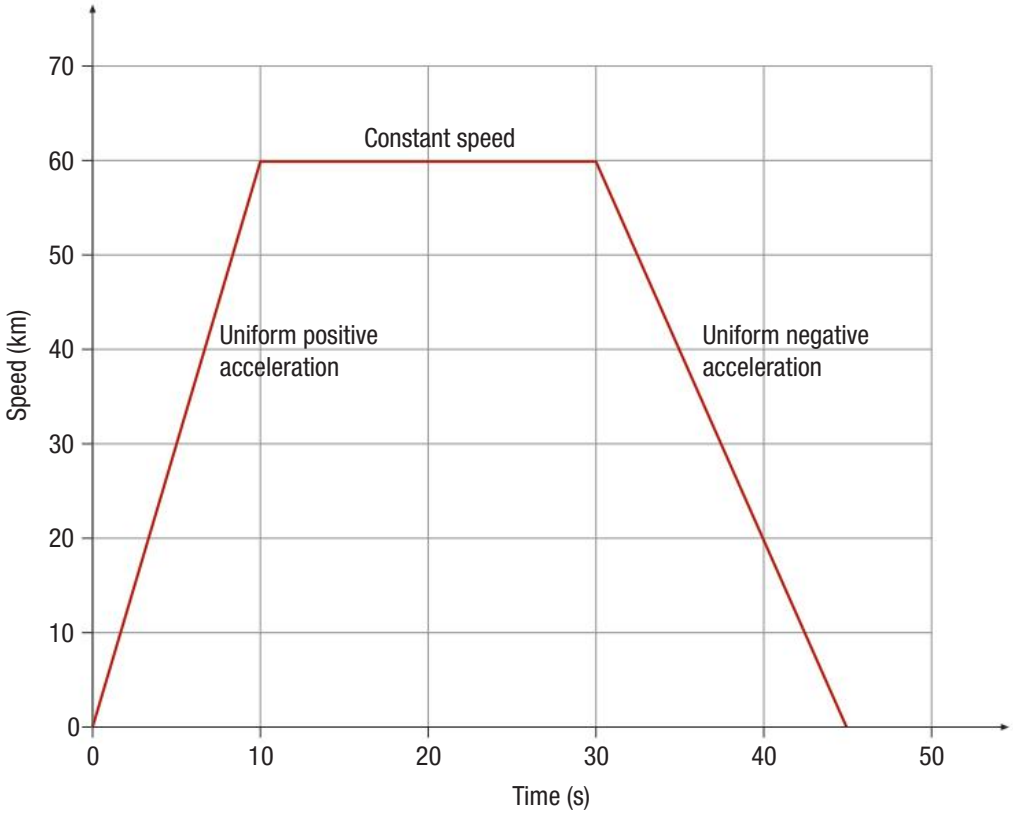


Figure 7.28 A short car trip, showing uniform positive acceleration, constant speed and uniform negative acceleration (deceleration)

2 If the driving force on the car is the same as the resistance force on the car, the car maintains a constant speed.

3 If the driving force on the car is less than the resistance force on the car, the car decelerates (negative acceleration).

One other factor affects the way a car accelerates. Imagine that you want to compare the acceleration of two cars. Both cars have the same driving force and resistance force; hence, the same net force is applied to them. The car that weighs less – that is, has less mass – will gain speed quicker. It will have a greater acceleration.

In summary, the acceleration of the car, a(car), is caused by the net force, F(net, on car), and affected by the mass of the car, m(car). We can write this as an algebraic relationship:

$$a(\text{car}) = \frac{F(\text{net, on car})}{m(\text{car})}$$

This relationship works for all masses, not just cars, that are subjected to net forces. We can remove the car reference and write it as:

$$a = \frac{F(\text{net})}{m}$$

Independent and dependent variables

A quantity that changes is called a variable because it changes. Some quantities are known to vary, but only when another one causes it to change. These are called dependent variables. The variables that cause change are called independent variables. In mathematical formulas, the dependent variable is always on the left-hand side and all the independent variables are on the right-hand side.

The relationship $a = \frac{F(\text{net})}{m}$ has all the variables in their correct positions. The acceleration depends on force and mass; it is therefore the dependent variable. Force and mass are independent variables.

Very frequently, you see this relationship turned into the formula $F(\text{net}) = ma$. This is algebraically correct, but it suggests that the net force is caused by the acceleration and the mass. This is not the case.

ISBN 9780170189071

Investigation 7.2

Newton's second law

Your challenge

Design and conduct a series of experiments that demonstrate the relationship between acceleration, force and mass. Revise the rules for experimental design.

This might help

1 For this investigation, there are two independent variables: force and mass. How will you make sure that you only change one at a time so that you can observe the effect of one independent variable at a time?

2 The dependent variable is the acceleration. How will you measure the acceleration?

You may like to consider the weblink 'Visualising Newton's third law' before starting out on your experiment.

WEBLINK
Visualising Newton's third law

CONNECTION
Maths: Newton's second law
SCI10SUCN00223

Things to think about

1 You could use a spring balance that you stretch to different lengths to act as the force. (The length by which the spring is stretched is a good measure of the force.)

2 A loaded trolley could be accelerated by masses falling vertically over a pulley. (This is reasonably simple, but there's a bit of a trick to the analysis – ask your teacher for advice on this one.)

3 How will you measure the acceleration? For example, will you use a data logger, ticker timer or some other technology that can measure acceleration.

4 How will you record the data?

5 What graphs will you draw to find:
- **a** the acceleration
- **b** the way the acceleration changes as the force is altered
- **c** the way the acceleration changes as the mass is altered?

Prepare a report on your work, including an evaluation of the quality of the data and the conclusions. Suggest improvements you would make if you did the experiment again. Write up your report using the guidelines on page 283.

Finding acceleration

The equation $a = \frac{F(\text{net})}{m}$ has three variables – a, $F(\text{net})$ and m – so there are three possible calculations, depending on what the unknown variable is. Before performing the calculations, however, we need to list the variables and the values given in the question. (Note that force is measured in newtons.)

Example 1: find *a*

A 10 newton (N) force is applied to a mass of 5 kg. What is the acceleration of the mass?

Solution

1 List the variables.

F(net)	*m*	*a*
10 N	5 kg	?

2 Write the equation: $a = \frac{F(\text{net})}{m}$.

3 Substitute the values and do the calculation:

$$a = \frac{10\,\text{N}}{5\,\text{kg}}$$
$$= 2.0\,\text{m/s}^2$$

Example 2: find *F*(net)

A 900 kg car accelerates at a rate of 1.5 m/s^2. What is the net force applied to the car?

Solution

1 List the variables.

F(net)	*m*	*a*
?	900 kg	1.5 m/s^2

ISBN 9780170189071

2 Write the equation: $a = \frac{F(\text{net})}{m}$.

3 Substitute the values, tidy up the algebra (one step is needed) and then carry out the calculation:

$$1.5 = \frac{F(\text{net})}{1000}$$
$$F_{\text{net}} = 1.5 \times 1000$$
$$= 1500\,\text{N}$$

Example 3: find *m*

A truck brakes at a rate of 2.0 m/s^2 by applying a net force of 22 000 N. What is the mass of the truck?

Solution

1 List the variables.

F_{net}	m	a
–22 000 N	?	–2.0 m/s^2

2 Write the equation: $a = \frac{F(\text{net})}{m}$.

3 Substitute the values, tidy up the algebra (two steps are required: multiply by *m* and divide by 2.0), and then do the calculation:

$$-2.0 = \frac{-22000}{m}$$
$$2.0 \times m = 22000$$
$$m = \frac{22000}{2.0}$$
$$= 11000\,\text{kg}$$

Newton's three laws of motion

Newton's three laws of motion summarise all that we have discussed about forces. The laws all assume that forces act externally to objects – that is, they are not contained in objects. We use a particular way of writing forces – *F*(by A on B) – so that we can always identify the agent and the receiver of a force.

VIDEO
Newton's laws
SCI10SUVD00190

Newton's first la

Objects stay still or travel in straight lines at constant speed unless a net force acts to cause:

- a gain in speed (positive acceleration)
- a loss of speed (negative acceleration, deceleration)
- a change in direction
- a change in speed and direction simultaneously.

Newton's second law

We can calculate the effect of force and mass on the acceleration of objects by the algebraic relation:

$$a = \frac{F(\text{net})}{m}$$

Newton's third law

Forces act in pairs: *F*(by agent on receiver) and *F*(by receiver on agent). They:

- are the same size
- are opposite in direction
- act on different objects.

You cannot form a net force with these two together!

Questions 7.5
What have you learnt?

WORKSPACE
What have you learnt? 7.5
SCI10SUWR00191

Understand

1 Forces cause masses to accelerate. Which of these variables depends on the other two? Explain.

2 a What is meant by net force?

b A net force of 6.0 N is applied to a 3.0 kg mass. What is the acceleration of the mass?

3 Create a blabber that completes this sentence: 'Learning about motion, speed, reaction time and distances will affect my life by …' Upload your blabber to your blog.

WEBLINK
Blabberize

Apply

4 There is no net force on an aeroplane flying horizontally at a constant speed of 325 km/h. Why then does it need to have the engines going?

ISBN 9780170189071

5 Complete the following table.

F(net) (N)	*m* (kg)	*a* (m/s²)
1000	50	?
?	85	2.3
2500	?	1.6

6 Phil applies a force to the right of 25 N to a 15 kg box. Kim pushes on the box with a force of 10 N to the left. A resistance force of 3.0 N is applied by the floor to the box.

a Use the naming convention *F*(by A on B) to describe each of the three forces.

b What is the net force on the box? Give size and direction.

c What is the acceleration of the box?

Analyse

7 Can a negative acceleration be associated with an object continuing to move forwards? Explain.

8 a A person pushes on a stationary car, which starts to move. The car pushes back on the person with the same size force but in the opposite direction. Do these two forces add up to a zero force applied to the car? Explain.

b How can an agent be a receiver in the same interaction between objects?

Reflect

9 Add to your annotated images from Activity 7.1 any new ideas – such as agent, receiver and net force – that you might need to make sure you understand fully the causes of motion.

10 Create an electronic crossword using 10 of the following 18 terms.

Average speed, velocity, scalar, magnitude, vector, displacement, natural motion, violent force, efficient cause, reaction time, stopping distance, braking distance, reaction distance, acceleration, Système Internationale, aether, agent, variables

Upload your crossword to the class wiki for others to solve. Choose 2 other crosswords to complete.

WEBLINK

Puzzle maker

ISBN 9780170189071

Unit review

ACTIVITY SHEET
Unit 7 checklist
SCI10SUAS00193

REVIEW QUIZ
Unit 7
SCI10SURQ00192

WORKSPACE
Unit 7 review
SCI10SUWR00194

Understand

1 A cheetah chases a kudu (antelope) for 150m and catches it in 6.0seconds. What was the average speed of the cheetah?

2 A clock always measures a time interval. Explain.

3 Define:

a reaction time **b** reaction distance **c** stopping time.

4 For a position versus time graph, what does the gradient measure?

5 For a speed versus time graph, what quantity can you calculate using:

a the gradient **b** the area under the graph?

6 Define Aristotle's ideas of:

a natural cause **b** efficient cause **c** violent cause.

7 According to Aristotle, in which region did Earth's physical laws apply? What was beyond this region?

8 Why are there always an agent and a receiver when a force is applied?

9 Is it true that a constant net force in the forward direction must be applied to a car travelling at constant speed? Explain.

Apply

10 Complete the following table.

v_{av} (m/s)	Distance (m)	Time interval (s)
18.0	?	0.4
10.2	100	?

11 A peregrine falcon swoops vertically past a window of a building at 80m/s. If the window is 2.5m high, for how long was the falcon directly opposite the window?

12 A car accelerates uniformly from a start to 20m/s in 5.0seconds. It travels at constant speed for 2.0seconds and then comes to a stop in 8.0seconds. Carefully draw a speed versus time graph to show this motion. Use the graph to find:

a the speed of the car at:

i 2.0seconds from the start **ii** 9.0seconds from the start

b the acceleration of the car:

i for the first 5.0seconds **ii** at 6.0seconds **iii** at 9.0seconds

c the distance travelled in:

i 2.0seconds **ii** 10seconds **iii** 5.0seconds.

ISBN 9780170189071

13 Complete the following table.

F(net) (N)	m(kg)	a(m/s^2)
1258	62.5	?
?	2500	1.9
15	?	26

Analyse

14 A car starts from rest (zero speed) and takes 10.0 seconds to cover 400 m, at which point it has a speed of 155 km/h.

a Calculate:

i the speed of the car at 400 m (in m/s)

ii the average speed of the car (in m/s)

iii the average acceleration of the car (in m/s^2).

b Draw a speed versus time graph for this motion. Assume the acceleration is constant. What is the average acceleration?

15 A driver travelling at 24 m/s sees a dangerous situation and reacts 0.15 second later. The car decelerates at 4.0 m/s^2.

a Sketch the speed versus time graph.

b On the graph, show how you found the values for:

i reaction time

ii braking time

iii stopping time

iv reaction distance

v braking distance

vi stopping distance.

16 According to Aristotle, the vertical motion of objects did not need a cause, such as a force. How did he explain vertical motion?

17 Explain why Aristotle was incorrect about the effect of a constant net force.

18 A car travelling at 75 km/h comes to a sudden stop. As a result, the driver, who is not wearing a seatbelt, hits the windscreen. Is the driver 'thrown forward' towards the windscreen? Discuss. Use Newton's laws to help your discussion.

Synthesise

19 Use a flowchart to show the steps needed to go from a data table, with position and time measurements, to a graph of speed versus time.

20 Explain how you can use a speed versus time graph to work out the net force applied to an object.

Evaluate

21 Nguyen says it is impossible to use Newton's third law to explain the fact that people can jump up above the ground. This is because the action and reaction forces are equal and opposite, so they add up to a zero net force. Explain why Nguyen is wrong.

22 What are the main differences between Aristotle's ideas about motion and Newton's ideas?

Reflect

23 Do you think some of your ideas about motion before you started this unit were similar to those of Aristotle? Have your ideas changed? Why do you think Aristotle's ideas were accepted for so long?

24 What ideas (new or otherwise) have you found that you needed to be more precise about? Complete your list of motion words, images and annotations from Activity 7.1.

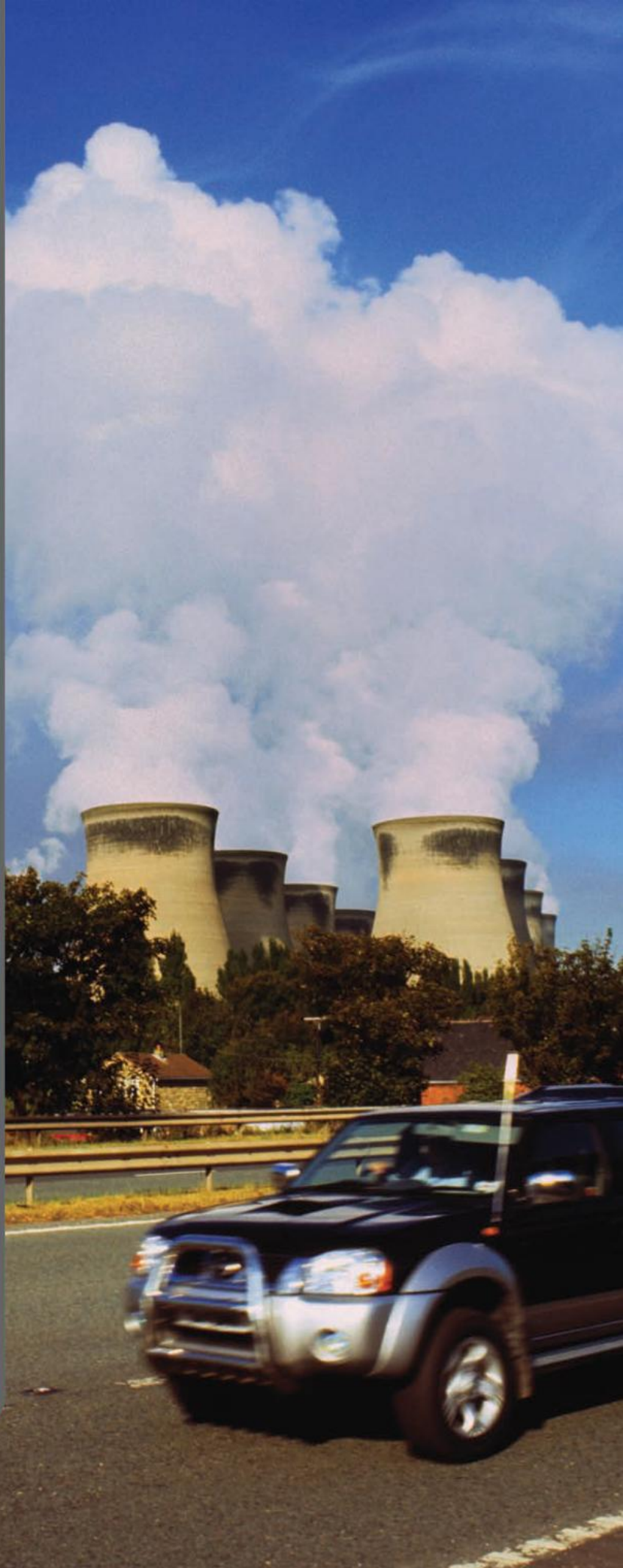
ISBN 9780170189071

8

Energy and systems

How can we understand energy flows into, through and out of systems?

Energy transfer and transformation systems are essential for our society. In this unit we look at three different energy transfer and transformation systems: vehicle movement and safety systems, and the electricity production system. Vehicles transform primary energy into energy of movement, whereas safety systems are designed to manage the transfer and transformation of that energy in collisions. Electrical energy production systems require the conversion of primary energy into electrical energy up to the point where it is distributed to customers. We look at a coal-fired power station in some detail and consider other primary energy sources, including nuclear energy as a source of heat and hydroelectric energy as a direct transformation of gravitational energy to movement energy. All systems transfer and transform energy inside the system. However, they also transfer and transform energy into nearby systems, and then out to the universe, which limits their efficiency. The efficient use of energy in combined heat and power systems is also discussed.



What do you already know about energy and systems?

Energy has many different uses and meanings. We talk about having energy and using energy and energy resources. There are different forms of energy, and ways to take energy in one form and use it in another. How then do you understand the meaning attached to the word 'energy'? How is energy used?

Activity 8.1
What do you already know about energy and systems?

WORKSPACE
What do you already know about energy and systems?
SCI10SUWR00196

1 List as many forms of energy as you can. Which ones are defined by the way they are measured? Which are defined by their source?

2 Write definitions for:
- **a** energy transfer
- **b** energy transformation.

3 Complete the following table.

Basic form of energy	Meaning	Forms	Examples
Kinetic energy			
Potential energy			

4 Give your own opinion about answers to the following questions.
- **a** Do you think chemical energy is best described as kinetic energy or potential energy? Perhaps chemical energy should be classified as both kinetic energy and potential energy. What do you think?
- **b** How is energy involved in car crashes?
- **c** Why do you think nuclear energy can be described as both potential energy and kinetic energy?
- **d** What do you think is meant by the word 'heat'?

5 Discuss your answers to Question **4** with a group of your classmates. If you need to, refine your answers based on the discussions.

6 Keep your own set of answers to these questions. You could do this in an electronic workbook or share them on a blog. From time to time, you can go back to them and change them as you build your understanding. You could get help from fellow bloggers to build up your understanding.

Culminating assessment task
Analysing an energy transfer and transformation system

Your task

Describe energy transfers and transformations in one of the following.

- Car movement systems
- Vehicle safety systems
- Electricity production systems

What to do

1 Decide on the system you will analyse.

2 Describe the purpose of the system.

3 Give a clear written and visual description of the selected system.

4 Define and identify the inputs, outputs, processes and emissions (intended and unintended) of the system.

5 Provide specific details of major design features that enable the system to work effectively.

6 Find and report details of the efficiency of the system:
- **a** overall
- **b** between major components of the system.

ISBN 9780170189071

7 Produce an annotated Sankey diagram to represent the energy flow into, through and out of the system from beginning to end (Figure 8.1).

8 Describe the educational pathways and science-based work undertaken by a person involved in the system's implementation.

9 Present your work in an engaging format, using at least three separate communication media.

ACTIVITY SHEET

Rubric: Analysing an energy transfer and transformation system

SCI10SUAS00197

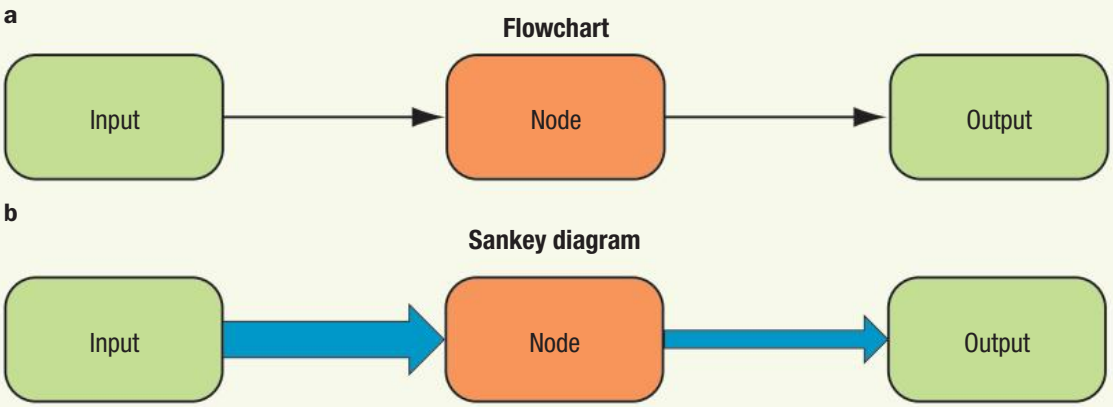


Figure 8.1 **a** A flowchart has boxes or nodes between input and output boxes and same-sized arrows. **b** A Sankey diagram has boxes or nodes between input and output boxes and different-sized arrows that show the relative flow of energy between nodes.

WOW!

Sankey diagrams

A Sankey diagram is a kind of flowchart to represent the flow of energy through a system. Similar to a flowchart, a Sankey diagram must have one node or box to represent an input and a second node to represent the output. In between the nodes, there is an arrow pointing from input to output. In a flowchart, all the arrows are the same size; in a Sankey diagram, however, they change size to represent the energy flowing into and out from a node as the energy flow proceeds. A Sankey diagram therefore shows how the energy flow changes throughout a process.

Energy

At the beginning of the universe, there was only energy. The total energy in the universe has not increased – where would it come from? Nor has it decreased – where would it go to? From this, it follows that energy can only be transferred from place to place or transformed – that is, changed into different forms. Whether the energy is transferred or transformed in a process, there is always the same amount of energy in the universe at the beginning of the process as at the end. This is just another way to express the law of conservation of energy.

Systems: local, surrounding and universal

One thing needs to be added to our understanding of energy conservation, however. It relates to the idea of a system. A system is a series of single components and processes that are connected. For example, the system that makes a car move includes such components as fuel, the engine and wheels. These components are connected: the fuel burns in the engine, which produces motion that drives the wheels. Vehicle crash systems have crumple zones and airbags to control energy transfers away from the occupants. Electric power production and distribution systems use turbines and generators to convert primary energy into electrical energy, which is distributed over a system of wires.

glossary terms

law of conservation of energy
the law that states energy can be neither created nor destroyed

system
a connected set of resources and processes

ISBN 9780170189071

A simple system has three parts: inputs, processes and outputs (Figure 8.2). The inputs are all the resources that you require to do what you intend to do. The outputs are the things you produce. In between, you undertake a series of actions that achieve your result. Throughout the system, every process consumes and emits energy.

A system may be part of a larger system. The universe is the ultimate system. Every other system is a subsystem of the universe. We shall distinguish between local systems, surrounding systems and universe:

- A local system comprises the components of immediate interest to us. For example, the space inside a refrigerator is the system in which we are often interested (Figure 8.3). By removing thermal energy from this space, the space becomes cold. No matter how hard we try, however, we cannot keep the space at this temperature indefinitely – hence, the need to keep the motor running.
- Some energy from the refrigerator is always transferred to the surrounding system, which in this case is the air in the room.
- Once the energy is 'out of the box', it can be shared with everything in the universe.

Remember that this energy was in the universe from the start. Thus, on the scale of the universe, nothing really has changed as a result of the refrigerator. However, from our local point of view, a refrigerator is very useful!

What do we make of all this? On the universal level, energy is conserved; however, at the local system level, the energy transfer and transformation processes lead to less energy being available at the end than at the beginning. This can be summed up as follows:

In any energy transfer or transformation process within a local system, some energy is always transferred or transformed into the surrounding system.

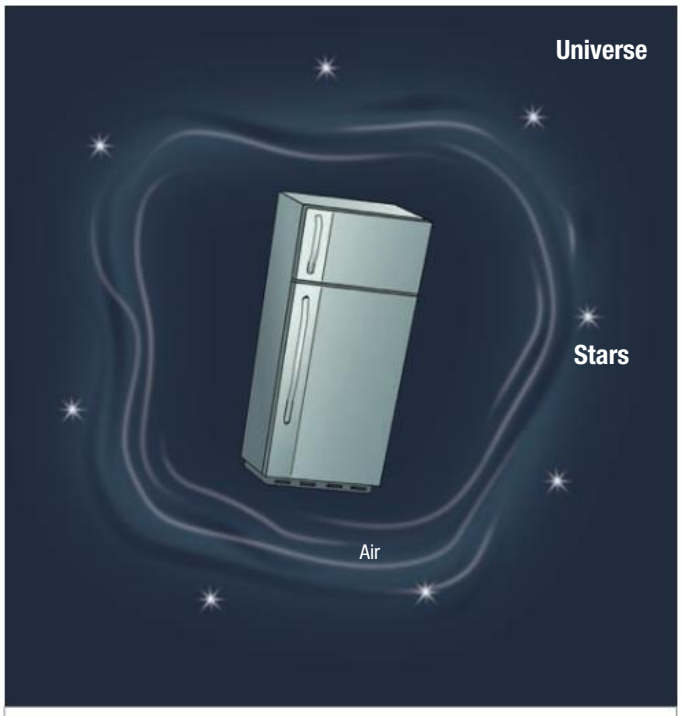


Figure 8.3 A local system (the refrigerator) connects to the surrounding system (air), and then out to the universe.

Efficiency

Every local system produces emissions. The intended emission is the end product. Unintended products – such as gases, solid and liquid wastes and waste heat – are also emitted. Quite a lot of the input, the primary energy, is not used efficiently.

Another way of expressing this loss of energy from a local system is to say that the efficiency of every local energy transfer or transformation process is always less than 100%. Efficiency is defined as the ratio of useful output energy to input energy:

$$\text{Efficiency} = \frac{\text{useful energy output}}{\text{energy input}} \times \frac{100}{1}\%$$

Figure 8.2 This flowchart shows a simple system comprising input, processes and outputs.

ISBN 9780170189071

Table 8.1 Energy units of measure

Name	Joule	Kilojoule	Megajoule	Gigajoule	Terajoule
Symbol	J	kJ	MJ	GJ	TJ
Quantity (J)	1	1000	1 million	1 billion	1 trillion
Power of 10 multiplier	1	10^3	10^6	10^9	10^{12}

Unit of energy

The unit of energy is the joule (J). It is named after English physicist James Prescott Joule (1818–1889). One joule is quite a small amount of energy, so we use multiples to show larger amounts. Be careful to use upper- and lower-case letters when using the symbols, as shown in Table 8.1.

Example 1

Over a 100 km trip, a car transformed 400 MJ of energy from the fuel. The amount of energy that went directly into the forward motion of the car was 80 MJ. What was the efficiency of the car?

Solution

1 List the variables.

Energy input	Energy output	Efficiency
400 MJ	80 MJ	?

2 Write the equation:

$$\text{Efficiency} = \frac{\text{useful energy output}}{\text{energy input}} \times \frac{100}{1}\%$$

3 Substitute the values and then calculate:

$$\text{Efficiency} = \frac{80\text{ MJ}}{400\text{ MJ}} \times \frac{100}{1}\%$$

$$= 20\%$$

The efficiency of the car was 20%.

Example 2

A power station produces electrical energy from coal. The plant is 25% efficient. For every 1000 GJ available from coal, how much electrical energy is produced?

Solution

1 List the variables.

Energy input	Energy output	Efficiency
1000 GJ	?	25%

2 Write the equation:

$$\text{Efficiency} = \frac{\text{useful energy output}}{\text{energy input}} \times \frac{100}{1}\%$$

3 Substitute the values and then calculate:

$$25\% = \frac{\text{useful energy output}}{1000} \times \frac{100}{1}\%$$

$$\text{Useful energy output} = \frac{25 \times 1000}{100}$$

$$= 250\text{ GJ}$$

The electrical energy produced for every 1000 GJ available from coal is 250 GJ.

glossary terms

efficiency
the ratio of useful output energy to input energy

emission
a product of the system; intended and unintended products, such as heat, solids, liquids and gases, and energy

input
a resource that flows into a system

local system
a defined system connected to other systems

output
the intended product of a system

surrounding system
the immediate system into which emissions from a local system are transferred

universe
the ultimate system

ISBN 9780170189071

Questions 8.1
What have you learnt?

WORKSPACE
What have you learnt? 8.1
SCI10SUWR00198

Understand

1 Emissions refer to two product types. What are they?

2 Draw a Venn diagram to show the relationship between a local system, a surrounding system and the universe.

Apply

3 State how many trillion joules there are in:
- **a** 5 TJ
- **b** 100 GJ.

4 As shown in the examples on page 249, use the efficiency equation to calculate the efficiency of a car that transforms:
- **a** 8000 MJ of fuel into 200 MJ of useful energy
- **b** 900 GJ of fuel into 300 GJ of useful energy.

5 The efficiency of a gas-fired power station is 30%. The useful energy produced is 300 GJ. Use the efficiency equation to calculate how much input energy was available from the natural gas fuel.

Analyse

6 How do you make sense of the law of conservation of energy when you know that 'energy is always lost from a local system'?

7 What form of energy is most associated with energy losses from a system? Explain.

Reflect

8 What have you learnt about the quantitative side of science so far?

9 How has your understanding of the law of conservation of energy changed as a result of thinking about systems?

Forms of energy

Energy is just that – energy. However, we find it useful to give names to energy when we experience it in different ways. Mechanical energy is experienced differently from sound energy, just as heat energy is experienced in a different way from electrical energy. Moreover, energy is identified according to its source; for example, nuclear energy comes from the nucleus of an atom, solar energy from the Sun and wind energy from the wind. They are just different ways that energy transfers and transformations are experienced.

All forms of energy can be divided into two important forms of energy: kinetic energy and potential energy. Kinetic energy is energy associated with movement. Potential energy is energy, other than kinetic energy, that is ready to be transferred or transformed.

As we develop our understanding of matter and energy, however, it becomes more difficult to allocate a form of energy clearly to only one of these forms. For example, every particle in matter has kinetic energy, as well as potential energy for chemical reactions. In a gas, the particles whizz around more or less unrestrained (Figure 8.4). In a liquid, they are more constrained but still moving. In a solid, they are reasonably tightly bound to one another but they still jiggle about. Nothing is supposed to be able to move at a

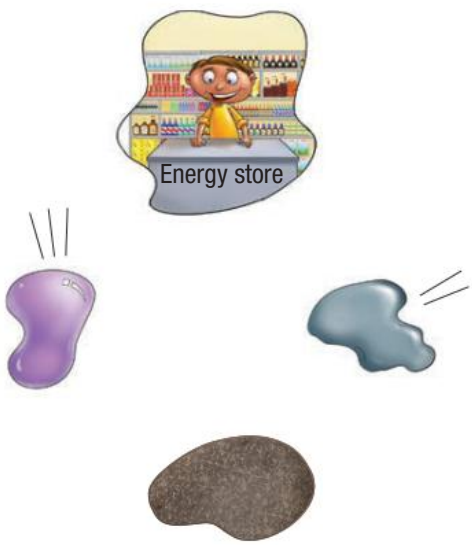


Figure 8.4 Atoms are little stores of energy that whizz about and jiggle, depending on how much energy they are given.

ISBN 9780170189071

temperature of absolute zero, but there is actually no way to achieve that particular temperature! Nevertheless, all atoms have been put together by storing energy, so they are all little stores of potential energy. Even at absolute zero, when they are not moving, the stores of potential energy locked up in the atoms' structures would still be ready for action.

Thermal energy

Matter is made of particles that are in constant rapid motion. Sometimes the particles bump into one another. The thermal energy of a substance is the sum of the kinetic energies of all of the particles of which it is made. In a collision between two particles, the particle with a bit more energy transfers some energy to the other one, which gains a bit more (Figure 8.5). In an isolated local system, all the particles give energy to one another so that, after a while, all the particles have, on average, the same energies. This is called thermal equilibrium.

As two interacting systems come to thermal equilibrium, the hotter system gets cooler and the cooler system gets hotter. Eventually, all the particles in both systems have the same average kinetic energy – hence, the same temperature. Therefore, all systems that interact eventually come to the same temperature.

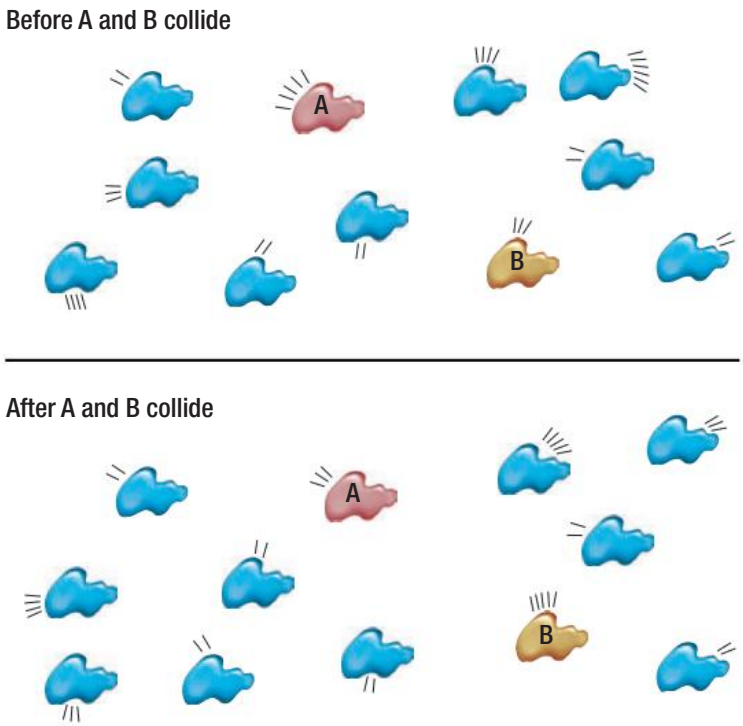


Figure 8.5 Particle A with more energy gives some energy to particle B with less energy. Afterwards, A has less energy and B has more. Eventually, all particles in a system will have, on average, the same kinetic energy. This average kinetic energy is what a thermometer measures.

glossary terms

kinetic energy
energy of movement

potential energy
energy other than kinetic energy that is ready to be transferred or transformed

thermal energy
energy of the particles of which a substance is made; heat energy

thermal equilibrium
the result of two interacting systems coming to the same temperature

ISBN 9780170189071

Activity 8.2

Thermal equilibrium: POE

WORKSPACE

Thermal equilibrium: POE

SCI10SIWR00199

What are the risks in doing this activity?	How can you manage these risks to stay safe?
The hotplate will become hot and could burn you.	Do not touch the hotplate. Use tongs or mitts to remove the beaker. Let the hotplate cool down before putting it away.

Predict, observe and explain what happens when different volumes of water at different temperatures are mixed.

Materials

- 2 beakers (100 mL)
- 2 beakers (250 mL)
- 2 thermometers or temperature probes
- heating equipment, such as a hotplate
- access to water

Method

1. Set up the table below in your workbook or use the one provided in the workspace.
2. Record your prediction about the final temperature after the two 50 mL volumes are mixed.
3. Heat 50 mL of water in each beaker to the temperatures indicated in the table below.
4. Carefully remove the beakers from the heat source and pour the contents of one into the other.
5. Measure the temperature every 5 minutes for 30 minutes.
6. While you are waiting, set up a similar experiment in which you vary only the volume in beaker 2.
7. Set up a new table and record your prediction for this new experiment, and then repeat steps 3–5.

Discussion

In the explanation column of your table, write why you think the combined volumes of water came to the final temperature that you measured. Use the ideas of particle and energy transfers in your explanation. You may find the weblink 'Heat versus temperature', which gives an explanation of the difference between the quantity of heat and the temperature in a beaker of water, useful in refining your explanation.

WEBLINK

Heat versus temperature

	Beaker 1	Beaker 2	Explanation
Initial volume (mL)	50	50	
Initial temperature (°C)	20	40	
Predicted final temperature (°C)			
Observed final temperature (°C)			

CONNECTION

ICT literacy: Thermal equilibrium experiment

SCI10SICN00201

ISBN 9780170189071

Measuring temperature

We can measure temperature qualitatively or quantitatively. Qualitative scales use descriptions – such as hot, cool and cold – rather than numbers. They are useful for some purposes, but they can be deceiving. For example, if you put cold feet into a warm bath, your feet feel very hot, even if the temperature is not really very hot. In contrast, quantitative temperature scales use numbers. They are carefully constructed using two well-defined calibration points. Both the Celsius and Fahrenheit scales use the temperatures of melting ice and boiling water as the two calibration points. For a Celsius thermometer, the scale is marked in 100 equal divisions or degrees, starting at 0°C and ending at 100°C. The Fahrenheit scale starts at 32°F and has 180 equal divisions to 212°F. The kelvin temperature scale is based on the Celsius scale; however, the zero is absolute zero, where nothing moves. This is 273 degrees below the zero for Celsius – that is, –273°C. Thus:

$$\text{Temperature (K)} = \text{temperature (°C)} + 273°$$

Figure 8.6 shows the relationship between the three temperature scales: Celsius, Fahrenheit and kelvin.

CONNECTION

Numeracy: Comparing temperature scales

SCI10SICN00202

Heat losses from local systems

Thermal energy is the major way that energy is lost from a local system. Cars transfer heat from hot engines. Car panels heat up in a collision. Electricity power stations that use steam lose heat when the steam condenses. Electricity distribution systems lose heat from power lines. There are three ways that thermal energy is transferred from a local system to the surrounding system: conduction, convection and radiation.

Conduction

The kinetic energy of particles – that is, the jiggling, bouncing and bumping between atomic and molecular particles – is transferred to particles in surrounding systems as jiggling, bouncing and bumping. This is known as conduction (Figure 8.7)

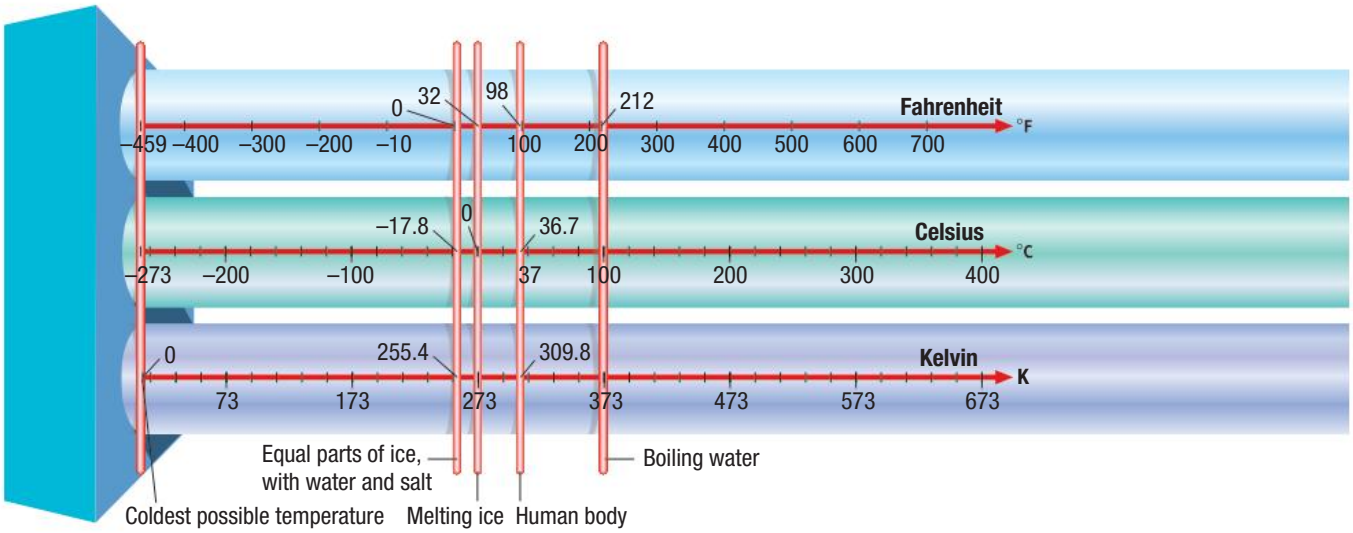


Figure 8.6 Three different temperature scales: Celsius, Fahrenheit and kelvin (or absolute)

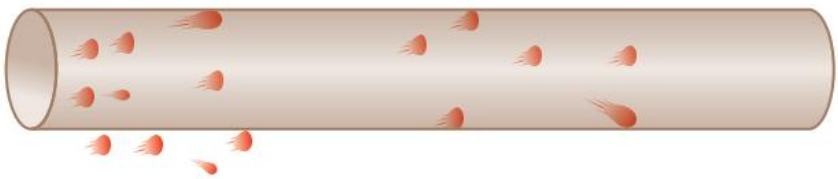


Figure 8.7 Heat transfer by conduction involves particles bumping into one another.

glossary terms

calibration point
a value of a quantity that is used to define a scale

conduction
the transfer of heat energy by direct contact between particles in systems

ISBN 9780170189071

Convection

Heat energy is carried away by bulk movement of fluids, such as air or water, associated with the particles bumping into one another. A volume of warm fluid becomes less dense than the surrounding material and flows away from the heat source. This is known as convection (Figure 8.8).

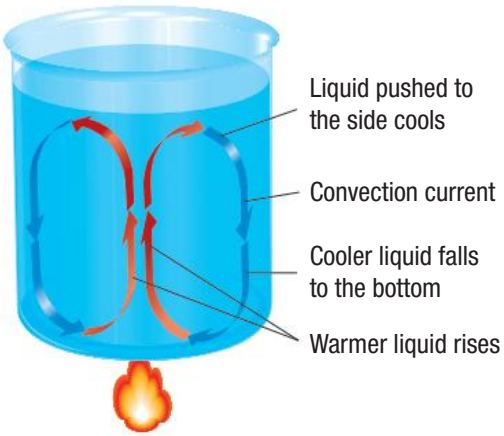


Figure 8.8 Convection is the bulk movement of a fluid that carries thermal energy through the system and out of the system.

Radiation

Thermal energy may be carried from a system by infrared electromagnetic radiation. This radiation travels away from the system without the need for particles. It can be absorbed by particles that then jiggle more, raising the temperature of the surrounding system (Figure 8.9).

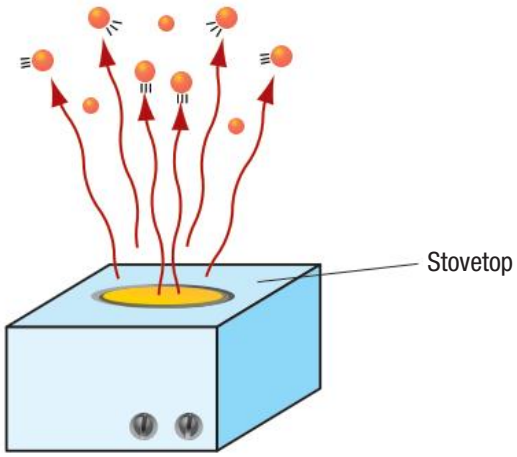


Figure 8.9 Heat radiation flows from all hot bodies. It can be absorbed by particles, causing the temperature of the surrounds to rise.

Investigation 8.1
Looking at heat transference

Heat transfer from one side of a wall relies both on the temperature difference between each side of the wall and on how thick the wall is.

What to do

1 Set up an arrangement in which these two variables – temperature difference and thickness – can be measured. Find out how quickly the temperature on each side of the wall becomes the same.

2 Is there a mathematical relationship between the variables? Use graphs and algebra to assist your explanation.

Questions 8.2
What have you learnt?

WORKSPACE
What have you learnt? 8.2
SCI10SUWR00203

Understand

1 What are two ways that we define different forms of energy?

2 Name two distinct categories into which forms of energy could be placed.

3 **a** Define the term 'thermal equilibrium'.
b How does 'heat' flow?

Apply

4 Draw a diagram to show radiant energy transfer.

5 Draw or sketch a graph of temperature on the Celsius scale versus temperature on the kelvin scale. Write the equation linking them.

ISBN 9780170189071

Analyse

6 How is it possible to say that there is only one 'energy', yet talk about 'thermal energy' and 'electrical energy' as though they are different?

7 Why is it difficult to categorise forms of energy in only two ways? Use 'heat' as an example.

8 'A thermometer measures its own temperature.' Explain this statement.

9 100 mL and 200 mL have the same temperature. Why does 200 mL have more quantity of heat?

Reflect

10 How has your understanding of heat, thermal energy and temperature changed so far?

A car as a system

Cars take in energy in the form of fuels, process that energy in the engine and produce movement. Along the way, they produce emissions, which are in fact transformed energy. A car converts chemical energy stored in fuels into the kinetic energy of the car's movement. About 0.5% of the energy available from the combustion of the fuel is used to move a person in the car. Energy is also used to move the car and its load. Some energy overcomes friction and air resistance. Some is transferred to the surrounding air as heat and gaseous emissions, such as carbon dioxide, water vapour and oxides of sulfur and nitrogen (Figure 8.10).

Input

Outputs

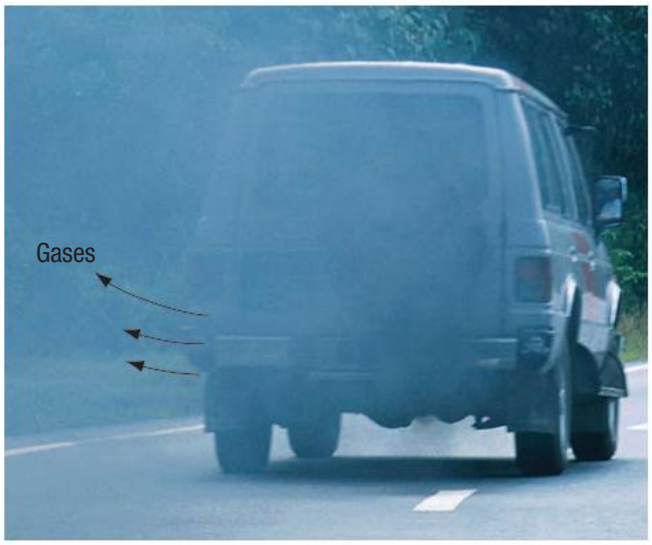


Figure 8.10 The input energy (petrol) is used to produce kinetic energy (car moves). The car emits radiant heat to the surrounding system. It also emits water vapour and noxious gases, such as carbon dioxide and oxides of sulfur and nitrogen.

glossary terms

convection
the bulk movement of a fluid that carries thermal energy from a system

radiation
the infrared electromagnetic radiation that carries thermal energy from a system

ISBN 9780170189071

Energy in car production

Cars are produced from a variety of materials, such as iron-based metals and alloys (steel and cast iron), as well as glass, rubber, water and other fluids. Even before we buy a car and start to drive it, energy has been used to produce it. Figure 8.11 shows that 50% of the energy used to build a car is represented by the steel components.

Energy available from fuels

Fuels react with oxygen in the surrounding air to produce an explosion in the engine. The rapidly expanding hot gases from the explosion push on a piston. The force on the piston acts over a distance – the expanding gases do work. The piston is connected to the drive shaft that rotates. This rotation is connected to the wheels so that the car can move (Figure 8.12).

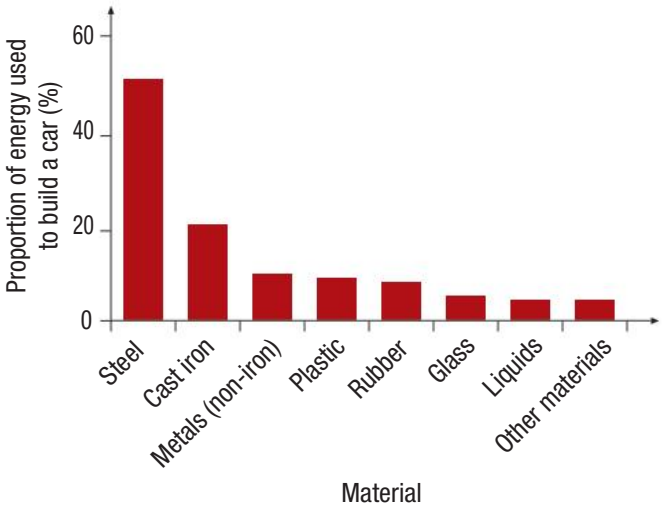


Figure 8.11 Proportion of energy used to produce the various parts of a car

The primary energy (or primary energy content) of the fuels is the amount of energy that can be released for use. Hydrocarbon-based fossil fuels release this energy when they are burnt with oxygen. Different fuels release different amounts of energy (Figure 8.13).

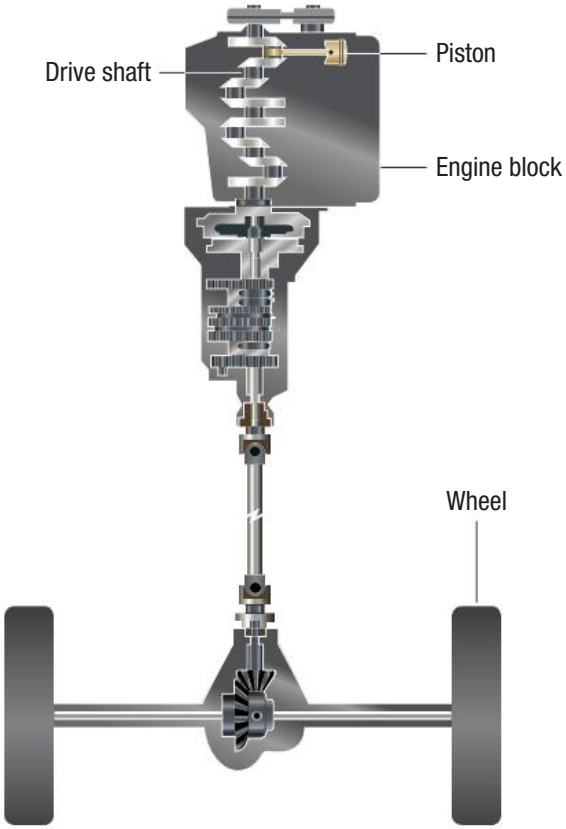


Figure 8.12 A piston is connected to the drive shaft. The rotation is transferred to the wheels.

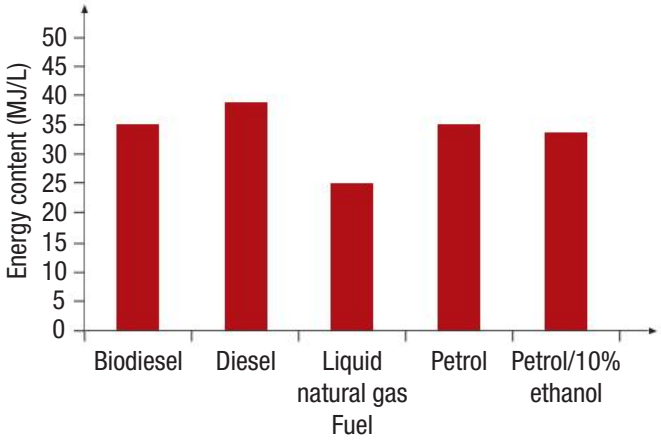


Figure 8.13 The primary energy content of some fuels. Energy is able to be released by the reaction of fossil fuels with oxygen from the atmosphere.

ISBN 9780170189071

The chemical reaction of hydrocarbons can be written simply as:

Hydrocarbon + oxygen → carbon dioxide + water + thermal energy

There are many other reactants and products because fossil fuels are not made only of hydrocarbons. The products include nitrogen- and sulfur-based oxides that contribute to acid rain. Fossil-fuel burning therefore produces many unwanted emissions.

CONNECTION

Numeracy: Index scales

SCI10SICN00221

Energy losses from the car system

The burning of fuel releases far more energy than is necessary for the car to achieve its purpose – that is, transporting people and goods. About 60% of the total energy is wasted as heat. The engine becomes hot and transfers this increased particle jiggling in the engine block to the surrounding materials and air (Figure 8.14). All objects radiate heat. The engine block is no exception.

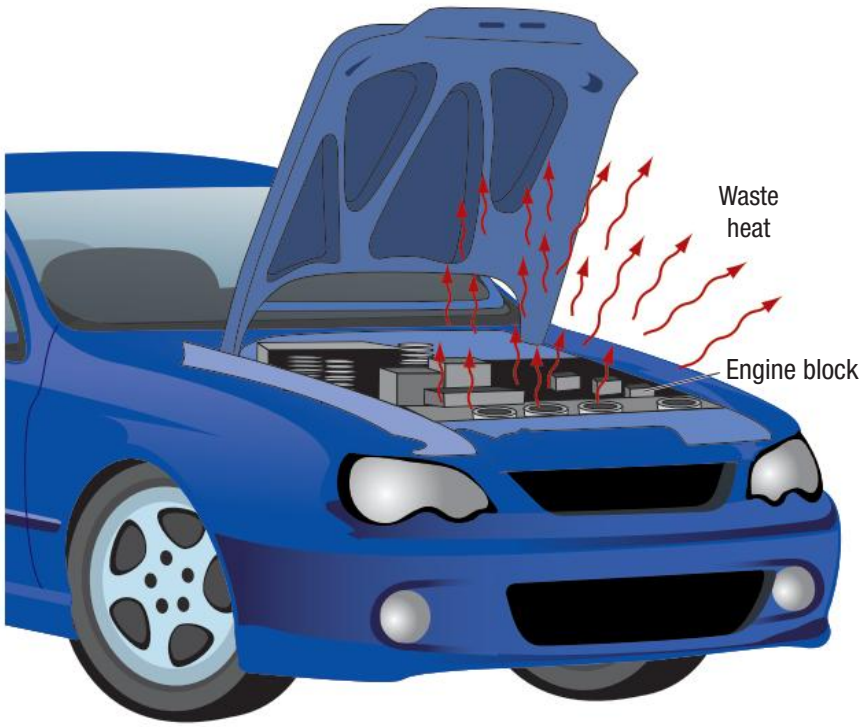


Figure 8.14 Heat is transferred from the engine to the surrounding system and is wasted.

glossary term

primary energy content
the amount of primary energy that can be converted in a reaction

ISBN 9780170189071

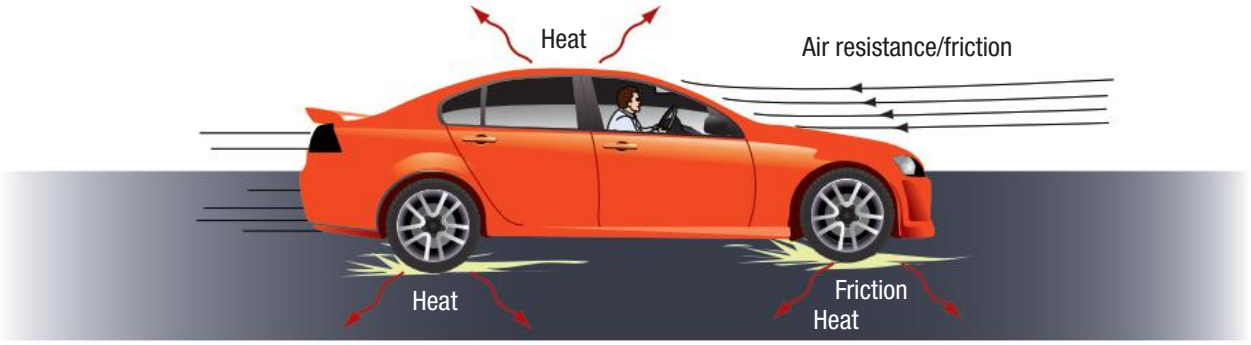


Figure 8.15 Energy flows from the car system via friction.

More energy losses are caused by friction in the motor, between the car body and the air, and between the tyres and the road. Friction causes rubbing, and rubbing causes particles to jiggle more; hence, the temperature rises and thermal energy flows away from the system (Figure 8.15).

The combined effect of energy losses from the car system means that cars are only about 20% efficient if powered by petrol. Diesel cars are more efficient at around 30%.

Car cooling system

The heat generated by fuel combustion is so great – the temperatures can be as high as 2500°C – that the metal engine block must be protected. The cooling system does this.

Coolant is piped through the engine and is heated by the cylinders. It is then passed through the radiator, where waste energy is transferred to the surrounding air (Figure 8.16). The coolant is kept under pressure so that it does not boil. (Water boils at higher temperatures when the pressure is high.) If the water boils, the steam becomes superheated and the engine itself can explode.

The main components of the cooling system are coolant, water pump, radiator, fan and thermostat. The water pump and fan use energy from the vehicle's engine to operate.

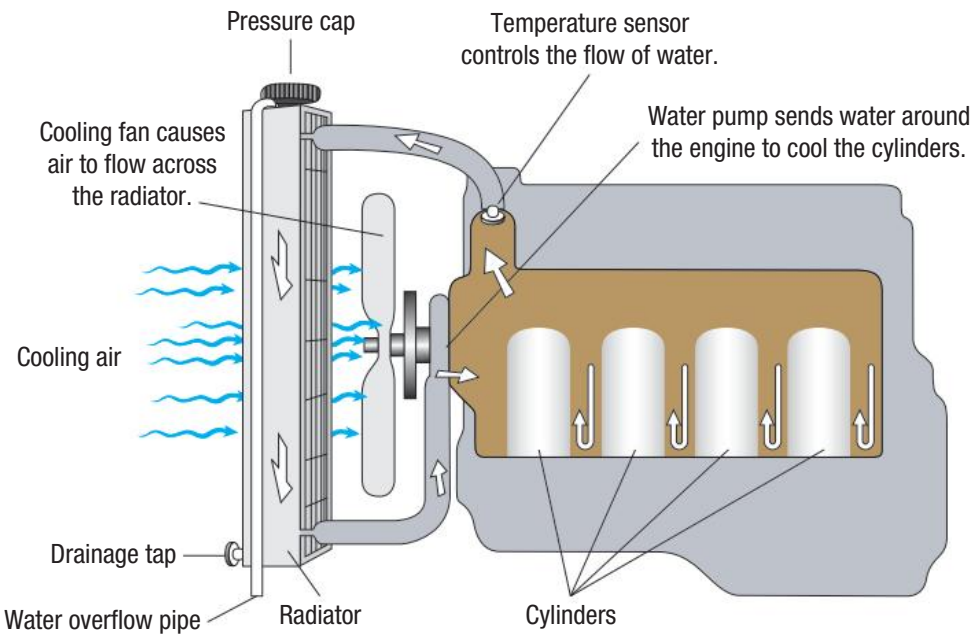


Figure 8.16 A car engine cooling system

ISBN 9780170189071

Questions 8.3
What have you learnt?

WORKSPACE
What have you learnt? 8.3
SCI10SUWR00204

Understand

1 Define the 'energy content' of a fuel.

2 Identify three of the main ways that a car will lose energy.

3 List the fuels in Figure 8.13 on page 256 in order from least to greatest energy content.

Apply

4 Draw a flowchart to show the main features of a vehicle as a local system. Include inputs, processes and outputs, including emissions.

Analyse

5 Why is so little of the energy from the fuel used in a vehicle for the purpose of moving a person from place to place?

Synthesise

6 Produce a Sankey diagram to show the flow of energy into, through and out of a car's:
- **a** movement system
- **b** cooling system.

7 Draw a diagram to represent the way the car movement system is connected to the car cooling system.

Evaluate

8 For Figure 8.13 on page 256:
- **a** Place the fuels in descending order of primary energy content into a data table.
- **b** Represent the data in a pie chart.
- **c** Which of the three ways of representing the data – bar graph, data table or pie chart – do you think is best? Give your reasons.

Reflect

9 What did you think when you worked out how energy *in*efficient a motor vehicle can be?

10 Consider whether you have enough information to get started on the culminating assessment task using a vehicle movement system or a car cooling system. What other information do you think you would need to obtain to complete the task?

Car safety systems

In the year ending 30 September 2011, car crashes resulted in the deaths of 1307 Australians. That's an average of more than three deaths each day. While we have produced significant improvements to road safety laws and penalties and much work is done to ensure safe roads and vehicles, the level of immediate community outrage about this level of tragedy in our community seems far less than it ought.

CONNECTION
Maths: Road crash statistics
SCI10SICN00222

Seatbelts and safety standards

Australian trauma surgeon Gordon Trinca (1921–2009) became fed up with patching up people on Saturday nights in the emergency department of his hospital. More than 30 years ago he asked, 'Can we afford the $6.5 billion, the 2% of GDP and the 10% of total hospital resources that traffic injury consumes each year in Australia?' With the Royal Australasian College of Surgeons, for which he was chairman from the mid-1970s to the early 1990s, he played

glossary term

coolant
a fluid that circulates to remove heat energy from a local system

ISBN 9780170189071

a significant role in achieving improved safety standards, random breath testing and compulsory seatbelt legislation. These actions have succeeded in reducing the total number of road deaths by two-thirds, even while the number of cars and road use have increased hugely.

CONNECTION
Literacy: Gordon Trinca
SCI10SHCN00205

WEBLINK
Gordon Trinca

All safety systems transfer and transform energy so that it has the least dangerous effect on people. Car safety systems are designed to ensure that occupants are able to survive because the energy is transferred gradually in ways and rates that are manageable. The key to these systems is the force applied over a distance – that is, the work – that causes the energy to be transferred. Energy transfers also cause work to be done. For example, the longer the distance over which a crash takes place, the less force is needed to transfer that energy.

Mechanical work and energy transfer

The word 'work' has many different meanings. We go to work. We have homework and schoolwork. We work things out. In science, work and energy are related. When work is done, energy is transferred. When energy is transferred, work is done. Ignoring the transfer of energy to the surrounding system, if 5000 J of work has been done on a car, the car gains 5000 J of energy; if the car's energy is reduced by 200 kJ when braking, the car has had 200 kJ of work done on it by the brakes.

Force and mechanical work

Mechanical work is done when a force $F_{\text{by A on B}}$ is applied over a distance d. The work is done by object A on object B (Figure 8.17). This is represented mathematically as:

$$\text{Work done } (W_{\text{on B}}) = F_{\text{by A on B}} \times d$$

The unit of work and the unit of energy are the same – that is, the joule (J). This means that if we know how much work has been done by a force, we know the amount of energy that has been transferred by the force – they are exactly the same. Equally, if we know how much energy has been transferred, we know how much work has been done – they are exactly the same. From this we see that:

$$\text{Work done} = \text{energy transferred}$$

Example

In Figure 8.17, Achariya applies a force to her bicycle for a distance of 20 m. She puts in 300 J of energy. What is the force that she applies to the bicycle?

Figure 8.17 Achariya applies a force on her bicycle for a given distance. She does work on object B (the bicycle) by object A (Achariya). The amount of energy transferred is equal to the work done by Achariya.

ISBN 9780170189071

Solution

1 List the variables.

$F_{\text{by Achariya on bicycle}}$	Distance	Work = energy transfer
?	20 m	300 J

2 Write the equation: Work done = energy transferred. That is:

$$F_{\text{by Achariya on bicycle}} \times d = \text{energy transferred}$$

3 Substitute the values, rearrange and then calculate:

$$F_{\text{by Achariya on bicycle}} \times d = 300$$
$$F_{\text{by Achariya on bicycle}} \times 20 = 300$$
$$F_{\text{by Achariya on bicycle}} = \frac{300}{20}$$
$$F_{\text{by Achariya on bicycle}} = 15\,\text{N}$$

Energy changes in car crashes

A speeding car that crashes into a wall has all its kinetic energy changed into other forms of energy. This occurs over a distance.

Crumple zones

Cars are deliberately made to crumple during a collision. These crumple zones are arranged at the places most likely to be affected by a crash – the boot and engine bay. During collisions, the crumple zone get squashed. They are sacrificed for people's safety (Figure 8.18). The cabin is made from stronger materials that directly protect the occupants. Car testing and road accident investigations clearly show the benefits of crumple zones.

WEBLINK
Australasian New Car Assessment Program (ANCAP)

Crumple zones take advantage of the fact that the longer the distance over which the stopping force acts, the smaller the force applied to the car. Let us see how this works. A 1000 kg car travelling at 20 m/s has 200 000 J of kinetic energy. When the car hits a wall, this energy is reduced to zero. It is the force by the wall on the car that stops the car, so it is the work done *by the wall on the car* that changes the car's energy. The energy is reduced to zero:

$$F_{\text{by wall on car}} \times d = \text{energy transferred}$$

Figure 8.18 Crumple zones sacrifice the car for the person.

glossary terms

crumple zone
the protective part of vehicle designed to buckle in a collision

work
the force applied over a distance; a way of transferring mechanical energy; $W = F \times d$

ISBN 9780170189071

Typically, a car coming to a stop on a wall at 20 m/s crumples by about 1.0 m at this speed. Therefore:

$$F_{\text{by wall on car}} \times 1.0 = 200\,000 \text{ J}$$
$$F_{\text{by wall on car}} = \frac{200\,000}{1.0}$$
$$= 200\,000 \text{ N}$$

A much 'stronger' car that crumples by only 0.1 m ($\frac{1}{10}$ of 1.0 m) would need 10 times the force applied to bring it to a stop. This is easy to see if you use 0.1 for *d* in the previous calculation.

ACTIVITY SHEET
Crumple zones
SCI10SUAS00261

CONNECTION
Literacy: Bad thinking
SCI10SICN00206

Seatbelts

Seatbelts are designed to keep the driver and passengers in contact with the car body as the car comes to a stop (Figure 8.19).

In a sudden stop, any unrestrained person simply keeps on going at the original speed – that's Newton's first law in action. For example, a front passenger coming to a stop from 100 km/h will crash into the windscreen at 100 km/h. Imagine running at two and a half times the speed of a 100 m athlete straight into an electric light pole. At that speed, your head will cave in.

Figure 8.19 Three-point seatbelt

Airbags

Airbags are added safety restraints to stop people colliding into the steering wheel and windscreen in a crash (Figure 8.20). They comprise a light material that can be automatically inflated rapidly and then slowly deflated (Figure 8.21).

Figure 8.20 A deployed airbag prevents direct contact with the steering wheel.

ISBN 9780170189071

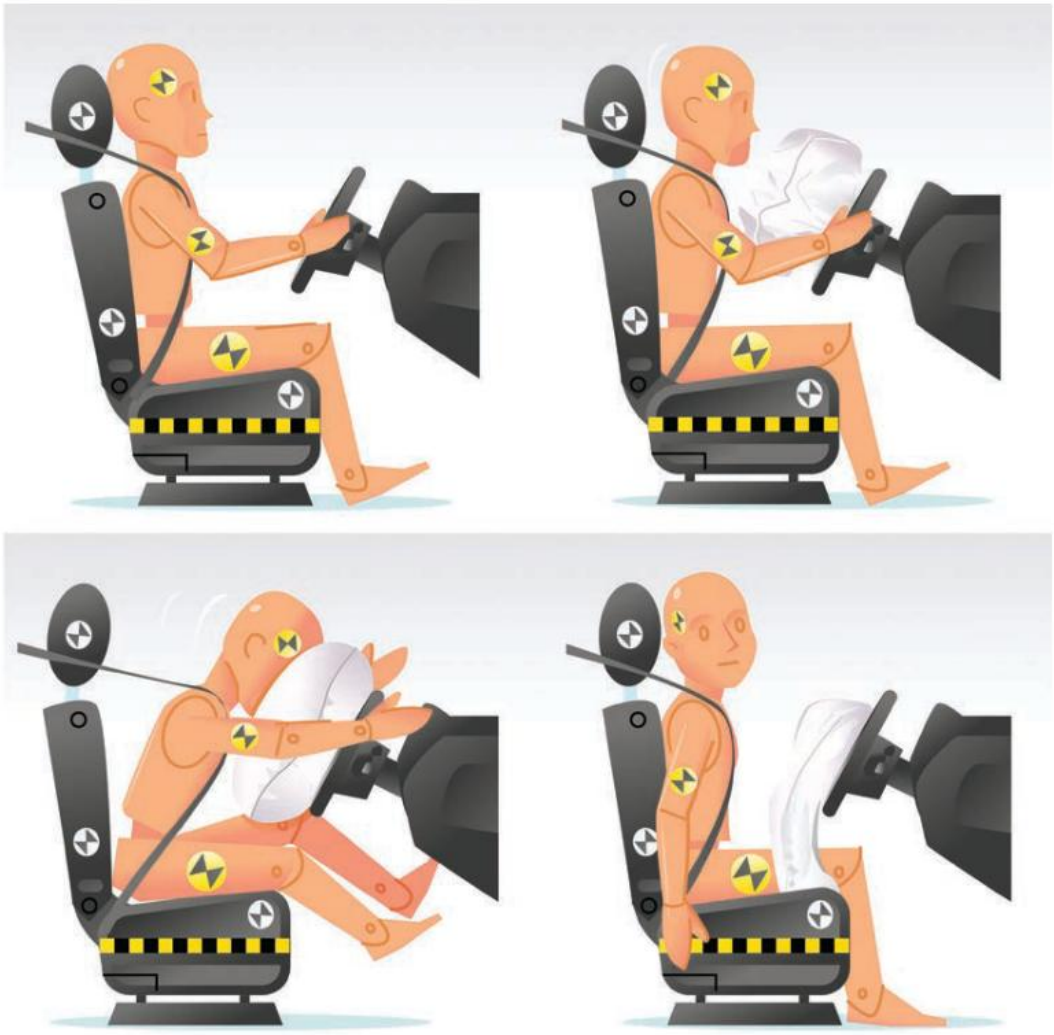


Figure 8.21 An airbag is deployed rapidly to slow the forward movement of the head and chest of the occupant towards hard surfaces.

Airbags exert a force on the occupant. This force is applied over the distance that the occupant moves despite the seatbelt. The airbag also helps to hold the occupant's head in place during the crash. It absorbs the energy that might otherwise be applied to the steering wheel, dashboard or windscreen by the person's head. The force is also spread over a greater area than the area over which the force applied by the seatbelt is exerted.

Without airbags, the head snaps forward and back more violently because the seatbelt restrains the head less than the hips and chest.

At 100 km/h (or 28 m/s), a car will crash to a stop over about 1.0 m in about 70 milliseconds. The airbag must deploy in less time. How does it do this? Once the braking acceleration goes above a preset value, automatic processes cause the airbag to deploy from its compartment and fill rapidly with nitrogen gas in less than 50 milliseconds. The nitrogen is harmless – 78% of the air we breathe is nitrogen – and readily escapes through pores in the airbag.

Chemical reactions in airbags

The chemicals in airbags are selected because they are highly reactive and very quickly produce large quantities of the harmless gas nitrogen. The leftover products need to be reacted to form something more stable quite quickly as well. Sodium azide is the first ingredient to react. It produces nitrogen and sodium, which is highly reactive. After some more reactions, an inert glassy silicate is formed. A white powder is used to make sure the airbag does not get sticky inside and fail to inflate. This puffs out of the bag as it deflates.

WEBLINK
Airbags

WEBLINK
Sodium azide

ISBN 9780170189071

WEBLINK
Deployment of an airbag

ACTIVITY SHEET
Head-on smash at 60 km/h
SCI10SIAS00207

Acquired brain injury

At 60 km/h, a person's forehead will be pushed in by 3.5 cm when it hits the windscreen. The brain sloshes towards the back of the skull as well. Blood vessels burst, causing swelling in the confined space of the bony skull. All this has serious effects. For example, people with acquired brain injury have great difficulty with physical movement, coordination, relationships, thinking, control of behaviour and holding down a job.

Energy disappears from crashes

In a car crash, the car body is at the temperature of the surrounding air – until it crashes. During the crash, the car body vibrates, producing sound energy, and its molecules move more rapidly. The car body heats up. Faster-moving molecules transfer their kinetic energy to the nearby air molecules. In turn, the air molecules bump into ones further away. Eventually, the energy of the whole atmosphere is affected by these collisions, but not by very much! The sound and thermal energy are transferred to the vast 'air bath' and are 'lost' (Figure 8.22). The car body heats up and then cools, returning to normal temperature, as the energy is transferred to the atmosphere. Some of the energy involved in a car crash is stored in the rearranged, twisted and crumpled shape of the panels.

On the universal scale, a car crash does not add to or take away energy. There is no universal effect. Clearly, however, the local effects can be catastrophic.

Science careers in car design and safety

People who study motor vehicle safety and the factors that contribute to road use accidents include mechanical engineers, design engineers, physicists, mathematicians, sociologists, behavioural psychologists and neuropsychologists.

ACTIVITY SHEET
Science careers in car design and safety
SCI10SHAS00208

Figure 8.22 In a car crash, the energy received by the car body's particles is used to heat and deform the panels, and to make sound. The car body returns to thermal equilibrium with the atmosphere.

ISBN 9780170189071

Questions 8.4

What have you learnt?

WORKSPACE

What have you learnt? 8.4

SCI10SUWR00209

Understand

1 How has the reduction in the road death toll been achieved over the last 20 years?

2 Define mechanical work in words and in a mathematical formula. What does mechanical work do?

3 **a** Why do we say that a crumple zone is a 'sacrifice'?

b What is the purpose of airbags?

Apply

4 Complete the following table.

Force applied (N)	Distance *d* (m)	Work done or energy transferred (J)
?	12.5	1250
1200	20	?
50	?	75000

Analyse

5 Show that the force that stops a car with 200000J of energy in 10 cm (0.1 m) is 10 times greater than that applied to stop the car in 1.0m. (See the example on page 261.)

6 A force of 600000N is applied to a 1200kg car to bring it to a stop. What is the car's acceleration until it comes to a stop? (Hint: Use Newton's second law.)

Synthesise

7 Draw Sankey diagrams to show energy transfers from input to output for car safety systems.

8 Explain how a panel beater uses energy to restore smashed car parts to their original shapes.

Reflect

9 What have you learnt about energy transfers and car crashes?

10 Consider whether you have enough information to get started on the culminating assessment task using a car safety system. What other information do you think you would need to obtain to complete the task?

Electrical energy production

The production of electrical energy and its distribution for use by communities are major achievements. Electrical energy can be produced at large-scale power stations and then distributed over a sizeable grid of wires. It can also be produced locally, near where it is used.

Electrical energy can be produced in many different ways, but almost all rely on the work of English scientist Michael Faraday (1791–1867). Faraday was the first to demonstrate both the electric motor and the electric generator effects. Thanks to Faraday's pioneering work, we now have very sophisticated electricity generation and distribution systems, as well as electric motors for a vast array of purposes. Can you imagine a life without electric lights, computers, electric motors, microphones and speakers? Perhaps Faraday, more than any other person over the last 200 years, has shaped the technologies we use every day.

glossary term

generator
a machine used to convert mechanical energy into electrical energy

ISBN 9780170189071

WOW!

Michael Faraday

Michael Faraday was brought up in a poor household in London. At age 14, he was apprenticed to become a bookbinder. He completed his apprenticeship 7 years later. His work meant that he had access to many books. He read the scientific ones voraciously! In fact, he became an enthusiast for science. For quite a long time he sought work at the Royal Institution and, at 22, became a laboratory assistant there. Soon, he gained the confidence of significant scientists because of his personal integrity, keenness and expertise. He travelled extensively through Europe and learnt how to speak and read French and to read Italian. In 1821, Faraday demonstrated the effect that led to the electric motor effect. Over the next 10 years, he became a fellow of the Royal Institution and then its director, and discovered benzene and how to turn chlorine gas into a liquid. Faraday developed public lecture programs for the general public and children (Figure 8.23). In 1831, he returned to his investigations of electricity and magnetism and demonstrated the principles behind electrical generation.

Figure 8.23 Michael Faraday gives the Christmas Lecture at the Royal Institution in 1855 in front of Prince Albert.

Electrical generation systems

A developed economy, more than any other, requires huge amounts of energy for daily use in business, industry, homes and leisure pursuits. Overwhelmingly, this energy is supplied by electrical energy generation and distribution systems. Electrical energy is the output, but there are many different inputs to the system. In Australia, coal is by far the most important input resource for electrical generation. Natural gas, oil and gravitational energy are also used extensively, and wind and solar energy are increasingly part of the mix.

The majority of electrical generation involves a mechanical turbine to transform the original energy into circular motion. This is done by an arrangement of fan blades driven by a fast-moving fluid, such as air, steam or water (Figure 8.24). The turbine is connected to a generator that actually produces the electrical energy.

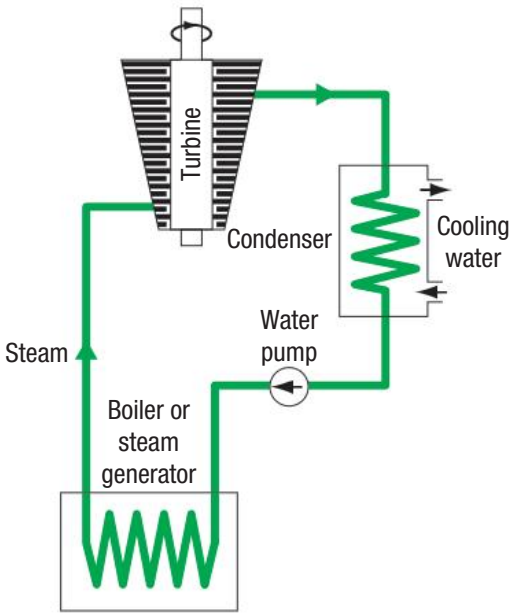


Figure 8.24 The steam turbine heating cycle: water is boiled to form steam, which drives the turbine. Waste steam is cooled and reused.

ISBN 9780170189071

Electromagnetism and electrical energy production

An electrical generator comprises a coil of wire and a magnet. The coil is made to spin. When the coil rotates in a magnetic field, electrical energy is produced. Almost all electrical energy is produced in this way. The original energy input, such as chemical energy, is turned into mechanical energy to rotate the coil. This is then transformed into electrical energy. Heat is a by-product of these transformations. Figure 8.25 features a Sankey diagram showing electrical energy production.

A simple electrical generator

Electrical energy is generated when a loop of wire is spun between the poles of a magnet. It is represented by the potential difference, measured in volts (V), between the output terminals *a* and *b* of the loop, as shown in Figure 8.26. The potential difference changes direction – that is, its polarity – every time the loop makes a half turn. When the potential difference changes direction regularly, the generator is an alternating current (AC) generator. This is shown on the graph in Figure 8.27 on page 268.

It does not matter whether you rotate the coil and keep the magnet still, or rotate the magnet and keep the coil still. Either way, electrical energy is generated.

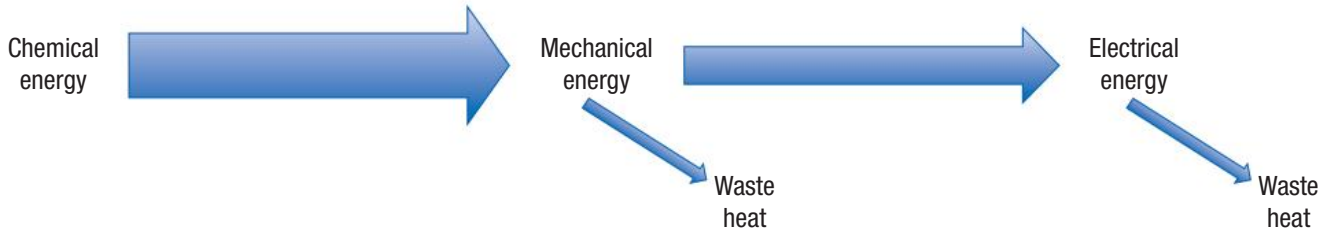


Figure 8.25 Sankey diagram showing electrical energy production

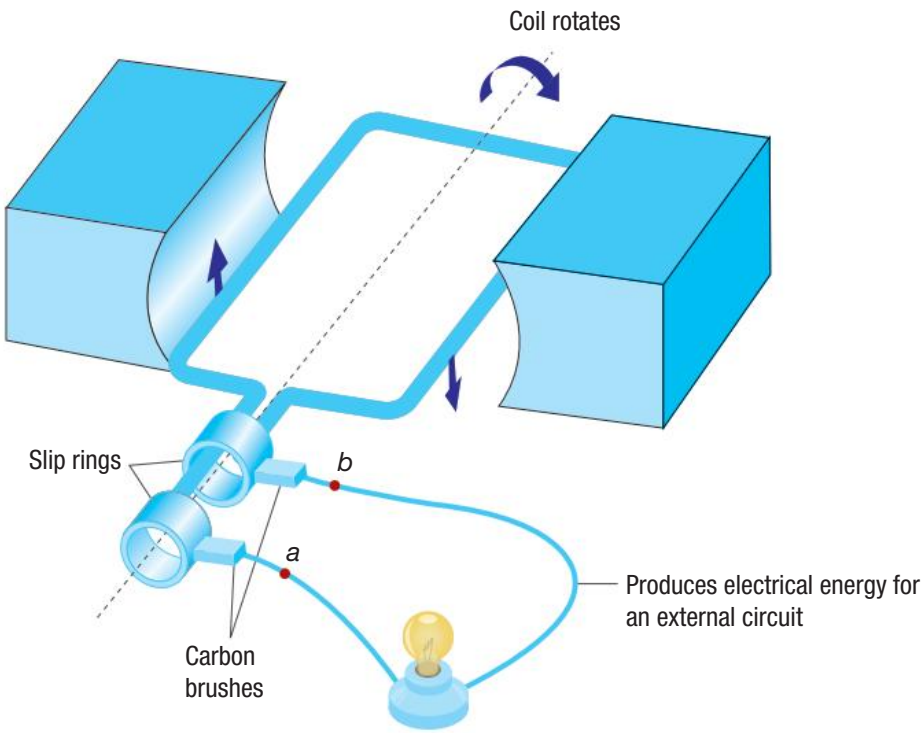


Figure 8.26 A loop of wire rotates between the poles of a magnet. Electrical energy is generated.

glossary term

turbine
a machine that rotates as a result of energy input

ISBN 9780170189071

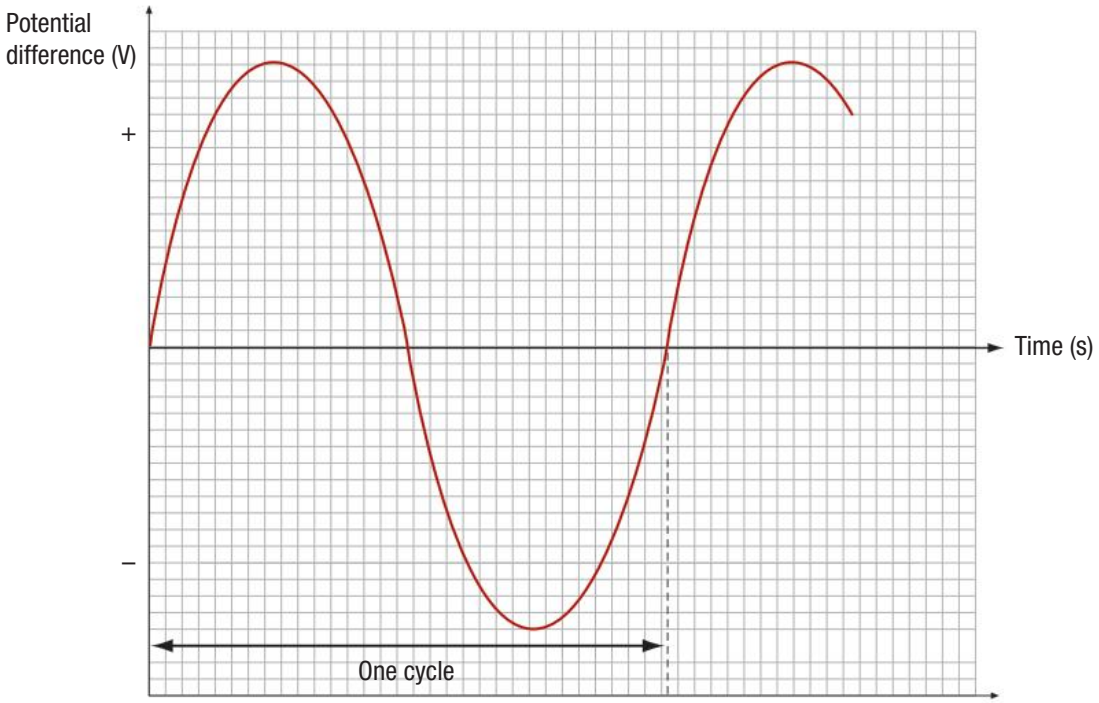


Figure 8.27 The potential difference between *a* and *b* changes polarity every half turn of the loop.

Activity 8.3

Make your own electrical generator

Electrical energy can be generated by moving a coil and a magnet relative to each other. In this activity, you will move a permanent bar magnet relative to a solenoid. A solenoid is a kind of loop-magnifier. It has hundreds of loops, so this multiplies the effect of one loop (Figure 8.28). You will measure the electrical effect, in this case current, with a sensitive measuring device called a galvanometer.

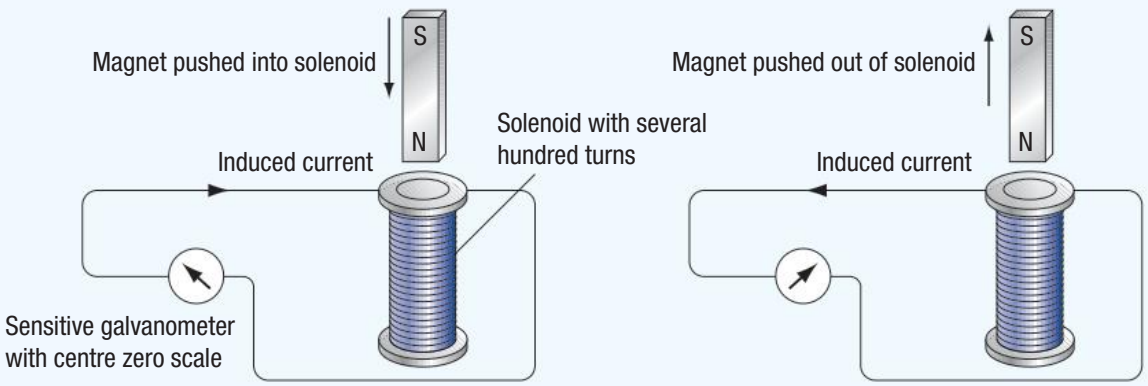


Figure 8.28 A simple electrical generator comprising a solenoid and permanent magnet

ISBN 9780170189071

Materials

- solenoid
- galvanometer with centre zero scale
- leads and connectors
- 2 permanent bar magnets
- digital camera (optional)

Method

1 Connect the solenoid to the galvanometer.

2 Note the reading on the galvanometer.

3 Move one of the magnets into the solenoid and stop. What happens to the galvanometer reading?

4 Take the magnet out and stop. What happens to the galvanometer reading?

5 Repeat steps 3–4; however, this time, keep the magnet still and move the solenoid. What do you observe?

6 How can you generate more electrical energy with the equipment provided?

7 Move the magnet in and out of the solenoid several times. Record your observations.

Discussion

1 Does the galvanometer add any energy into the system?

2 What can you do to increase the amount of electrical energy you generate?

3 What is the difference between putting a north pole into one end of the solenoid and putting a south pole into the same end?

4 Draw a Sankey diagram to show the energy transformations involved in the generation of electrical energy in this activity. Start with your own food intake. Indicate where the thermal energy goes.

5 Upload your results, Sankey diagram and any digital images or videos to the class wiki.

Extension: reading a CRO screen

WEBLINK
Virtual CRO

A cathode ray oscilloscope (CRO) is a meter that reads the way the potential difference between two points varies with time. An AC supply changes direction every half cycle. The potential difference has a peak value. This peak voltage is shown on the vertical axis. The time it takes for the wave to complete one cycle is shown on the horizontal axis. This is the period of the wave (Figure 8.29).

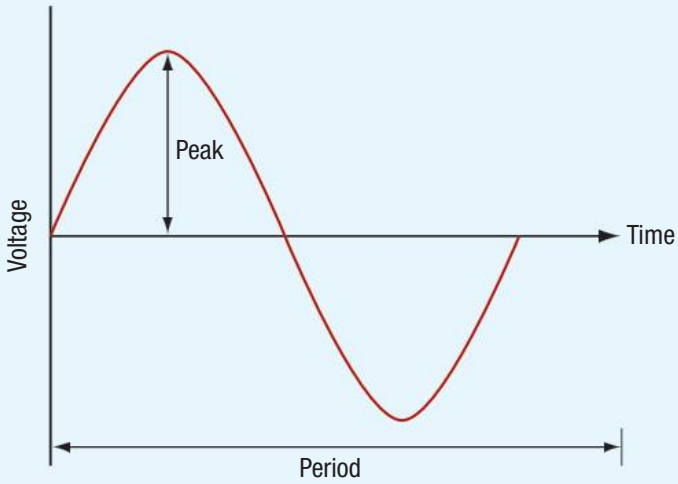


Figure 8.29 CRO screen showing peak voltage and the period for an AC supply

1 Connect this experiment to a CRO and see if you can find the actual size of the potential difference you generated.

2 Use one or more springs to help you generate a continuous AC potential difference. Observe its period (time for one cycle) and peak potential difference on the CRO.

3 What factors change the amount of electrical current induced in the solenoid?

glossary terms

cathode ray oscilloscope
a measuring device that shows the way that voltage changes with time

peak voltage
a maximum value of a time-varying potential difference

ISBN 9780170189071

Coal-fired power stations

Most power stations in Australia burn a fossil fuel, usually coal, to produce the heat necessary to turn water into steam. The steam is directed at a turbine, which is a set of specially designed fan blades. The turbine is connected to an electrical generator. There is a magnet that rotates, called the rotor, in the presence of conducting wires. This set of wires, which is stationary, is the stator. The turbine rotates the magnetised rotor and induces a potential difference that drives the AC current (Figure 8.30).

Three-turbine power station

Figure 8.31 shows a three-turbine coal-fired power station.

ACTIVITY SHEET

Annotating a diagram of a three-turbine, coal-fired power station

SCI10SIAS00212

Air is heated as it is drawn into the furnace. Fine, powdered coal is forced into the furnace and combines with the air to burn. This produces the thermal energy used to heat water into steam.

The steam is condensed back to water and recycled. In most power stations, several turbines use the steam. The turbines are designed to work with different steam pressures because the energy of the steam is reduced each time it is used in a turbine. The output from the three turbines utilises as much of the energy in the steam as possible. The low-pressure waste steam is returned to the system via a system comprising a condenser and cooling towers, which turns it back into water.

Waste emissions include carbon dioxide (a major influence on climate change), water vapour and ash. Some other gases, mainly based on the nitrogen and sulfur in the coal, are also produced. These have significant environmental effects by increasing the acidity of the atmosphere. Some can be removed before getting into the atmosphere. Electrostatic precipitators remove the majority of the ash before it is vented from a high tower (Figure 8.32).

If the ash is not removed, it circulates in the air and falls to the ground as fine particles. This affects the health of people living nearby. The remaining ash and water vapour disperses into the atmosphere, along with the carbon dioxide and other gaseous emissions that have not been removed.

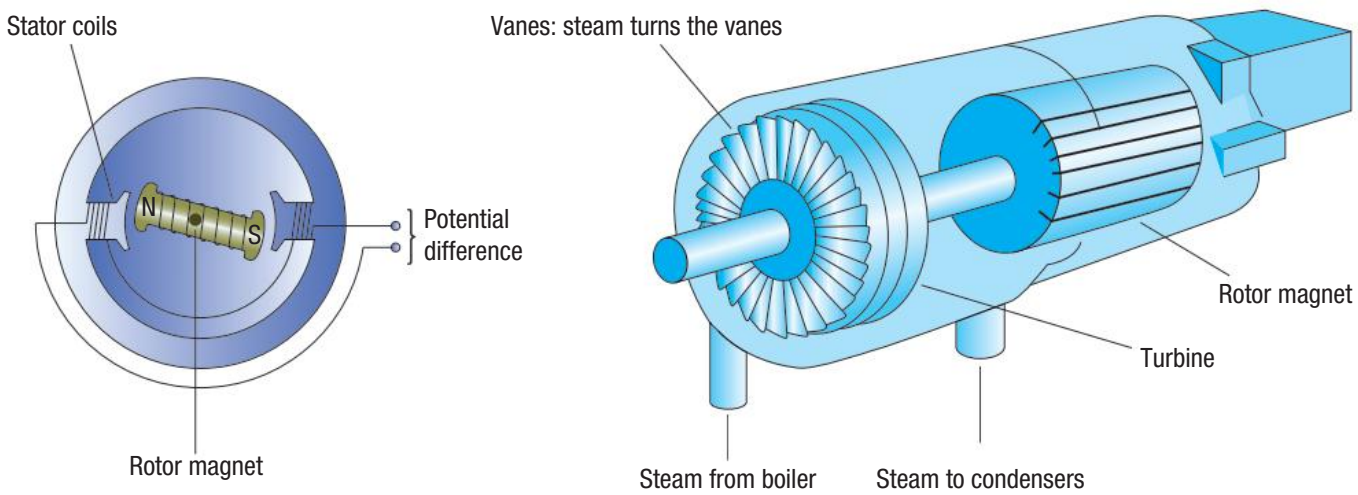


Figure 8.30 The magnetised rotor spins in the presence of the wire coils of the stator. Electrical energy is produced.

ISBN 9780170189071

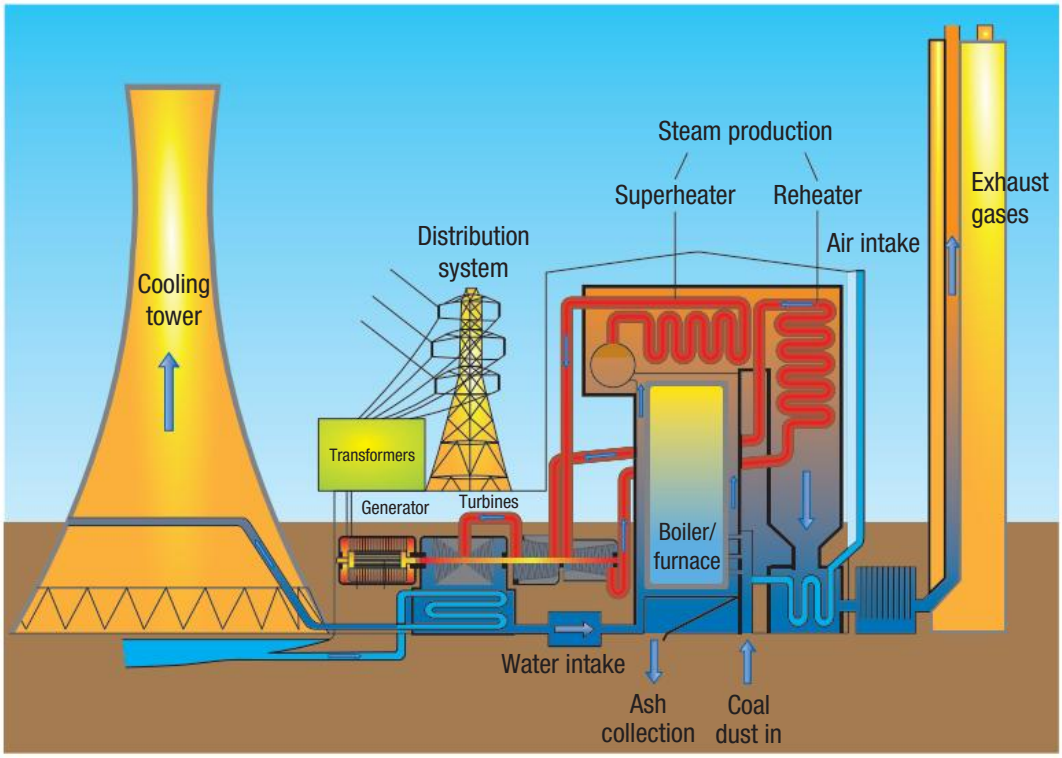


Figure 8.31 Three-turbine coal-fired power station

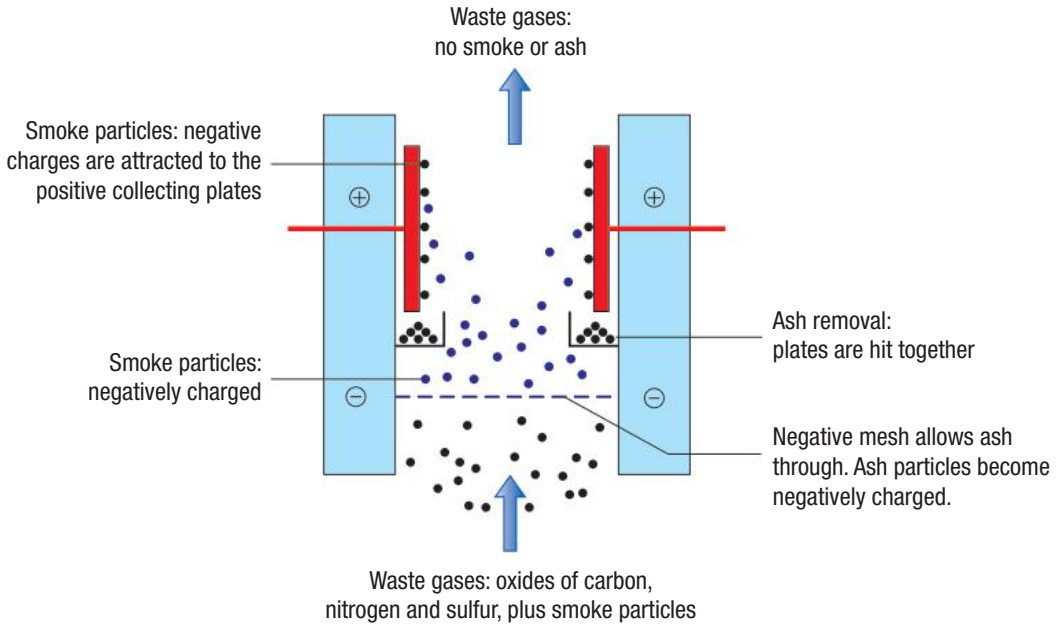


Figure 8.32 Electrostatic precipitator: ash particles gain electrons from the negatively charged mesh. They are then attracted to positively charged plates on the sides, where they stick. These plates are regularly cleaned.

glossary terms

electrostatic precipitator
a structure in a coal-fired power station that removes ash by use of electrical force on electrically charged ash particles

rotor
a rotating magnet in a generator

stator
a stationary set of wires surrounding the rotor in a generator

ISBN 9780170189071

Questions 8.5

What have you learnt?

WORKSPACE

What have you learnt? 8.5

SCI10SUWR00210

Understand

1 In order, list the three most common energy resources used for electrical energy production in Australia.

2 **a** What does a turbine do?

b How is it related to a generator?

c Draw and label a diagram, or sequence of diagrams, to show how a simple electrical generator works.

Apply

3 On a sketch, show the meaning of peak voltage and link it to the reading on a CRO.

Analyse

4 What are the similarities and differences between the generation of electrical energy by wind and natural gas?

Synthesise

5 Michael Faraday was the first person to demonstrate two important electromagnetic effects. What are they? For each effect, describe how it is used in two different technological examples.

Evaluate

6 Suggest three criteria you would use to decide whether to develop one of two different electricity production systems. Use these criteria to decide which one you prefer.

Reflect

7 Do you have enough information to get started on the culminating assessment task using an electricity generation system? What other information would you need to complete the task?

Transformers

Transformers are an important part of a power supply system (Figure 8.33). After the generator produces electrical energy, the output potential difference or voltage is increased by a transformer. The output of the transformer is the output of the electrical energy generation system. It is also the input for the electrical distribution system.

Transformers increase the potential difference produced at the generator. The result is a lower current in the distribution wires, which reduces the waste heat from the wires.

A transformer is made from two independent coils of wire: input primary coil and output secondary coil. Each coil has a number of turns or loops to make the coil.

There is no electrical connection between the coils; rather, they are connected by a magnetic field. They have a magnetic material, such as soft iron, to help direct and maintain the magnetic connection between them. The magnetic connection is only useful when an AC is in the coils. Therefore, transformers only work with AC.

The output potential difference across the secondary coil can be less than, the same as or greater than the input potential difference. This is achieved by changing the

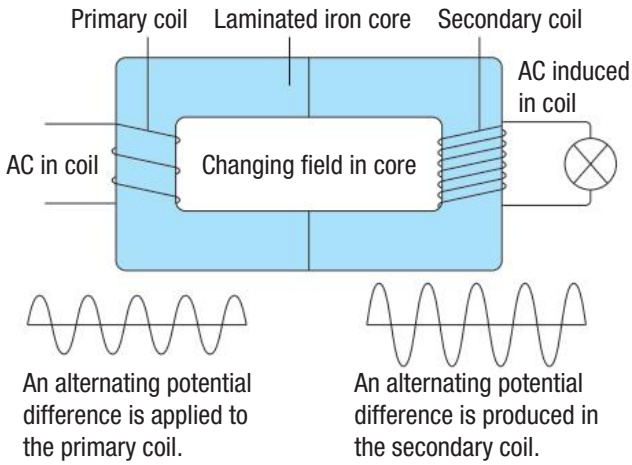


Figure 8.33 A transformer. The primary and secondary potential differences differ because one coil has more turns than the other.

ISBN 9780170189071

number of turns in the secondary coil relative to the number of turns in the primary coil. This is known as the turns ratio, which is given by the following:

$$\text{Turns ratio} = \frac{\text{number of turns in secondary coil}}{\text{number of turns in primary coil}}$$

When the turns ratio is greater than 1, the potential difference across the secondary coil is made greater than that across the primary coil. This makes the current less in the secondary side compared with the primary side of the transformer. Lowering the current ensures the power losses in the distribution system's wires is as low as possible.

Activity 8.4
Make a transformer

WORKSPACE
Make a transformer
SCI10SIWR00211

What are the risks in doing this activity?	How can you manage these risks to stay safe?
Transformers change the secondary potential difference compared with the primary potential difference. This affects the power delivered to circuit components, which may overheat. Burns to skin and damage to equipment may occur.	Make sure you follow all directions carefully. Do not increase the primary voltage above 2 V AC. Do not alter the turns ratio unless approved by your teacher. The turns ratio must never exceed 2 for this activity.

Materials

- 2 laminated iron cores or soft iron rods
- 2 long, insulated conducting leads
- 12 V AC power supply (2V AC only to be used)
- 2 globes (2.5 V, 0.3 A) in holders
- CRO (a dual trace CRO is very useful for this activity), or multimeter with AC setting

Method

1 Wrap 20 turns of insulated conducting wire around one end of the iron core to form the primary coil.

2 Connect the ends of the primary coil to the AC terminals of the power supply.

3 Wrap 20 turns of the second insulated conducting wire around the other end of the iron core to form the secondary coil.

4 Connect the ends of the secondary coil to one globe.

5 Connect the other globe across the terminals of the power supply.

6 Turn the power supply to 2 V and turn it on. (Do not exceed 2 V.)

7 Record your observations.

8 Use the CRO to record the potential difference versus time graphs for the primary and secondary coils.

9 Increase the number of turns in the secondary coil to 30 and record your observations of globes and CRO or multimeter readings.

10 Decrease the number of turns in the secondary coil to 10 and record your observations of globes and CRO or multimeter readings.

Discussion

1 For each case, calculate the turns ratio:

$$\frac{\text{number of turns in secondary coil}}{\text{number of turns in primary coil}}$$

2 For each case, calculate the ratio:

$$\frac{\text{secondary voltage}}{\text{primary voltage}}$$

3 Place the ratios in a data table so that you can compare their values in each case. What do you conclude?

glossary terms

primary coil
multiple turns of wire on the input side of a transformer

secondary coil
multiple turns of wire on the output side of a transformer

transformer
an electromagnetic device that converts an alternating current of a certain voltage to an alternating current of a different voltage

turns ratio
changing the number of turns in the secondary coil relative to the number of turns in the primary coil

ISBN 9780170189071

Occupational hazard: black lung disease

Coal workers are subject to coal dust, which they breathe. The dust is small enough to enter the lungs and settle there, resulting in asthma-like symptoms. The coal interacts with lung tissue, causing it to break down. Figure 8.34 shows the devastating effects of coal dust on lungs. If you have ever seen a potato go black with rot, this is similar to what happens to lungs when coal dust gets in.

Black lung disease, or coal worker's pneumoconiosis, affects the ability to breathe and is mostly distressing, painful and fatal. It is an entirely preventable, work-related disease.

Healthy tissue | Progressive massive fibrosis

Figure 8.34 Lung affected massive fibrosis (right) compared with normal lung tissue. Note the thickening and scarring of the affected tissue.

Questions 8.6
What have you learnt?

WORKSPACE
What have you learnt? 8.6
SCI10SUWR00213

Understand

1 How are magnets involved in electricity generation?

2 Sketch a simple transformer. Label the primary and secondary coils. What does the transformer do?

Apply

3 Draw a flowchart to show the main energy transfers and transformation in a coal-fired power station.

4 Describe two ways energy is lost from a power station that uses steam.

Analyse

5 What is the advantage of using three turbines in the power station shown in Figure 8.31?

Synthesise

6 Construct a single diagram or flowchart to show the way heat energy is used in the following parts of a coal-fired power station: air intake, exhaust gases, water intake and steam production and water cooling system.

Reflect

7 In what ways have your ideas about electricity generation and energy losses been altered or developed?

8 Consider whether you have enough information to get started on the culminating assessment task using an electricity distribution system. What other information do you think you would need to obtain to complete the task?

ISBN 9780170189071

Electricity production: other primary energy sources

Electricity can be produced in numerous ways. Any heating process that causes gases to expand can be used to make magnets and wires move relative to each other. So can other processes that cause this relative motion.

Nuclear energy

Nuclear and thermal power stations produce steam that turns turbines to produce electrical energy. The main difference is in the source of the thermal energy. In a nuclear power station the source is the energy already locked up in the nucleus of atoms – usually uranium atoms. There are several different uranium nuclides. The term 'nuclide' is used to describe any atomic nucleus. Uranium has three main nuclides (isotopes): uranium-234, uranium-235 and uranium-238.

Naming nuclides

Most elements have several different nuclides. These are referred to as isotopes ('iso–' means 'equal', and 'tope' means 'type'). The nucleus of each isotope is a nuclide. Uranium has three isotopes – that is, three nuclides of uranium. All are uranium because they have 92 protons; however, their number of nucleons – their mass numbers – differs. The three naturally occurring uranium nuclides are: $^{234}_{92}U$, $^{235}_{92}U$ and $^{238}_{92}U$.

Nuclear fissio

When a slow-moving neutron is fired at a uranium-235 nuclide, the uranium nuclide splits into two different nuclides. Two or three neutrons are also released (Figure 8.35). The process is called nuclear fission.

Each of the two nuclides produced during fission is a fission fragment. The fission fragments and neutrons move very rapidly and carry the energy, which was formerly locked up in the nuclide, out to meet other atoms and nuclei. The result is a burst of energy that becomes available for use in the system. Figure 8.36 shows how the reactor is used to transfer heat energy to the steam generator and then to the power station.

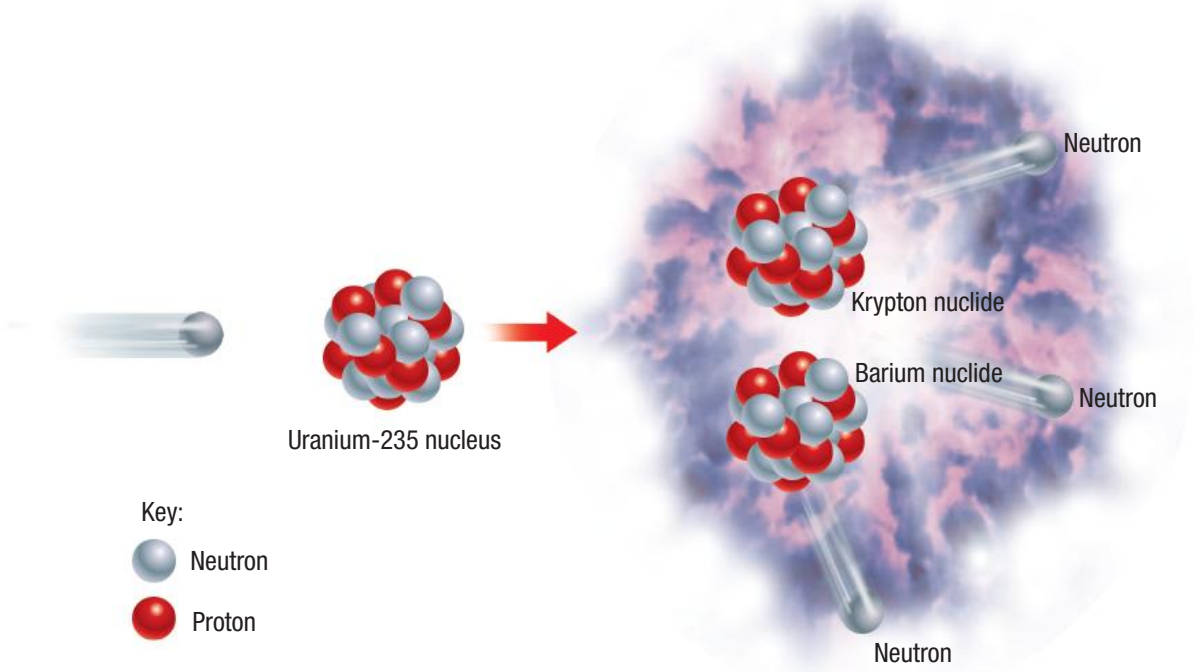


Figure 8.35 The nuclear fission of $^{234}_{92}U$ produces two nuclides and three neutrons.

glossary terms

fission
the splitting of a nuclide into two fragments

fission fragment
a nuclide produced during fission

isotope
one of several nuclides of an element

nucleon
a proton or neutron

nuclide
an atomic nucleus

ISBN 9780170189071

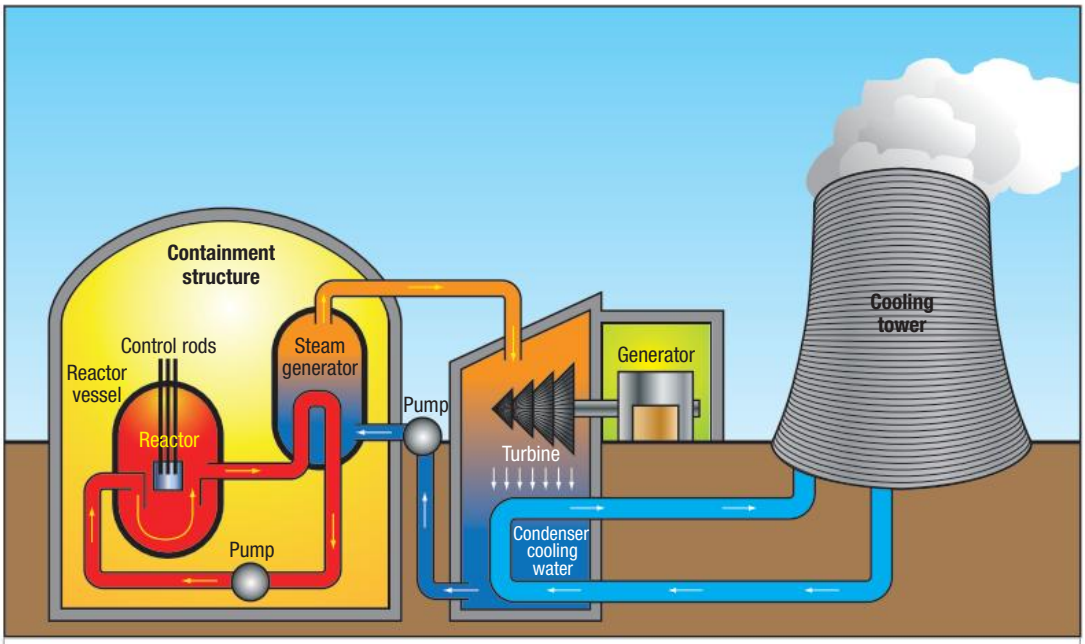


Figure 8.36 A nuclear power station

A single fission event produces only a tiny amount of energy, but there are trillions and trillions of uranium nuclides to be set off. In a sample of uranium, some nuclides will spontaneously split into fission fragments and release neutrons. This means there are always some neutrons in the sample to set off the process in other uranium nuclides.

If each of the three neutrons released in a fission event causes fission in other nuclides, $3 \times 3 = 9$ neutrons will be produced, then 27, 81, 243 and so on. It is not too hard to see that lots more fission events are likely to occur. The process in which neutrons multiply rapidly is called a chain reaction. However, the neutrons produced in these fission events are going too fast to be useful. They have to be slowed down by a moderator before they can trigger a new fission event.

Good design and careful management mean that, before you know it, there are trillions of fission events and that small amount of energy from one event has been multiplied by trillions. There is therefore more than enough energy to run a power station. In fact, you have to be very careful that the process does not overshoot. A nuclear power plant must only allow one neutron to be active at any one time so that a chain reaction does not lead to a runaway. The control of the nuclear reaction in the nuclear pile is done by the control rods that absorb neutrons whenever necessary.

Risks of nuclear power: nuclear accidents

There have been three major nuclear accidents since nuclear power plants first started to operate commercially in 1954: Three Mile Island in the United States (1979), Chernobyl (1986) in the former Soviet Republic (now Ukraine) and Fukushima in Japan (2011). In all these cases, human error in design, planning, operation and response caused unnecessary damage, deaths and long-term environmental and health problems.

The Three Mile Island incident was the least damaging; for the Chernobyl disaster, very few people died at the time or were immediately affected.

In Fukushima, a major tsunami caused damage that could have been predicted from the geological records at that location. The nuclear reactions ceased immediately – the design guaranteed that; however, the plant was simply unable to respond properly to massive earthquake and water damage. Pipes and storage tanks cracked open and released nuclear material that should have been contained. Gases such as hydrogen were released and reacted in air to produce water, accompanied by explosions (Figure 8.37). The explosions caused further damage to the nuclear containment system. The substantial number of

Figure 8.37 A hydrogen–oxygen explosion released nuclear radiation at the Fukushima Daiichi nuclear power plant soon after the earthquake and tsunami in March 2011.

ISBN 9780170189071

deaths directly attributable to the nuclear component of the earthquake and tsunami disaster is likely never to be known.

In all three disasters, long-term environmental and health issues are still emerging. These include the contamination of food supplies, ground and ocean water, and long-term genetic effects in plants and animals, including humans. Some of these effects take 20 to 40 years to become obvious.

WEBLINK
Fukushima Power Plant explodes

Hydroelectric power

Moving water can be used to generate electrical energy. Hydroelectric power stations use falling water to produce a high-energy flow of water through a turbine system (Figure 8.38). Falling water is subject to gravitational force. Above the power station, the water has gravitational potential energy. Most of this potential energy is converted into kinetic energy for use in the turbines (Figure 8.39). The electrical energy is generated by electromagnetic induction.

Figure 8.38 The Snowy Mountains Scheme: water races from the upper dam down the pipes to the turbines and then flows into the lower dam.

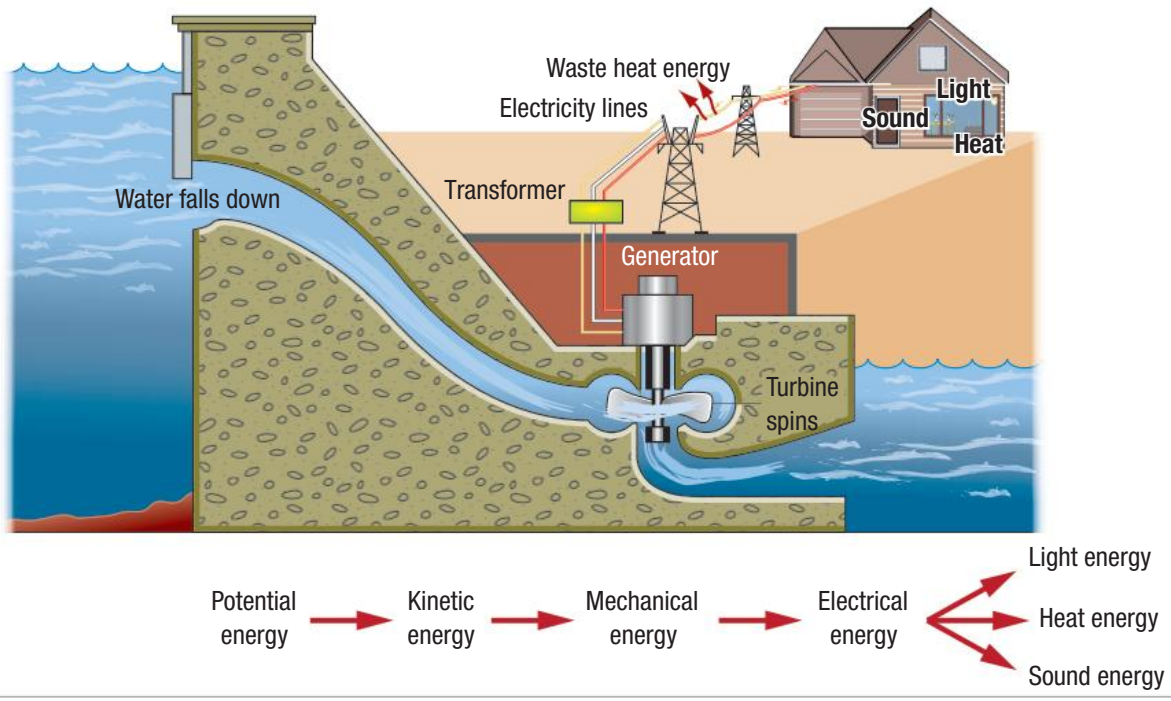


Figure 8.39 Hydroelectric energy is produced from the conversion of gravitational potential energy into kinetic energy.

glossary terms

chain reaction
the production of more than one neutron during multiple fission events

control rod
the material used to absorb excess neutrons in a nuclear pile

moderator
material that slows down neutrons from fission events

runaway
an uncontrolled fission reaction, such as in an atomic bomb

ISBN 9780170189071

WOW!

Snowy Mountains Scheme

Australia is a nation that has welcomed people from all parts of the world. After the Second World War, many European immigrants came to Australia looking to start a new life. Many ended up in the Snowy Mountains and contributed to building a vast hydroelectric plant that is still very important to Australia's electricity distribution system (Figure 8.40). It was an extraordinary accomplishment.

Today, the effects of the plant on the Snowy River downstream are devastating, with low water flows reducing the river to little more than a weed-filled drain in places. Nevertheless, the social and economic benefits were, and are, considerable. Hydroelectricity is used as a rapid response system to ensure there is sufficient electrical energy when there are rapid demands of the system from customers, such as on very cold or hot nights.

Figure 8.40 Migrant workers building a future at the Snowy Mountains Scheme (c. 1959)

Gravitational potential energy

Potential energy is energy ready to do work. Gravitational potential energy is energy ready to do work under the influence of gravity. Figure 8.41 shows a boulder sitting on the edge of a cliff. It is ready to release its energy – if only it were given the chance! Roll it over the edge and all that potential energy will be transformed into kinetic energy.

In the same way, a mass of water that is allowed to fall from a higher to a lower place will transform the gravitational potential energy into kinetic energy. The gravitational force is the only force acting on the water, causing the water to accelerate. Since the gravitational force is applied over a distance, it works on the water. This energy transfer goes to the kinetic energy of the water. As the potential energy becomes less, the kinetic energy gets more. There are transfers and transformations of energy to the surrounding system, mostly to the air and friction in the pipes.

Figure 8.41 A rock ready to roll

This is the principle behind hydroelectric energy production. Water is stored in a dam above the power station. It is allowed to fall through a pipe to the turbines, where its energy is directed through narrow nozzles onto the blades of the turbine (Figure 8.42).

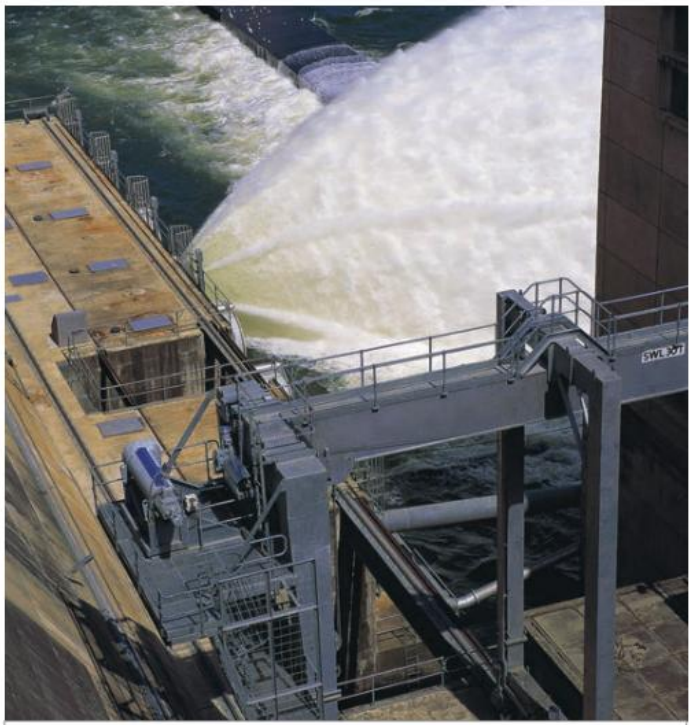


Figure 8.42 A mass of water flows from a high dam to a lower dam through turbines. The gravitational energy is converted into kinetic energy that is used to spin the turbines.

ISBN 9780170189071

Combined heat and power system

All power generation produces heat energy. That is a lot of heat to be removed from the system. This thermal energy is usually wasted because it is hard to store and use efficiently.

Electrical energy production far from the place at which it is used means that the thermal energy, which is a by-product of the process, cannot be used efficiently across the system. It cannot be carried around the electricity distribution system. The waste heat is usually associated with hot water from the steam that drives the turbine. Steam temperatures as high as 540°C are typical. The steam is condensed in cooling towers before the water is stored in large, artificial lakes or pondages, where it cools even more. Eventually, the warm water is released into neighbouring waterways. Thermal energy is also transferred to the air from the wires of the distribution system. The longer the wires, the larger the energy losses (Figure 8.43). What if we could return this waste heat energy to the input side to reduce the rate at which primary fuels need to be burnt?

Cogeneration, or combined heat and power (CHP) system, is the use of waste heat from the electrical energy production cycle for another purpose. In a CHP system, natural gas or another fuel is used to run a small generator within the production process. It takes a comparatively small amount of energy to pipe the gas to the plant. Energy losses in supplying and converting the primary energy source for CHP are relatively small compared with the energy losses from a large-scale electricity generation and supply system.

For the CHP system, fuel is burned at the location it is to be used. Water is heated to steam that drives the turbine and spins the generator. This generates the electrical energy for the process. The waste heat from the burning of fuel and from the heated water (steam) is returned to the production cycle, as either a source of heat for the generator or heat for another process within the factory, such as industrial cleaning processes and space heating for offices and amenities. Some companies claim they can increase efficiency of energy production and claim around 60%, up to 90% efficiency.

Figure 8.43 A section of the powerlines that carry electricity from the Latrobe Valley in eastern Victoria to Portland in western Victoria to supply the aluminium smelter – a distance of over 500 km

Figure 8.44 A CHP system uses water heated by waste energy to improve efficiency.

VIDEO
Transporting electricity
SCI10SUVD00214

VIDEO
Transformers and stepping down current
SCI10SUVD00215

glossary terms

combined heat and power (CHP) system
the use of waste energy from the electrical generator as part of the electrical energy production cycle or for other processes in a system

gravitational potential energy
the energy associated with the position of mass above or below a defined zero point

ISBN 9780170189071

Questions 8.7

What have you learnt?

WORKSPACE

What have you learnt? 8.7

SCI10SUWR00216

Understand

1 Write down the nuclide symbols for the three naturally occurring nuclides of uranium.

2 Use a diagram to describe fission. Label the fission fragments.

3 What is gravitational potential energy? How is it used in hydroelectric energy generation?

Apply

4 How are nuclear power stations the same as, and different from, thermal coal-fired stations?

5 Compare sources of energy losses in coal-fired and hydroelectric power stations.

6 Draw a Sankey diagram for the production of electrical energy from a hydroelectric system.

Analyse

7 What do control rods do in a nuclear power station? How do they prevent a runaway reaction?

8 Coal, gas and nuclear electricity generation are similar. How?

9 Give three reasons why CHP systems are being developed.

Synthesise

10 Use a diagram or flowchart to show how energy is transferred and transformed in a CHP system. Explain how this is different from other power supply systems.

Reflect

11 What have you learnt about electricity generation systems? How will you use this knowledge to develop your culminating assessment task further?

CONNECTION

Literacy: Volkswagen case study

SCI10SICN00217

WEBLINK

Volkswagen

ISBN 9780170189071

Unit review

ACTIVITY SHEET
Unit 8 checklist
SCI10SUAS00219

REVIEW QUIZ
Unit 8
SCI10SURQ00218

WORKSPACE
Unit 8 review
SCI10SUWR00220

Understand

1 Define thermal equilibrium. How does it relate to temperature measurement?

2 Why does a car need a cooling system?

3 What is the purpose of crumple zones in cars?

4 Define mechanical work in words.

5 Draw a diagram of a turbine system. How is it related to the generator?

6 How does a transformer work? Use a diagram to show your understanding.

7 Use a diagram to show your understanding of a fission chain reaction. Refer to nuclides, fission fragments and neutrons as part of your diagram.

8 What is meant by a CHP system?

Apply

9 A car engine is 15% efficient when it converts 4000 MJ of fuel energy into the kinetic energy of the car. How much kinetic energy does the car have?

10 Two 50 mL samples of water are heated, one to 40°C and the other to 90°C. They are then mixed together. What temperature will they come to after thermal equilibrium is reached? What assumption must you make to provide an answer?

11 Describe the way that crumple zones work.

Analyse

12 Energy is always lost from a system. Given the law of conservation of energy, how is this possible?

13 Why is it difficult to categorise forms of energy as only kinetic energy or potential energy? Use chemical energy as an example.

14 Diesel fuel produces 39 MJ/L, but a diesel engine is about 24% efficient. If a diesel vehicle travels 100 km on 5 L of fuel, how much energy does it transform as useful energy?

15 Complete the following table.

Force applied (N)	Distance interval (m)	Energy transfer (J)
1867	9.21	?
?	0.57	45.7
46.8	?	15473

ISBN 9780170189071

16 How can a magnet and solenoid generate electrical energy? Sketch a diagram to show how this occurs. How is this system the same as, and different from, a large-scale electricity generation process?

17 What are the similarities and differences between a coal-fired power station and a hydroelectric power station?

18 Why might CHP systems be desirable for local use in homes, factories and schools?

Synthesise

19 A car with 30 000 J of energy stops suddenly in a crash. It crumples by 0.60 m before coming to a stop.

- **a** How much work was done on the car?
- **b** What force was applied to the car?
- **c** What was the average acceleration of the car while stopping?

20 Draw a flowchart to show how energy flows in and out of a vehicle engine cooling system.

21 Draw a Sankey diagram to show the production of electrical energy from a nuclear power station.

Evaluate

22 List three significant problems for coal-fired power stations. How do you think you could overcome them?

23 Coal-fired power stations produce more radioactive emissions than nuclear power stations. Why, then, are there more coal-fired power stations?

Reflect

24 Describe some of the new insights you gained into energy and systems.

25 Compare the use of flowcharts and Sankey diagrams in your culminating assessment task.

26 How will your understanding of energy transfer systems help you to relate to personal decisions about energy use, design and social issues discussed publicly and considered by governments? Give at least one example.

ISBN 9780170189071

Appendix 1: Writing a scientific report

The main purposes of a scientific report are to communicate the results of your experiment and to ensure that it can be repeated by another person.

There is an accepted format for scientific reports. You need to ensure that your scientific report contains the following elements: title, introduction, materials, method, results, discussion, conclusion, bibliography and appendixes, if required. Make sure your report is written in the past tense (telling the reader what you did, rather than what you are going to do) and in the third person. For example, 'The elastic bands were selected on the basis of their length and width' rather than 'We selected the elastic bands on the basis of their length and width'.

There are some variations to writing a scientific report and your school may already have a version that they want you to use.

Elements of a scientific report

Make sure you start your report by including the following at the top of the page.
Name:
Date:
Partners:

Title

The title should be less than 10 words long, and it should address the factual content of the experiment, such as 'The effect of heat on the elasticity of elastic bands.'

Introduction

The introduction is made up of a number of subheadings that outline the scientific objective(s) for the experiment and give the reader sufficient background to understand the rest of the report.

Aim

Describe the aim of your experiment, or what you are trying to find out.

Background

Relate your report to what you have already learnt in class to give the reader an understanding of the scientific concepts that underpin the experiment.

Hypothesis

Explain the hypothesis you are testing in this experiment. Remember to write it in the 'If . . . then . . .' format; for example, 'If elastic bands are subjected to heat over 40°C, then their elasticity will be reduced.'

Approach to the experiment

- Name your independent variable (the one you changed).
- Name your dependent variable (the one you measured).
- List the variables that you controlled so that they would not affect the results.

Materials

List the quantity and type of materials that you used to conduct the experiment. If you only used one of an item, you do not need to include the amount. Remember to be specific about what you used, such as:

- 12 elastic bands (4 cm long × 0.3 cm wide)
- Bunsen burner.

Include here any specific safety precautions that you needed to take with the materials that you used. You can present this as a safety audit.

Method

This is a numbered step-by-step record of everything that you did in your experiment. It should be detailed enough so that someone else can repeat your experiment. Include diagrams or photos if this assists in describing what you did.

Results

The results section records what you observed (qualitative data) and what you measured (quantitative data). Display the data in an appropriate form, such as photos, tables or graphs. If you performed some analysis on your data, such as averages, show the calculations here.

Discussion

This is a discussion or explanation of what your results show. It should consider the following questions.

- Are there any patterns in your results? Refer back to the theoretical information that you presented in the introduction to your report, and see how your results fit with that.
- Did you obtain any unexpected results? How can you explain them?
- Critique the design of your experiment, with particular attention to the method and results gathering. What were the sources of error in your results? That is, was your sample too small, did you measure incorrectly or did you control the variables poorly?
- Do you have any suggestions for improvement? How would this be an improvement on the current design? For example, could you have used more elastic bands and run more tests? Could you have tested the elastic bands at a lower or higher heat?
- Do you have any ideas for further experimentation that could add to our understanding of this topic? For instance, could you go on to test thicker elastic bands to see if they respond the same way to heat?

Conclusion

This is where you explain what you can conclude from your experiment. Was the hypothesis supported or disproved?

Bibliography

Acknowledge any sources that you used to design, conduct or write up your experiment. See `Appendix 2: How to write a bibliography' for the accepted format.

Appendix

If required, present your raw data in table form here.

Appendix 2: How to write a bibliography

Whenever we do research it is very important that we acknowledge where we have got our information from. We can do this by including information about the source in a bibliography at the end of our report or assignment.

In a bibliography we list each source in alphabetical order by the author's surname. If there is no author, the title is used instead, with the words 'A' and 'The' being ignored for alphabetising purposes.

The information below shows the information needed, and the order in which it is listed, for different types of resources.

Books

Author's surname followed by their initials
Year of publication in brackets
Title in italics or underlined
Edition (if relevant)
Publisher and the place of publication
(If the author is unknown, put the book title first.)

For example:

Denning, A. (1994) *The craft of woodcarving*, Sandstone: London.

Encyclopaedia (printed)

Title of article in single quotation marks
Year of publication in brackets
Title of encyclopaedia in italics or underlined
Volume number
Publisher and place of publication
Page number(s)

For example:

'Minerals in Australia' (1996) *The World Book Encyclopedia*, Vol. 6, World Book: Sydney, p. 308.

Encyclopaedia (online)

Title of article in single quotation marks
Year of publication
Title of encyclopaedia in italics or underlined
(Online)
<URL address>
[Date accessed in square brackets]

For example:

'Jupiter', *Encyclopaedia Britannica Online School Edition* 2006, (Online) <www.school.eb.com.au/all/comptons/article-9345009> [accessed 10/11/2011].

Journals, magazine or periodicals (printed)

Author's surname followed by their initials
Year of publication in brackets
Title of article in single quotation marks
Title of magazine or journal in italics or underlined
Volume number if relevant
Issue number if relevant
Page number(s)

For example:
Choi, C. (2003) 'Cleaner living', *Scientific American,* vol. 289, no. 5, p. 32.

Journals, magazines or periodicals (online)

Author's surname followed by their initials
Year of publication in brackets
Title of article in single quotation marks
Title of magazine or journal in italics or underlined
Volume number if relevant
Issue number if relevant
Page number(s)
(Online)
<URL address>
[Date accessed in square brackets]

For example:
Coghlan, A. (2003) 'GM crops can be worse for environment', *New Scientist.com* (Online) <www.newscientist.com/hottopics/gm/gm.jsp?id=ns99994283> [accessed 9/1/2012].

Newspaper

Author's surname followed by their initials
Year of publication in brackets
Title of article in single quotation marks
Title of newspaper in italics or underlined
Date
Page number

For example:
Shaw, P. (1996) 'Mining shares drop', *The Age,* 31 August, p. 1.

Internet

Author's surname followed by their initials (if identified)
Last update (if identified) in brackets
Title of article in italics or underlined
Sponsor name
(Online)
<URL address>
[Date accessed in square brackets]

For example:

Ward, C. (2004) *Australian bush fires burn on*, Disaster Relief, (Online) <http://disasterrelief.org/Disasters/020104Austfires4> [accessed 10/1/2012].

Audiovisual materials

Title in italics or underlined
Year of publication in brackets
[Type of media in square brackets]
Publisher and place of publication

For example:

Diet and Health (1997) [videocassette] Classroom videos: Melbourne.

Glossary

absolute dating
the process of determining the age of a material by looking at their radioactive content

absolute magnitude
brightness as though all objects were at 10 pc from Earth

absorption spectrum
dark lines in a continuous spectrum in which radiation that is characteristic of particular elements is absorbed

acceleration
the rate of change of speed

acid
a substance that tastes sour, stings or burns the skin, reacts with bases and has a pH less than 7

activity series of metals
a list of metals in order from the most reactive to the least reactive

adaptation
a genetic trait that is advantageous to survival

adenine
a base found in DNA and also another nucleic acid called RNA

aether
for Aristotle, a heavenly substance

agent
the thing applying the force to another thing (receiver)

alkanes
the main family of hydrocarbons present in crude oil and natural gas

allele
an alternative form of a particular gene

alloy
a substance with metallic properties that is a mixture of a metal with one or more other elements

alpha particle
a helium nucleus emitted when an unstable larger nucleus decays

amino acid
the subunit that makes proteins

anaphase
the stage in which homologous chromosomes or sister chromatids are separated and pulled to either pole of the cell

anion
a negatively charged ion formed when electrons are gained

apparent magnitude
brightness of a celestial object as seen from Earth

Aristotelian
adhering to the ideas of Greek philosopher Aristotle

artificial selection
intentional breeding for certain characteristics

astrometry
the study of the measurement of the universe

astronomical unit (AU)
half the Earth's orbital diameter

atmosphere
the gaseous mass or 'envelope' surrounding the Earth and retained by the Earth's gravitational field

atomic emission spectrum
the set of wavelengths of light emitted by heated atoms; this is seen as a set of coloured lines on a black background when viewed through a spectroscope

autosome
a chromosome that does not determine sex (in humans, pairs 1–22)

average acceleration
a single value for acceleration that best represents how the speed of an object changes

average speed
a single value for speed that best represents the motion of an object; speed change divided by time interval

base
a substance that tastes bitter, may feel slimy, reacts with acids and has a pH greater than 7

baseline
the line between two observation points

binary fission
the asexual division of a prokaryote cell or organelle into two

biodiversity
the variety of organisms in an environment

biogeography
the study of the geographical distribution of living things

bioinformatics
the application of computer science to study molecules

biosphere
the part of the Earth and its atmosphere in which living organisms exist or that is capable of supporting life

blast furnace
a huge steel stack lined with brick used to extract iron from iron ore

Bohr model
the model of the atom developed by Niels Bohr that proposed the electrons orbited the nucleus in energy shells

bonding
the joining together of two or more atoms or ions

braking distance
the distance travelled while applying the brakes until coming to a stop

braking time
the time over which a negative acceleration applies

calibration point
a value of a quantity that is used to define a scale

carbohydrate
an organic compound that includes sugars, starches, celluloses and gums and that serves as a major energy source in the diet of animals; they are produced by photosynthetic plants and contain only carbon, hydrogen and oxygen

carbon capture
the process of capturing carbon dioxide from large point sources, such as fossil-fuel power plants, and storing it in such a way that it does not enter the atmosphere

carbon cycle
the combined processes – including photosynthesis, decomposition and respiration – by which carbon as a component of various compounds cycles between its major reservoirs: the atmosphere, oceans and living organisms

carbon dioxide
a colourless, odourless, incombustible gas (CO_2) formed during respiration, combustion and organic decomposition

carbon footprint
the amount of carbon dioxide emitted by a person, organisation or event

carbonate
a compound containing the chemical group CO_3

carrier
a heterozygous individual who carries the recessive allele

cast
a fossil in the shape of a sedimentary rock that fills the space once occupied by a dead organism

catalase
an enzyme that catalyses the decomposition of hydrogen peroxide into water and oxygen

catalyst
a chemical that speeds up a chemical reaction but does not itself change

cathode ray oscilloscope
a measuring device that shows the way that voltage changes with time

cation
a positively charged ion formed when electrons are lost

cellular respiration
a process that requires oxygen to generate high-energy storage chemicals (abbreviated as ATP) and that produces water and carbon dioxide as wastes; the process of cell metabolism in which cells release usable energy from stored nutrients

centromere
the part of a chromosome that joins sister chromatids and where the spindle fibres attach

Cepheid variables
stars whose magnitudes vary

chain reaction
the production of more than one neutron during multiple fission events

chlorofluorocarbon
an organic compound that only contains carbon, chlorine, fluorine and hydrogen; formerly used as a refrigerant and as a propellant in aerosol cans, the chlorine in CFCs causes depletion of atmospheric ozone

chromatid
each vertical strand of a chromosome

chromosome
a densely coiled structure that holds the DNA ready for cell division

climate
the meteorological conditions, including temperature, precipitation and wind, that characteristically prevail in a particular region over an extended period of time

coke
coal that has been heated to high temperatures in the absence of air

combined heat and power (CHP) system
the use of waste energy from the electrical generator as part of the electrical energy production cycle or for other processes in a system

combustion
a chemical reaction with oxygen that produces heat

comparative anatomy
the study of similarities and differences in the anatomy of organisms

complementary base pairing
a rule that states the chemical bases are always found in pairs; for example, adenine will always bond with thymine, and guanine will always bond with cytosine

concentration
a measure of the amount of a substance in a given amount of solution

conduction
the transfer of heat energy by direct contact between particles in systems

continuous spectrum
a spectrum in which all radiation 'colours' are emitted

control rod
the material used to absorb excess neutrons in a nuclear pile

convection
the bulk movement of a fluid that carries thermal energy from a system

coolant
a fluid that circulates to remove heat energy from a local system

coprolite
fossilised dung

corner mirror
an arrangement of mirrors that reflects light parallel to the incoming rays

corrosion
the chemical reaction in which a metal reacts with one or more substances in the environment to produce a compound of the metal

cosmic background radiation
radiation from 300 000 years after the big bang

cosmic inflation
the incredibly rapid expansion of space

cosmic redshift
relative to spectra produced on Earth, absorption spectral lines for galaxies far away are all shifted towards the red end of the spectrum

cosmological principle
the principle that states that the laws of physics are the same throughout the universe

covalent bonding
the strong electrostatic force of attraction between the negatively charged electrons shared between two atoms and their positively charged nuclei

crossing-over
an exchange of genetic material in maternal and paternal homologues

crumple zone
the protective part of vehicle designed to buckle in a collision

cytokinesis
the process of dividing a cell in two, at the end of the division of DNA

cytosine
a base found in DNA and RNA

dark energy
a kind of negative pressure that is thought to be responsible for the accelerating expansion of the universe

dark matter
very weakly interacting material

daughter cells
cells produced through mitosis or meiosis (daughter cells created through mitosis are identical to the parent cell; those produced through meiosis are genetically different)

deceleration
negative acceleration, usually associated with braking

deep ocean current
the water movement caused by changes in both water temperature and salinity below a depth of 400 m

delocalised electron
an electron from the outermost occupied shell of a metal atom that has detached from the atom and now moves randomly among the metal ions formed as a result

deoxyribonucleic acid (DNA)
the inherited code of genetic information

deuterium
an isotope of hydrogen with one proton, one neutron and one electron

displacement
final position relative to a starting point, taking direction and magnitude into account

diploid ($2n$)
the total number of chromosomes in a body cell

distance
the difference between two position measurements

divergent evolution
evolutionary change caused by the modification of existing structures

DNA helicase
the enzyme molecule that unzips the DNA

DNA polymerase
the enzyme that lays down new bases on an exposed DNA strand to create a new DNA strand

DNA–DNA hybridisation
a technique for combining single DNA strands from two species, to compare their similarity

dominant trait
a trait that masks the other trait of a pair, if present

Doppler effect
the effect on observed frequency as a result of the relative motion of observer and source

double helix
the spiral shape of DNA

earthquake
a sudden movement of the Earth's crust caused by the release of stress accumulated along geologic faults or by volcanic activity

East Australian Current
an oceanic current that carries a stream of warm water from the Coral Sea into the cool waters of the Tasman Sea; it is the largest ocean current around Australia

efficiency
the ratio of useful output energy to input energy

efficient cause
for Aristotle, the force needed to make things move horizontally or change direction

El Niño
a period of extensive warming of the central and eastern Pacific Ocean that leads to a major shift in weather patterns across the Pacific

electrolysis
the decomposition of a compound using an electric current

electron configuration
a listing of how many electrons are in each successive shell of an atom

electrostatic precipitator
a structure in a coal-fired power station that removes ash by use of electrical force on electrically charged ash particles

emission
a product of the system; intended and unintended products, such as heat, solids, liquids and gases, and energy

endemic
native (to a particular location)

energy shell
a possible energy level that an electron might occupy; in the Bohr model of the atom, electrons can only be found in the electron shells according to definite rules

enzyme
a protein that acts as a catalyst in biological reactions

equator
the centre of a cell where the chromosomes line up during metaphase and anaphase

evolution
any process of formation, growth, change, development or transformation

exoplanet
a planet-like object revolving around a star other than the Sun (Sol)

exoskeleton
a hard, protective, supportive outer structure, such as the shell of a mollusc or the hard outer surface of an insect or arthropod

exothermic
a reaction in which energy is produced

extant
still in existence

extinction
the death of all members of a species

first filial (F_1) generation
the generation that results after breeding parent organisms

fission fragment
a nuclide produced during fission

fission
the splitting of a nuclide into two fragments

force
a push or pull applied by agent A on receiver B

fossil
any evidence of an organism from a former geological time

fossil record
the history of life on Earth as recorded by fossils

frequency
the number of waves per second

fusion
the process of combining two nuclei to make a third nucleus

gamete
a sex cell – sperm in males and ova in females

gene
a section of the genome that provides the code for a particular protein/characteristic

generator
a machine used to convert mechanical energy into electrical energy

genetic engineering
the technique of manipulating the genetic make-up of an organism

genetics
the study of genes and inheritance

genome
the total genetic information within an organism or species

genotype
the pair of alleles controlling a trait, such as *Rr*

global warming
an increase in the average temperature of the Earth's atmosphere, especially a sustained increase sufficient to cause climatic change

gonad
an organ that produces sex cells; in humans, ovaries in females and testes in males

gravitational potential energy
the energy associated with the position of mass above or below a defined zero point

greenhouse gas
an atmospheric gas that contributes to the greenhouse effect by absorbing infrared radiation produced by solar warming of the Earth's surface

group
a vertical column in the periodic table; elements in the same group have similar properties

guanine
a base found in DNA and RNA

Gulf Stream
a relatively warm ocean current flowing north-eastwards off the Atlantic coast of the United States from the Gulf of Mexico

hadron
a family of observable particles, including protons and neutrons

haploid (*n*)
a cell with half the number of chromosomes (one from each pair); a sex cell

heterozygous
when an individual has two different forms of a gene, such as *Rr*

homologous
relating to a pair of chromosomes with matching genes

homologous structures
body parts that are similar in different species because the species share a common ancestor

homologue
a pair of chromosomes with matching genes

homology
a structural or developmental similarity based on descent from common ancestors

homozygous
when an individual has two identical versions of a gene, such as *RR* or *rr*

Hubble's law
the law that states that the recession speed is proportional to the distance from the observer

Humboldt Current
a cold ocean current of the South Pacific, flowing north along the western coast of South America

hydrocarbon
an organic compound that contains only hydrogen and carbon

hydrosphere
the waters of the Earth's surface in solid, liquid and gaseous forms

ice cap
extensive sheets of ice; technically, they cover an area that is smaller than 50 000 km^2

index fossil
a widely distributed fossil, of narrow range in geological time, that can be used as a marker

inorganic chemistry
the branch of chemistry that studies the compounds of elements other than carbon compounds

input
a resource that flows into a system

interface
a dividing line or boundary

interphase
the period in which a cell is not dividing, and the cytoplasm is active

ion
a positively or negatively charged particle formed when electrons are lost or gained from atoms

ionic bond
an electrostatic force of attraction between positive and negative ions

ionic compound
a compound that is composed of positively and negatively charged ions

isotope
one of several nuclides of an element

karyogram
an arrangement of homologous chromosomes in order of size

karyotype
the chromosome set typical for a species

kinetic energy
energy of movement

La Niña
a period of cooler-than-average sea surface temperatures in the central and eastern tropical Pacific Ocean

law of conservation of energy
the law that states energy can be neither created nor destroyed

law of conservation of mass
the law that states that matter is neither created nor destroyed in a chemical reaction

light year
the distance a photon travels in one Earth year (or 10 trillion kilometres)

lipid
an organic compound – including fats, oils, waxes, sterols and triglycerides – that is insoluble in water, oily to the touch and constitutes the principal structural material of living cells

lithosphere
the outer part of the Earth, consisting of the crust and upper mantle, approximately 100 km thick

living fossil
an organism that appears in the fossil record from early geological periods and can be still found as a living specimen

local system
a defined system connected to other systems

logarithmic scale
a scale where equal distances mean the previous number has been multiplied by 10

magnitude
size

magnitude scale
the scale that shows the brightness of a celestial body; negative numbers are very bright, and positive numbers are less bright

main sequence
the central band of stars on the Hertzsprung–Russell diagram; stars that fuse hydrogen to helium

maternal
coming from the mother

meiosis
a type of cell division that halves the number of chromosomes, necessary to produce four haploid sex cells

Mendelian ratio
the 3 : 1 pattern of the second filial (F_2) generation

messenger RNA (mRNA)
a type of RNA that moves the information from the DNA template into the cytoplasm

metal displacement reaction
a reaction in which metal A is added to a solution of a salt of metal B, producing crystals of metal B and a salt of metal A; that is, the metals swap places

metallic bonding
the electrostatic force of attraction that operates between the negatively charged delocalised electrons and positively charged metal ions; it holds the metal together

metalloids
nine elements whose properties are between metals and non-metals; they are found between metals and non-metals in the periodic table

metaphase
the stage of cell division when the chromosomes are arranged around the equator of the cell

meteorological bureau
a government agency responsible for providing weather information to the community

mimicry
the ability to physically resemble a different organism to benefit from the mistaken identity

mitosis
a type of cell division that reproduces the DNA information exactly; it occurs in body cells

moderator
material that slows down neutrons from fission events

molecule
two or more atoms joined by sharing a pair of electrons

mould
a fossil that consists of the space left by a decayed organism

mutation
a change in the cell DNA code or chromosome number

natural motion
what things do, of themselves

nebula
a huge region of cosmic gas

net force
the addition of two or more forces applied to a single thing

neutralisation
a reaction between an acid and base that produces a salt and water

niche
a place in which an organism can live

nitrogenous base
one of the four bases – adenine, cytosine, thymine and guanine – that make up DNA

nuclear reactor
any of several devices in which a chain reaction is initiated and controlled, with the resulting heat typically used for power generation

nucleic acid
a complex compound found in all living cells and viruses and, when in the form of DNA and RNA, controls cellular function and heredity

nucleon
a proton or neutron

nuclide
an atomic nucleus

nucleosynthesis
the process of making atomic nuclei

nucleotide
the subunit that makes up DNA

orbit
a circular path taken by an electron as it revolves around the nucleus

ore
a naturally occurring rock that contains metal or metal compounds in sufficient amount to make it worthwhile extracting them

organelle
a small structure inside the cell that helps maintain its function

organic chemistry
the branch of chemistry that studies carbon compounds

origin
the start; a reference point

output
the intended product of a system

ozone
an unstable form of oxygen (O_3) that is formed naturally in the ozone layer from atmospheric oxygen by electrical discharge or exposure to ultraviolet radiation; it is also produced in the lower atmosphere by the photochemical reaction of certain pollutants

palaeoclimatologist
a scientist who studies climatic conditions, and their causes and effects, in the geological past, using evidence found in glacial deposits, fossils and sediments

palaeontologist
a scientist who studies life in the geological past, especially using fossils

parallax
the apparent movement of an object as a result of the change of observing position

parallax second, parsec (pc)
the distance to an object that has a parallax angle of 1 arc second when observed using the Earth's orbital radius as the baseline

parental generation (P)
the parents

patent
a legal right permitting an inventor to exclude others from making, using or selling an invention for a defined period of time

paternal
coming from the father

peak voltage
a maximum value of a time-varying potential difference

pedigree
a chart showing family relationships over several generations

pentadactyl limb
a limb with five digits (or fingers)

period
a horizontal row in the periodic table; elements in the same period have similar size

permafrost
permanently frozen ground; soil, sediment or rock that remains at or below 0°C for at least two years

pharyngeal
to do with the throat

phenotype
a trait that is physically visible, such as round seeds

photon
a 'particle' of light; an electromagnetic force carrier

photosynthesis
the process in green plants and certain other organisms by which carbohydrates are synthesised from carbon dioxide and water using light as an energy source; most forms of photosynthesis release oxygen as a by-product

phyla
a very large taxonomic group, such as echinoderms, arthropods and chordates

pitch
heavy oil fractions that seep to the surface of the Earth through a fault line

Planck curve
the continuous spectrum typical of a radiating body

plasma
the gas of charged particles; the fourth state of matter

point mutation
the substitution of a single base during DNA replication

pole
the top or bottom end of a dividing cell

pollutant
any contaminant introduced into a natural environment that causes instability, disorder, harm or discomfort to the ecosystem – that is, to physical systems or living organisms

polymer
a large molecule made up of many amino acids

position
the place relative to an agreed origin

post-combustion carbon capture
the process in which carbon dioxide is separated from other waste products of the combustion process before they are released into the environment

potential energy
energy other than kinetic energy that is ready to be transferred or transformed

pre-combustion carbon capture
the process in which carbon dioxide is trapped before the fossil fuel is burned

primary coil
multiple turns of wire on the input side of a transformer

primary energy content
the amount of primary energy that can be converted in a reaction

principle of superposition
a geological observation that, in undisturbed sedimentary rocks, the lowest layer is the oldest

prophase
the first stage of cell division

protein
a complex organic macromolecule that contains carbon, hydrogen, oxygen, nitrogen and usually sulfur, and is composed of one or more chains of amino acids; proteins are the fundamental components of all living cells

protein synthesis
the process within cells that builds protein molecules

Punnett square
a table that is used to determine the probability of offspring characteristics of a genetic cross between two parents

pure-breeding
relating to offspring of every generation who are the same for a particular trait; this indicates the organism is homozygous

quark
a particle that makes up a hadron

quasar
a highly energetic galactic nucleus

radiation
the infrared electromagnetic radiation that carries thermal energy from a system

reaction distance
the distance travelled before responding to the need to act

reaction rate
the speed at which a reaction occurs

reaction time
the time between observing a need to act and acting

receiver
the thing being forced on by another thing (agent)

recessive
a trait that is only visible if no dominant trait is present

relative dating
the process of determining the order of past events

replication
the process in which cells copy the DNA prior to cell division (also known as semi-conservative replication)

resistance force
the force applied to an object in the direction opposite to its motion

respiration
a reaction between glucose and oxygen that produces carbon dioxide, water and energy

retrodiction
a prediction about the past

ribosome
the structure in the cytoplasm in which protein synthesis occurs

rotor
a rotating magnet in a generator

runaway
an uncontrolled fission reaction, such as in an atomic bomb

salt
a compound produced when an acid and base react

scalar
a quantity without reference to direction, such as speed, distance and time

sea ice
ice that forms at the ocean surface once the surface temperature drops to freezing point during autumn and winter; the freezing point for salty ocean water is about −2°C, which is slightly colder than it is for fresh water at 0°C

seagrass meadow
the only flowering plants that can live underwater; seagrasses live in the coastal waters of most of the world's continents

second filial (F_2) generation
the generation produced from breeding the first filial (F_1) generation

secondary coil
multiple turns of wire on the output side of a transformer

seismologist
a scientist who studies earthquakes

selection pressure
the driving force that favours organisms with a particular characteristic over those without that characteristic

semiconductor
a substance that can weakly pass heat or electricity from one end to the other

semi-conservative replication
DNA replication whereby one strand is from the old DNA molecule and one strand is a new DNA molecule

sex chromosomes
chromosomes (X and Y) that determine the sex of an organism

sex-linked
relating to a gene found on one of the sex chromosomes

sexual selection
the advantage that certain individuals of the same sex have over other individuals, causing them to be more successful in reproduction

SI units
a set of units agreed on by all nations

single covalent bond
a covalent bond in which one pair of electrons is shared

sister chromatids
two identical chromosomes joined together, after the chromosome has replicated and before it divides

smog
fog that has become mixed and polluted with smoke

somatic cell
a body cell (not gamete) that contains a diploid number of chromosomes

space–time
the interconnected nature of measurements of space and time

spectroscope
an instrument that is constructed from lenses and prisms and designed to break up light into its wavelengths

speed
the rate of change of position

spindle (fibres)
protein fibres in the cytoplasm that attach to the centromere and control chromosome movement

spontaneously
occurring without additional energy input

stator
a stationary set of wires surrounding the rotor in a generator

stellar blueshift
relative to spectra produced on Earth, spectra from local stars moving towards Earth are shifted towards the blue end of the spectrum

stellar redshift
relative to spectra produced on Earth, spectra from local stars moving away from Earth are shifted towards the red end of the spectrum

stopping distance
the total distance to come to a stop after observing the need to react

stopping time
the total time to come to a stop after observing the need to react

strata
beds or layers of sedimentary rock; singular 'stratum'

surface area
the area of the surface of a substance; more finely divided substances have a greater surface area than the same mass of larger pieces

surface current
the water movement in the upper 400 m of the ocean

surrounding system
the immediate system into which emissions from a local system are transferred

system
a connected set of resources and processes

telophase
the final stage of cell division, just before cytokinesis

the heavens
for Aristotle, the region beyond the Moon

thermal energy
energy of the particles of which a substance is made; heat energy

thermal equilibrium
the result of two interacting systems coming to the same temperature

thymine
a base found in DNA (but not RNA)

time interval
the difference between two time measurements

transcription
the process in which the DNA information is copied, nucleotide by nucleotide, into mRNA

transfer RNA (tRNA)
the molecule that delivers amino acids to ribosomes

transformer
an electromagnetic device that converts an alternating current of a certain voltage to an alternating current of a different voltage

translation
the process in which the mRNA information is converted into an amino-acid sequence

triangulation
the use of triangles on a baseline to measure distance

trisomy
an extra copy of one chromosome

tritium
an isotope of hydrogen with one proton, two neutrons and one electron

tsunami
a very large ocean wave caused by an underwater earthquake or volcanic eruption

turbidity
a measure of water clarity or murkiness

turbine
a machine that rotates as a result of energy input

turns ratio
changing the number of turns in the secondary coil relative to the number of turns in the primary coil

universe
the ultimate system

upwelling
the movement of deeper colder waters to shallower depths

uracil
a base found in RNA (but not DNA)

UVB radiation
ultraviolet light, or the ultraviolet part of the electromagnetic spectrum

variation
differences between things

variety
a low taxonomic subdivision of a species consisting of naturally occurring or selectively bred populations, like a breed

vector
a quantity that includes direction, such as displacement, velocity and force

velocity
speed in a particular direction

vestigial
reduced, degenerate or non-functional

viable
healthy and able to reproduce

violent force
for Aristotle, the force that made things go off course, such as circular motion

water cycle
the cycle of evaporation and condensation that controls the distribution of the Earth's water as it evaporates from bodies of water and then condenses, precipitates and returns to those bodies of water

weather
the state of the atmosphere at a given time and place, with respect to variables such as temperature, moisture, wind velocity and barometric pressure

work
the force applied over a distance; a way of transferring mechanical energy; $W = F \times d$

X-ray crystallography
a technique that shines a beam of X-rays through purified materials, revealing the patterns of atoms

zygote
the diploid cell produced by the fusion of a sperm and an ovum

Index

absolute dating 46
absolute magnitude (stars) 170–2
absorption spectra 175, 176, 177
acceleration 213, 221–2
  force and mass 239, 240–1
  and net force 238–9
acid–base reactions 108–9, 115
acid–carbonate reactions 109–10
acid–metal reactions 110
acid rain 191, 257
acids 108–12
acquired brain injury 264
activity series of metals 99–100
adaptation 61
adenine 4
airbags 262–3
albinism 28, 29
alkali metals 73, 86, 98
alkanes 137–9
alleles 22, 27
alloys 113
alpha particles 74
aluminium oxide 123
amino acids 8, 10
anaphase 14, 15, 17, 59
anatomical structures, comparison 50–1
anions 93
antibiotics 67–8
apparent magnitude 169–71
Arctic sea ice 203–4
argon atom 120
Aristotle's ideas on motion 230–1
artificial selection 65
asexual reproduction 58
astrometry 159–79
astronomical unit 164–5
atavism 67
atmosphere 186, 188–9, 190, 191
  gases trapping heat in 195–6
  and ozone layer 196–7
atomic emission spectrum 86, 87
atomic nuclei 153, 154
atomic number 91, 92
atomic structure, Bohr model 86–9
atoms 72, 74, 75, 250–1
  and electrons 86–8
autosomes 11
average acceleration 222
average speed 217, 219–20

bacteria, drug-resistant 67–8
balancing chemical equations 117
bases (alkalis) 108–9
Batesian mimicry 63
bibliographies 285–7
big bang theory 75, 149, 152–4, 155–8
binary fission 58
biodiversity 39, 47, 48, 200–3, 207
biofuels 139
biogeography 54–6
bioinformatics 51–3
biosphere 186, 188, 189, 197, 207
black lung disease 274
blast furnace 125, 126
blueshift, stellar 176, 177
body fossils 44
Bohr model of the atom 86–9
bonding 86, 96, 119, 136
braking distance 226
braking time 224, 226
brightness and magnitude (stars) 169–71

car crashes, energy changes in 261–4
car driving
  forces involved 236–7
  reacting to an emergency 224–9, 237
car systems 255
  energy losses from 257–8
carbon 134–5, 188
carbon atom(s) 134, 135
  gaining four electrons 137
  model of 89
carbon capture 190–3
carbon cycle 187–9
carbon dioxide 188, 189, 190, 191, 194, 199, 270
carbon footprint 192
carbonates 109
careers, in car design and safety 264
carriers 27
cars
  cooling system 258
  energy used in manufacture 256
  performance (acceleration) 221–2
  safety systems 237, 259–64
catalase 130
catalysts 130, 132
cathode ray oscilloscope (CRO) 269
cations 93
celestial distances, measuring 164–5
cellular respiration 52, 188
Celsius temperature scale 253
centrioles 17
centromere 13
Cepheid variables 172–4
chain reaction 276
chemical equations, balancing 117
chemical reactions 99–100, 108–12, 114–16, 132
  products of 113–14
  reaction rate 107, 128–32
chemofossils 44
chloride ion 120
chlorine atom 129
chlorofluorocarbons (CFCs) 194, 196
chromatids 13, 16
chromosome number 12
chromosomes 11–12, 13–15, 17, 27, 59
climate 198
climate change 184, 197–9
  and biodiversity 200–3
coal dust, health effects 274

coal-fired power stations 270–2
colour and temperature 166–8
combined heat and power (CHP) system 279
combustion reactions 107, 114
common ancestors 50–1, 57
comparative anatomy 50
comparative embryology 50–1, 66
complementary base pairing 4
concentration, and reaction rate 129, 131
conduction 253
continental drift 54
continuous spectrum (stars) 175
convection 254
copper extraction 127
coprolites 44
corner mirror array 162
corrosion 98, 101
cosmic background radiation 155, 158
cosmic distance ladder 161
cosmic inflation 152
cosmic redshift 177, 178
cosmological principles 150–1
covalent bonding 136
crossing-over 14, 16
crumple zones 261–2
cytochrome c 52, 53
cytokinesis 15, 17
cytoplasm 8–9
cytosine 4

dark energy 148, 178
dark matter 148
Darwin, Charles 40–1, 50, 57–8
dating fossils 46–7
daughter cells 7, 14, 17
deceleration 222
decomposition reactions 114, 132
deep ocean currents, and global warming 204–5
delocalised electrons 95, 96
dependent variables 239
deuterium 75, 154
diamond 135
diploid (2*n*) 12
displacement 218
distance 213, 214, 218
divergent evolution 66
DNA (deoxyribonucleic acid) 3–8, 11, 52
DNA code 7, 8–9
DNA–DNA hybridisation 52
DNA helicase 7
DNA polymerase 7
dominant trait/allele 21, 22, 27, 28
Doppler effect 176–7
double helix 3, 7
double replacement reaction 115
Down syndrome 29, 30
driver concentration 226–7
drug-resistant bacteria 67
ductility 96

Earth–Moon distance 162
Earth–Sun orbital diameter 164
earthquakes 186
Earth's orbit, and the astronomical unit 164
Earth's spheres 185–6
East Australian Current 206
Einstein, Albert 149–50, 151
El Niño 205, 206
electrical conductivity 96
electrical energy production 189–90, 191, 192, 265–79
electrical generation systems 266–73, 275–9
electrical generator, simple 267–9
electrolysis 114
electromagnetism 267–9
electron arrangement 91–4, 120
electron configuration 88–9
electron dot formulas 121, 136
electrons 86–8
electrostatic precipitators 270, 272
elements 73, 74
  comparing properties 78, 93–4
  electron configuration 88–9
  formation 75–6
  modelling 88–9
  and periodic table 77, 79, 80–1, 91–2
embryology, comparative 50–1, 66
emission spectrum 175, 176
endemic species 39
energy 247, 249
  available from fuels 256–8
  forms of 250–1
  and work 260–1
energy changes in car crashes 261–4
energy content of fuels 256
energy losses from car systems 257–8
energy shells 87, 88, 91
energy transfer and transformation systems 245, 247–8, 250
  in cars 255, 259–64
  efficiency 248–9
  thermal equilibrium 251–2
enzymes 7, 52, 53, 130
equator (cells) 13
evolution 38, 57–61
  anatomical evidence 50–1
  and artificial selection 65
  and bacterial resistance 67–8
  biographical evidence 54–6
  bioinformatics 51–3
  Darwin's Galapagos finches 40–1
  divergent 66
  fossil record 41–3, 47, 48
  and genetics 66
  isolation and competition 59–60
  selection and speciation 60–1
  and theory of natural selection 57–61, 62–3
  variation within a species 58–9
exoplanets 151
exoskeletons 44

exothermic reactions 108
extinction 39
extracting metals 123–7

F_1 generation (first filial generation) 21, 22, 23
F_2 generation (second filial generation) 21, 22
Fahrenheit temperature scale 253
Faraday, Michael 265, 266
fertilisation 17
finches, Galapagos 40–1, 60–1, 62
fission fragments 275
fluoride ion 94, 121
fluorinated gases 194
fluorine atom 94, 121
forces 211
  acceleration and mass 239, 240–1
  acting in pairs 233, 234–5
  agent and receiver 233–4, 236
  in car driving 236–7
  and mechanical work 260–1
  and motion (Aristotle's views) 231–2
  net force 232, 236, 237, 238–9
  representing 236–7
  summary 237
fossil fuels 134, 137–9
  emissions from burning 257
  primary energy content 256
fossil record 41–3, 47, 48
fossils 41–5
  dating 46–7
Franklin, Rosalind 6
friction 258
fuels, energy content 256–7

Galapagos finches 40–1, 60–1, 62
galaxies 154, 177
gametes 11, 12
gases 81, 83
general theory of relativity 150, 151
generators 265, 267–9
genes 8, 11, 22, 27, 66
genetic code 10
genetic crosses 21–5
genetic engineering 31
genetic variation 19, 58–9
genetics 2, 3–6, 66
  Mendelian 20–5
genome 32
genotype 24, 28
genotypic ratio 24
global systems 184
  human impact on 185–93, 207
  and planet Earth's spheres 185–7
global warming 196, 198, 199, 201
  and deep ocean currents 204–6
  and sea ice 203–4
glossary 288–97
gonads 13
graphite 135
gravitational potential energy 277, 278
greenhouse effect 194–6, 198
greenhouse gases 194, 196, 198
groups (periodic table) 80, 81, 86
guanine 4
Gulf Stream 205

hadrons 153
halogens 86
haploid (*n*) 1
heat conductivity 96
heat energy see thermal energy
heat losses from local systems 253–4
helium 75, 153, 154
Hertzsprung–Russell diagram 171–2
heterozygous 22, 28
homologous chromosomes 13, 14
homologous structures 50
homozygous 22, 28
Higgs boson 152
Hubble's law 177, 178
Human Genome Project 32
Humboldt Current 205
hydrocarbons 137–9, 257
hydroelectric power 277–8
hydrogen 75, 87, 153, 154
hydrogen atom, Bohr model 87, 88
hydrogen molecule 136
hydrogen peroxide 130, 132
hydrosphere 186

independent variables 239
index fossils 47
inheritance 21–8, 57
inorganic chemistry 135
inputs 248
Intergovernmental Panel on Climate Change 199
interphase 13, 59
ionic bonding 119
ionic compounds 119–23
ions 120, 121
  electron arrangement 93–4, 120
  and the periodic table 91–2
iron(III) chloride 123
iron extraction 125–6, 127
isolation and competition (evolution) 59–60
isotopes 75, 275

karyograms 29, 30
karyotype 29
kelvin temperature scale 253
kinetic energy 250, 251, 253, 277, 278
Kyoto Protocol 199

La Niña 205
Lamarck, Jean-Baptiste 57
law of conservation of energy 247
lead extraction 127
light year 159–60
lithium 153, 154
lithium sulfide 123
lithosphere 185

living fossils 47
local systems 248
  efficiency 248–9
  heat losses from 253–4
lustre (metals) 95–6

magnesium atom 121
magnesium ion 121
magnesium oxide 123
magnitude scale (stars) 169–72
main-sequence stars 171, 172
malleability 96
mangroves 202
mass, acceleration and force 239, 240–1
mechanical work 260–1
meiosis 11, 13–15, 16, 59
Mendel, Gregor 20, 21–2
Mendeleev, Dmitri 77
Mendelian ratio 21, 23
messenger RNA (mRNA) 8, 10
metal replacement reactions 99–100, 115
metallic bonding 96
metalloids 81, 83
metals 81, 119
  activity series 99–100
  applications 118–19
  extraction 123–7
  ionic compounds 119–23
  properties 78, 81–2, 83–4, 95–6
  reaction with acids 110
  reactivity 98–102
metaphase 14, 15, 16, 17
methane 189, 194
methane molecule 138
mimicry 62–3
mitosis 17, 58
molecular homology 52–3
motion 211, 212
  analysing 212–23
  describing 213–14
  early Greek ideas 230–2
  measuring 215–16
  and net force 238–41
  new physics of 233–7
  Newton's laws 241
  position–time graphs 217–18, 219–20
mutations 19, 50

natural greenhouse effect 195, 198
natural selection, theory of 57–63
nebulae 174
neon atom 93, 120
net force 232, 236, 237, 238–9
neutralisation reactions 108–9
Newton, Isaac
  laws of motion 241
  universal gravitation law 150, 151
niches 60
nitrogenous bases 3, 4, 8, 10
nitrous oxide 194
noble gases 73, 86, 91, 93
non-metals 81, 83–4, 135
nuclear accidents 276–7
nuclear fission 275
nuclear fusion 153–4
nuclear power 275–7
nucleosynthesis 153
nucleotides 4
nucleus (atoms) 86

occupational hazards 274
ocean currents, and global warming 204–6
orang-utan habitat 54, 55
orbits (electrons) 87
ores 113, 119, 125
organelles 15
organic chemistry 135
outputs 248
ozone 196
ozone hole 197
ozone layer 196–7

parallax 163, 164–5
parental generation (P) 21
parsec (parallax second) 164–5
patents 32
pea breeding experiments (Mendel) 21–2
pedigrees 28–9
pentadactyl limb 66
periodic table 72, 73, 77, 79, 86
  and electron arrangement 91–2
  formats 79–90
  and ions 93–4
  patterns 80–1, 85
periods (periodic table) 80
permafrost 203
pharmaceuticals 114, 134, 140
pharyngeal gill slits 50–1
phenotypes 24, 27, 66
phenotypic ratio 24
photosynthesis 188
Planck curves 166–8, 175
plants 188, 189
plastics 113
plate tectonics 54
pole (cells) 14
pollutants 190, 191, 270, 272
position–time graphs 217–18
  average speed from 219–20
post-combustion carbon capture 192, 193
potential difference 267, 268, 272–3
potential energy 250, 251
power stations
  carbon capture 191–3
  coal-fired 270–2
pre-combustion carbon capture 191–2
primary coil 272
principle of superposition 46
prophase 13, 15, 17, 59
Proteaceae 54, 55

protein synthesis 8–9
proteins 8, 10
protons 86
Punnett square 24–5
pure-breeding 21

radar ranging 161
radiant energy, and colour 166–8
radiation (heat) 254
rare earth metals 119
reaction distance 226
reaction rates, factors affecting 107, 128–32
reaction time 224, 225, 226
recessional speed 177
recessive trait/allele 21, 22, 27, 28
redshift
    cosmic 178
    stellar 176, 177
relative dating 46
replication (DNA) 7–8
resistance force 232
respiration 108
ribosomes 9
rising sea levels 201, 202–3
road safety science 224–9
rotor 270, 271
rusting 128

salts 108
Sankey diagrams 247
scalar quantities 218
scientific report writing 283–4
sea ice, and global warming 203–4
sea level rises 201, 202–3
seagrass meadows 200–1, 202
seatbelts 237, 259–60, 262
secondary coil 272
sedimentary rock 44
selection, and speciation 60–1
selection pressure 61
selective breeding 31, 65
semi-conservative replication 7
semiconductors 83
sex cells 11, 12, 13–15
sex chromosomes 11, 16, 27, 29–30
sex determination 16
sex-linkage 27
sexual reproduction 17, 19, 58, 59
sexual selection 63
shininess (metals) 95–6
SI units 220
single covalent bond 136
single replacement reaction 115
sister chromatids 14, 15
smog 196
sodium atom 93, 120
sodium chloride 121
sodium ion 93, 120
somatic cells 13

space–time 149–50
special theory of relativity 149
spectroscope 86, 87
speed 213, 217, 218, 219, 220–1
spindle (fibres) 13, 17
spontaneous reactions 128
standard or scientific form 160
stars
    absorption and emission spectra 175, 176
    brightness and magnitude 169–72
    Cepheid variables 172–4
    element formation 75–6
    Hertzsprung–Russell diagram 171–2
    Planck curves 166, 168, 175
stator 270, 271
steam turbine heating cycle 266
stellar redshift and blueshift 176, 177
stopping distance/time 224, 226
strata 46
stromatolites 46
structural formula 136
superbugs 67
supergenes 66
supernova 76
surface area, and reaction rate 129, 131
surface currents 204
surrounding systems 248
symbols, used in pedigrees 28
synthesis reactions 115
systems 247–8
    cars as 255
    see also local systems

telophase 14, 15, 17
temperature
    and colour (radiant bodies) 166–8
    measurement 253
    and reaction rate 107, 129
temperature scales 253
theory of natural selection 57–63
thermal energy 251, 253–5, 279
thermal equilibrium 251, 252
three-turbine power station 270–2
thymine 4
time interval 213, 215, 218
trace fossils 44
transcription 8
transfer RNA (tRNA) 9
transformers 272–3
transition metal ions 123
translation 9
triangulation 163
trilobites 46, 47
trisomy 21 29, 30
tritium 75, 154
tsunamis 186–7, 276
turbines 266
turns ratio 273

universal gravitational law 150, 151
universe 75, 144, 248
  accelerating 178–9
  age of 178
  big bang theory 75, 149, 152–4, 155–8
  cosmic background radiation 155, 158
  and cosmological principle 150–1
  and Einstein's space–time 149
  energy and matter in 148
  expanding 177–8
  fate of the 179
  history 156–7
  measuring the 159–79
  origins 147–8
upwelling 204
uracil 8
uranium nuclides 275
UVB radiation 196, 197

variables 239–40
variation
  through artificial selection 65
  within a species 58–9
vector quantities 218
velocity 218, 220–1
vestigial organs 66

Wallace, Alfred Russel 54, 57, 58
Wallace's Line 56
warning systems 187
water vapour 194, 270
Watson and Crick's DNA model 6, 8
weather 198, 205
Wollemi pine 47, 48
work, and energy 260–1
writing scientific reports 283–4

X chromosomes 16, 27
X-ray crystallography 6

Y chromosome 16, 27

zygote 17

Nelson iScience for the Australian Curriculum 10

Nelson iScience series is a truly twenty-first-century science esource for students.

Nelson iScience combines higher-order thinking tools and ICT to promote innovative and creative problem-solving and approaches to learning science. It builds on the collaborative nature of learning by enabling students to learn with and from one another by sharing their work, ideas and thoughts through the vast capabilities of ICT.

For each year level, the suite of resources includes:

- a student book that focuses on fully integrating the overarching ideas, general capabilities, cross-curriculum priorities and three strands of the Australian Curriculum – Science into the fascinating story of Science
- an exciting web-based, interactive NelsonNetBook that students and teachers can personalise and annotate, with additional tools for teachers to share their annotations with particular groups of students
- a NelsonNet website that provides an extensive collection of resources, including activity sheets, connection sheets, workspaces, videos, animations, interactive, review quizzes and weblinks
- a NelsonNet teacher website that includes secure unit tests and answers, curriculum grids, teaching plans, as well as access to the free ExamView question bank software
- a printed, full-colour Teacher's Edition of the student book, with page-by-page wraparound commentary providing useful advice and practical ideas on implementing the new curriculum, nurturing the general capabilities and integrating the cross-curriculum priorities.

Nelson iScience 7
Student Book
9780170214209

Nelson iScience 8
Student Book
9780170214292

Nelson iScience 9
Student Book
9780170189262

NELSON CENGAGE Learning
For learning solutions, visit **cengage.com.au**

PHOTOCOPYING OF BOOKS IS RESTRICTED UNDER LAW

ISBN: 978-0170189071
9 780170 189071