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biology

VCE UNITS 1 + 2

4E

Xenia Pappas
Ann Cathcart
Tony Chiovitti
Amanda Clarke
Adrianne Harrowfield
Susan Ryan

Nelson VICscience Biology VCE Units 1 & 2
4th Edition
Xenia Pappas
Ann Cathcart
Amanda Clarke
Tony Chiovitti
Adrianne Harrowfield
Susan Ryan
ISBN 9780170452465
Contributing authors: Pam Borger, Jacinta Duncan, Sarah Jones, Elizabeth Thrum

Publisher: Eleanor Gregory
Editor: Felicity Clissold
Cover design: Leigh Ashforth (Watershed Art & Design)
Text design: Alba Design
Project designer: James Steer
Permissions researcher: Debbie Gallagher
Typeset by: MPS Limited
Production controller: Renee Tome

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.

Acknowledgements
Cover: Getty Images/Kantor
Fig 6.11a, p.234: Wikimedia/Kira V Bulazel,Gianni CFerreri, MarkDB Eldridgeand Rachel JO'Neill, CCBY 2.0; **6.11b**: Wikimedia/divaldo HerculanoC. de Oliveira, Marcella Mergulhão Tagliarini, Michelly, S. dos Santos, Patricia C. M.O'Brien, Malcolm, A. Ferguson-Smith,CC BY 2.5; **6.11c**: Maneechot, N., Yano, C.F., Bertollo, L.A.C. et al. Genomic organization of repetitive DNAs highlights chromosomal evolution in the genus Clarias, (Clariidae, Siluriformes). Mol Cytogenet 9, 4 (2016), Figure 2. CC BY 4.0. https://doi.org/10.1186/s13039-016-0215-2;
6.11d: Photo showing Karyotype of tetraploid shallot (Allium ceta) from Sulistyaningsih, E., Aoyagi, Y. & Tashiro, Y. Flower Bud Culture of Shallot (Allium cepa L. Aggregatum group) with Cytogenetic Analysis of Resulting Gynogenic Plants and Somaclones. Plant Cell Tiss Organ Cult 86, 249–255 (2006). https://doi.org/10.1007/s11240-006-9114-2 courtesy of Dr. Endang Sulistyaningsih, Fac. Agriculture, Gdjah Mada University
Fig. 6.6, p.229: The Genome Analysis Centre, Bioinformatics (2015) DOI: 10.1093/bioinformatics/btv069. First published online: February 2, 2015
Fig. 9.4, p.344 Text: 'Humans coexisted with three-tonne marsupials and lizards as long as cars in ancient Australia', by Scott Hocknull, Anthony Dosseto, Gilbert Price, Lee Arnold, Patrick Moss, Renaud Joannes-Boyau, The Conversation, May 18 2020, Creative Commons license. Read the original at https://theconversation.com/humans-coexisted-with-three-tonne-marsupials-and-lizards-as-long-as-cars-in-ancient-australia-138534
Fig. 9.39, p. 376: CUMPSTON, J.S. 1968. Macquarie Island. Australian National Antarctic Research Expedition Scientific Reports, Series A (1) Publication No. 93. Antarctic Division, Department of External Affairs, Melbourne., in Taylor, R.H. (1979) How the Macquarie Island parakeet became extinct. New Zealand Journal of Ecology, 2: 42–45, Fig 1. http://newzealandecology.org/zje/1448.pdf
Fig. 9.40, p.377: Terauds A., Doube J., McKinlay J. and Springer K. (2014) Using long-term population trends of an invasive herbivoreto quantify the impact of management actions in the sub-Antarctic. Polar Biology, 37: 833–43
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National Library of Australia Cataloguing-in-Publication Data
A catalogue record for this book is available from the National Library of Australia.

Cengage Learning Australia
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South Melbourne, Victoria Australia 3205

Cengage Learning New Zealand
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331 Rosedale Road, Albany, North Shore 0632, NZ

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Printed in China by 1010 Printing International Limited.
1 2 3 4 5 6 7 25 24 23 22 21

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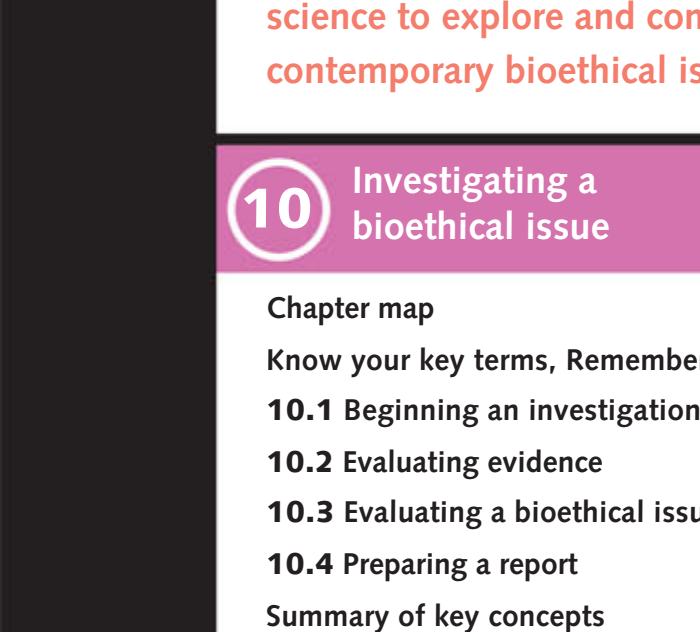
9780170452465



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Foreword

> **Biology is fantastic because it's both complicated and, when you finally get to some understanding, beautiful!**

Starting out as a veterinary scientist trying to understand how viruses kill, and how we might prevent that, I made a chance discovery with my Swiss colleague, Rolf Zinkernagel, that led to us sharing the 1996 Nobel Prize for Physiology or Medicine. Rolf trained as a medical doctor but, so far, I'm the only vet to win a Nobel. We found that the so-called transplant or *surveillance* molecules focus the *assassins* of immunity, the *killer* T cells, on cells that are damaged by infection or oncogenic (cancerous) changes. The following year I had the honour of being named the Australian of the Year. When asked to write this foreword my response was: are they thinking of Pete Doherty the musician? In a world where science communication has rapidly declined and fake news (or gossip over the back fence) is too often the norm, I felt it was important to add my opinion to the study of Science, specifically Biology, and say a little bit about how it can change thinking and lives.

I am passionate about promoting an evidence-based view of reality: my most recent book, *The Knowledge Wars*, describe the 'warts and all' view of science for non-scientists, even for people who don't like science. That's the great thing about biological science. It may be a surprise to some arty types, but science does teach you how to write clearly and concisely, though we're no good at fiction! So far I've published a diverse range of general books about science and the scientific life: *A Light History of Hot Air, The Beginners Guide to Winning the Nobel Prize : a Life in Science, Sentinel Chickens: What Birds Tell Us About our Health and our World and Pandemics: What Everyone Needs to Know*, and *The Incidental Tourist*.

Biology is fantastic because it's both complicated and, when you finally get some understanding, beautiful! Of course, it is important to pass exams if you want to get into medical or vet school, or become a researcher like me. Studying biology teaches all of us about ourselves, while strengthening important life skills such as critical thinking, problem solving, collaboration, scientific literacy and the importance of working together. And if you have a good basic grasp of biology, you'll understand why this discovery or that is important. It will also help you to tell the difference between reality, hype and downright lies. The *VICscience Biology* series tackles some of the big ethical issues and teaches students how to think scientifically and question ideas.

Now, having been involved in infectious disease research (especially immunity) for more than 55 years, I've handed over my research lab (plus whatever grant money I bring in) to my younger colleagues. I've still got stuff to say, and my focus now is on writing more books. Part of the delight of being a senior researcher is to see those who've worked with you mature and become great scientists. And it starts for them, as it did for me, at one place: with learning the basics and being excited by biology. Apart from allowing me to live and work in different countries, and opening doors, in terms of social and economic mobility, being part of the unravelling of the story of life has been immensely gratifying. There is still an enormous amount to be discovered and even if you are not intending to be part of that, understanding the basics of biology can only serve to position you better for any future you might be contemplating.

Dr Peter Charles Doherty AC FRS FMedSci
Laureate Professor, The University of Melbourne.
5 December 2019

Author team

Xenia Pappas

Xenia Pappas is a Biology teacher with more than 30 years' experience. She has taught across all sectors of the Victorian education system, including time with the Zoo Education Service and Museum Victoria. She has held leadership roles within the Department of Education's Gifted Education Unit as well as Head of Year and Head of Biology for many years in schools. Xenia has always worked to engage her students by offering alternative approaches that taps into a range of learning modalities. As a long-time author of Biology and General Science resources, Xenia has developed a well-rounded knowledge and understanding of the curriculum from Year 7 to VCE and works to deliver the curriculum in a manner that addresses the individual needs of students.

Ann Cathcart

Ann Cathcart (MEdAdmin, BSc, DipEd) has extensive experience in the development of scientific curriculum content of a biological and scientific nature. She also has vast experience in the publication of materials for learning. Ann brings specific skills to an authoring role. She is a current and practising secondary school teacher who has taught Years 2–12 in many Australian school systems, predominantly in senior Biology and Chemistry, for more than 40 years. She has also managed school science departments in positions of Head of Science and Head of Biology. Ann has worked in science-related industries, such as medicine, agriculture and mining, and at the tertiary level in medical education. Ann understands secondary students. She has addressed stakeholders' needs in each part of her career. She has written educational materials and loves doing this. While applying attention to detail based on a strong technical background, she demonstrates a passion for enabling others, including her students, to achieve an outcome.

Dr Tony Chiovitti

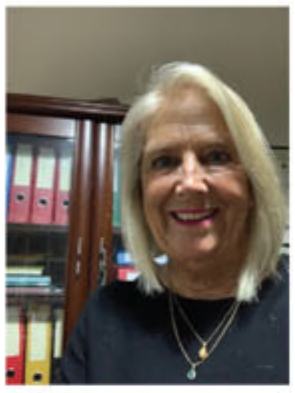
Tony Chiovitti attained a BSc (Hons) at the University of Melbourne in 1992. He completed his PhD at the School of Botany, University of Melbourne in 1997 investigating cell wall biochemistry of Australian red algae and algal evolution using gene sequences. He has eight years of postdoctoral research experience in Australia and overseas with biochemical studies of bacteria and microalgae, including collaboration in the first phytoplankton genomes to be sequenced. He obtained a Dip. Ed (2004) and joined the education team at the Gene Technology Access Centre (GTAC), Parkville, Victoria becoming Deputy Director in 2012. Tony has developed and delivered educational programs for students and professional learning programs for teachers on the themes of cell and molecular biology, bioinformatics, immunology, ecology and evolution. He has also led educational programs that enable secondary school students to contribute as citizen scientists to biological research projects.

Dr Amanda Clarke

Amanda Clarke's interest in biology started when she was a child. Initially, she wanted to be a veterinarian, but at university she became fascinated with genetics, microbiology and immunology. She was granted a PhD in Immunology from the University of Melbourne for her studies into house dust mite allergy. While studying, she also taught practical classes at several universities and thoroughly enjoyed opening her students, minds to the wonders of medical research. Amanda then decided to become a Biology and Chemistry teacher. She developed a special interest in the biomedical applications of nanoscience and nanotechnology. She was part of a team at St Helena Secondary College who won a Victorian Government Education Innovation Award for the development of a nanotechnology curriculum at the school. Amanda is still teaching Nanotechnology and Biology and thoroughly enjoys it. She is currently employed as a learning specialist at Balwyn High School.

Adrianne Harrowfield

Adrianne studied Genetics and Microbiology at La Trobe University gaining her BSc and subsequently received an Honours degree in Genetics. She began her scientific career as a research assistant at the Walter and Eliza Hall Institute of Medical Research within the Genetics Department. After two years working in research, she completed her DipEd at the University of Melbourne and has been teaching VCE Biology for 20 years. She has been a VCE Biology examination assessor and is currently a passionate teacher of Biology.



Susan Ryan

Mrs. Susan Ryan BSc(Ed), BSc(Hons) has taught Senior Biology for many years in all areas of secondary education, as well as tertiary level and Foundation year Biology. Her long involvement in writing trial exams for Units 1–4, as well as for VCAA exams, and practical and course chapters; working in zoo education and specialised laboratory courses; and working with many overseas students, has given her a comprehensive understanding of the needs of students and requirements to achieve their potential in Biology education.

Publisher acknowledgements

Eleanor Gregory sincerely thanks the following people for their assistance in reviewing and commenting on the author's manuscripts during the development phase of this product:

- Natalie Cookson, Sacred Heart College, Geelong
- Tegan Tinsley, Lighthouse School
- Julie Gould, Brunswick Secondary College
- Susan Ryan, consultant
- Nicole Henry, consultant

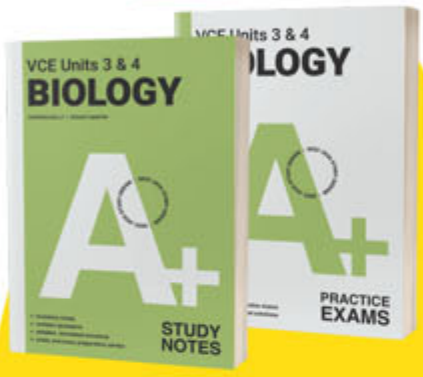
And special thanks to:

- Nicole Henry for compiling the Area of Study reviews
- Rebecca Famlonga, who reviewed the Aboriginal and Torres Strait Islander content. Rebecca is a proud Wadawurrung woman and Traditional Owner. She has taught and led in secondary schools for more than 20 years and is passionate about Aboriginal and Torres Strait Islander Education.

VICscience VCE Biology Learning Ecosystem

exam+

exam*plus* is a comprehensive and innovative assessment platform that simulates real exam practice. exam*plus* provides an extensive bank of filterable and difficulty-graded past VCAA and unseen exam questions, all in the one place.



A+ Biology Study Notes **includes detailed summaries and revision questions, as well as study tips and information about the exam. *A+ Biology Practice Exams* contains 14 topic tests and two perforated practice exams.**

Textbook

Students learn through stimulating, engaging and scaffolded content, activities and investigations. All content can be directly mapped to the VCAA *VCE Biology Study Design*.

Logbook

Students record all their investigation materials in one place for assessment and authentication purposes as required by the VCAA *VCE Biology Study Design*.

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Teachers expand their teaching and students reinforce their learning through the rich variety of extra resources provided on the NelsonNet student and teacher portals.

Workbook

Students develop, use and demonstrate key science skills through engaging activities; they practise exam skills by completing exam-style questions.

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To the student

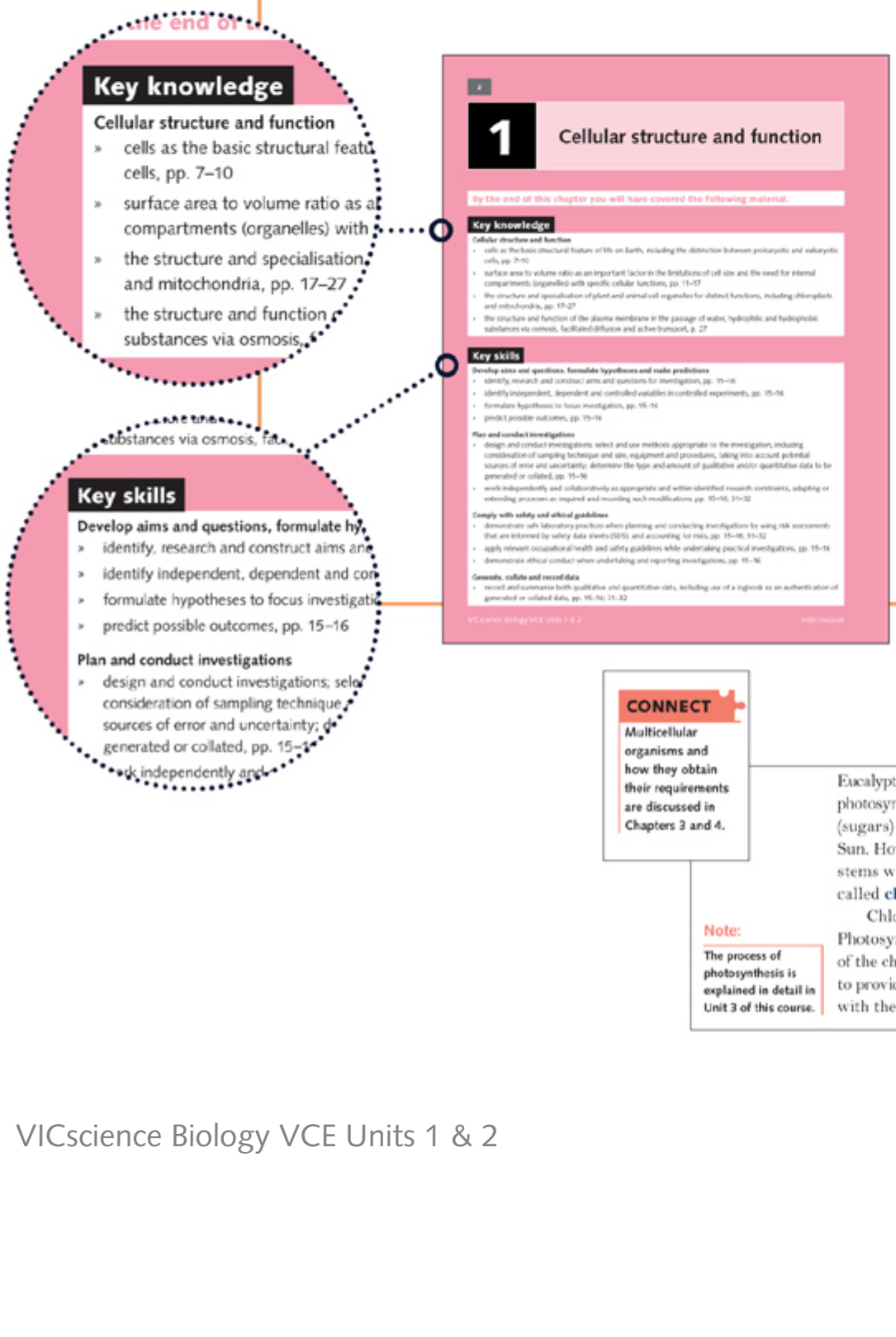
The VCE Biology course comprises both key knowledge and key science skills components, which will be assessed throughout your studies. We understand that undertaking VCE Units 3 & 4 can be an exciting but sometimes overwhelming time. You will learn a lot of content and develop scientific skills throughout a very busy year that will culminate in an external assessment. We have taken these stressors into account when designing the *VICscience Biology* suite of products. You will not need to go beyond these learning materials to study VCE Biology; they have been designed to work in unison so you can achieve at your best.

10 steps to study success

Ensure you take time to read the 10 ways we have organised your VCE biology study journey. You will see that at various stages in your studies, different aspects of this textbook will be more useful. Whether you are learning new concepts for the first time, reviewing what you have learnt or preparing for tests and exams, spending a little time now getting to know your textbook will help you reach your learning potential for VCE Biology.

1 Focus on the Study Design

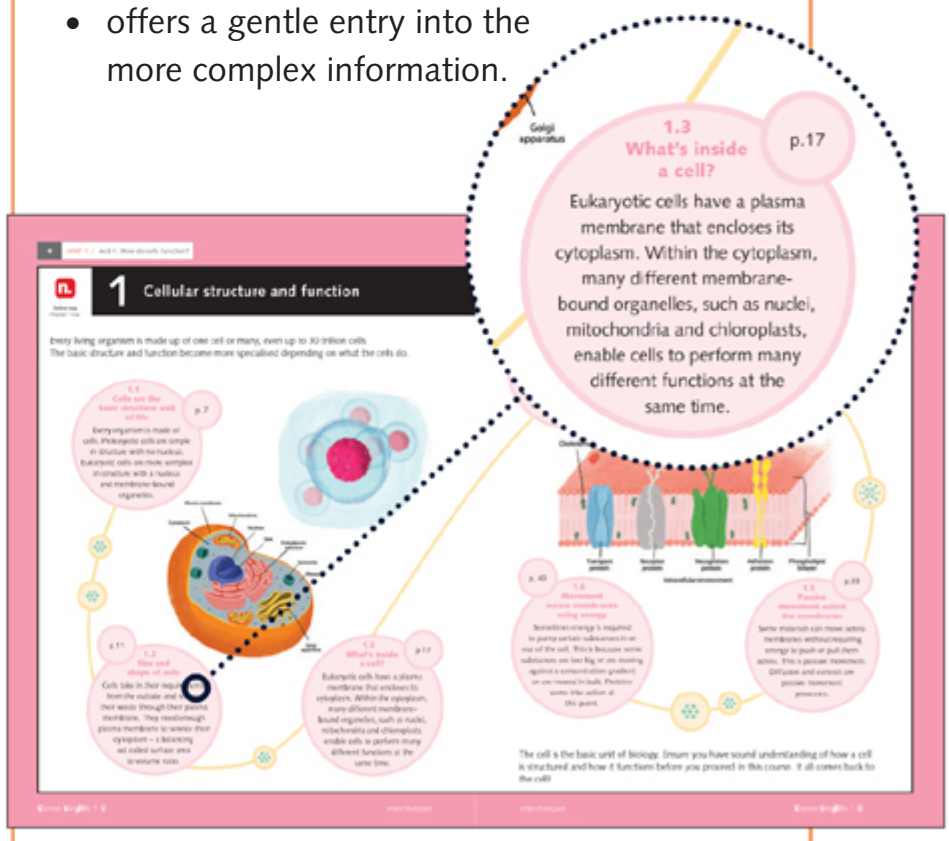
Each chapter starts with a chapter opening page that will guide you through the **key knowledge** and **key skills** that are covered in the chapter with page reference numbers to help find all the content that you need quickly.



2 Look for connections

Each chapter begins with a **chapter map** that:

- are easy-to-use
- use shorthand familiarisation
- is a navigational tool to guide you through each chapter
- offers a gentle entry into the more complex information.

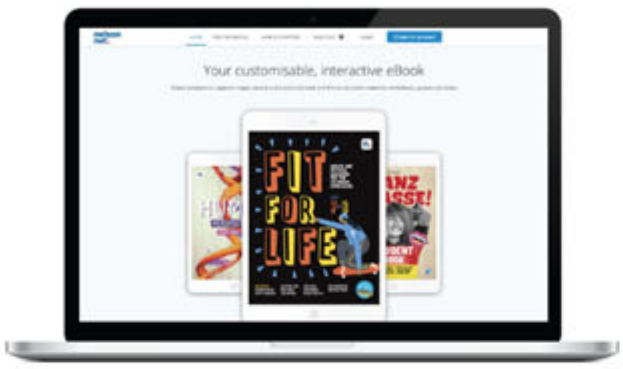


We have made further connections throughout each chapter using margin **Notes**, which offer further explanation and **Connect** boxes, which link content to other relevant chapters where more information is provided.

3 Rehearse key terms

We have listed all the key terms at the beginning of each chapter.

You can use the **flashcards** study tool to learn and review key terms with their definitions, and assist with pronunciation and spelling of key vocabulary.



5 Develop your skills

Key science skills are examinable in the external assessment and therefore are a significant and important part of the course. To further develop and refine all the key science skills set out in the course, complete the activities in the accompanying *VICscience Biology Skills Workbook*.

Signposts to workbook activities are found throughout the textbook. Look for the **Workbook icon**.

REMEMBER PAGE 35

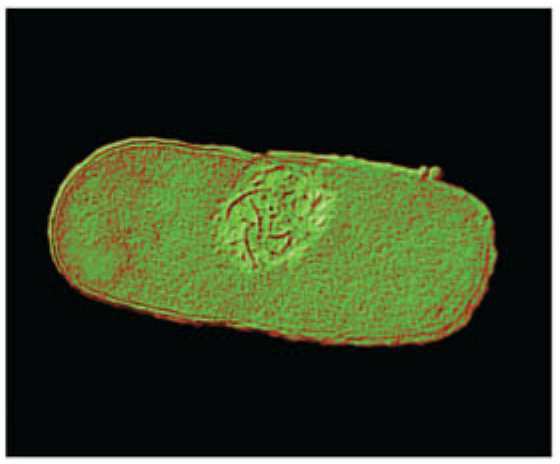
4 Test your memory

At the beginning of each chapter, use the **Remember** statements under the key terms list to bring previously learnt concepts to the front of your mind. Stronger foundations of knowledge make learning more difficult concepts easier.

The *VICscience Biology Skills Workbook* provides you with stepped questions to help you to engage your past learnings.

6 Understand the concepts

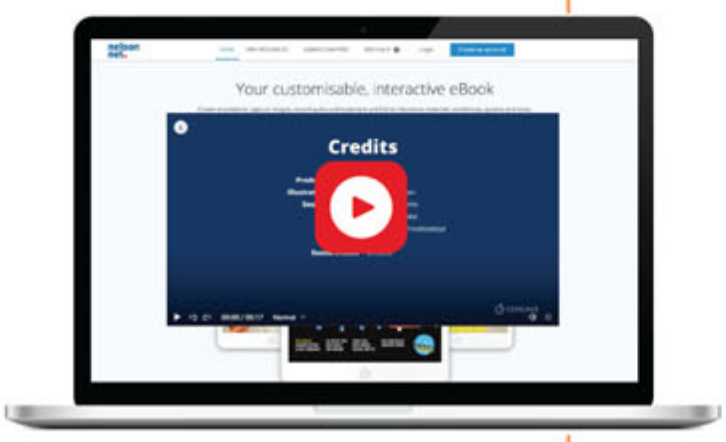
Pictures tell a thousand words and are key in strengthening understanding, so ensure you look carefully at each **figure** and read the **labels** and **captions** so that you can understand what it is telling you.



Alamy Stock Photo/Science Photo Library

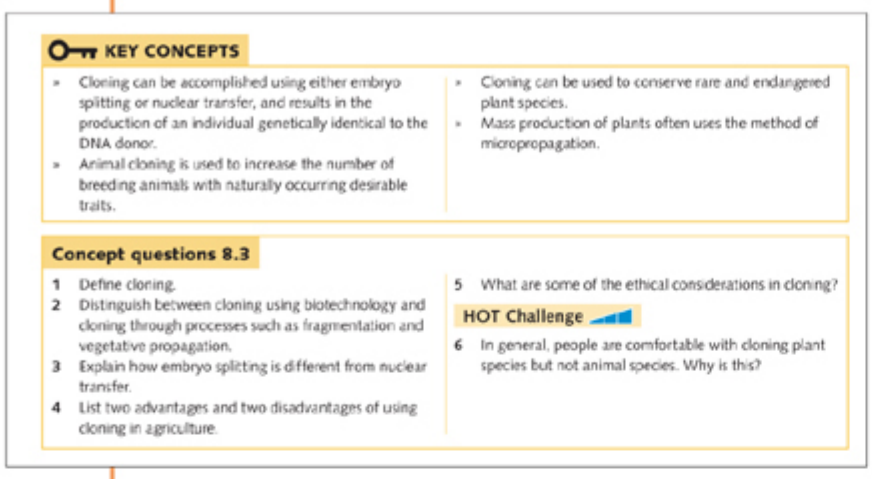
Figure 1.3 ***Escherichia coli*** **cell, showing internal structure. Note the nucleoid region in the top middle of the cell.**

Sometimes words and pictures are not enough. Some of the key knowledge has been explained in videos. Look for the **video icons** throughout the chapters as these animated videos will help you to understand and make connections between content.



Sometimes you will need to use mathematics to analyse your data. We have presented mathematical relationships in context by providing step-by-step instructions on how to perform mathematical calculations in **Worked examples**.

Important ideas, concepts and theories are summarised in **Key concept** boxes.



KEY CONCEPTS

- Cloning can be accomplished using either embryo splitting or nuclear transfer, and results in the production of an individual genetically identical to the DNA donor.
- Animal cloning is used to increase the number of breeding animals with naturally occurring desirable traits.
- Cloning can be used to conserve rare and endangered plant species.
- Mass production of plants often uses the method of micropropagation.

Concept questions 8.3

1 Define cloning.
2 Distinguish between cloning using biotechnology and cloning through processes such as fragmentation and vegetative propagation.
3 Explain how embryo splitting is different from nuclear transfer.
4 List two advantages and two disadvantages of using cloning in agriculture.
5 What are some of the ethical considerations in cloning?

HOT Challenge

6 In general, people are comfortable with cloning plant species but not animal species. Why is this?

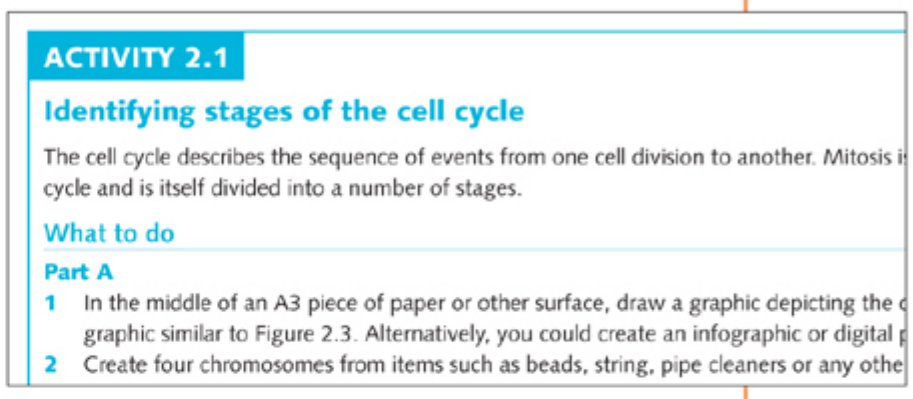
Concept questions follow each key concept box. These questions will help you to determine whether you have fully understood the content before you progress further in the chapter.

If you are feeling confident with the concepts you can give the **HOT Challenge** a go! This question is more difficult and may need further research. It will extend your understanding to a higher level.

7 Explore and learn

You will collaborate, explore and discover the living world through practical activities and investigations and also come to appreciate the collegial nature of Biology.

Complete short, hands-on tasks designed to clarify or reinforce a concept through the **Activity** boxes.



ACTIVITY 2.1

Identifying stages of the cell cycle

The cell cycle describes the sequence of events from one cell division to another. Mitosis i
cycle and is itself divided into a number of stages.

What to do

Part A

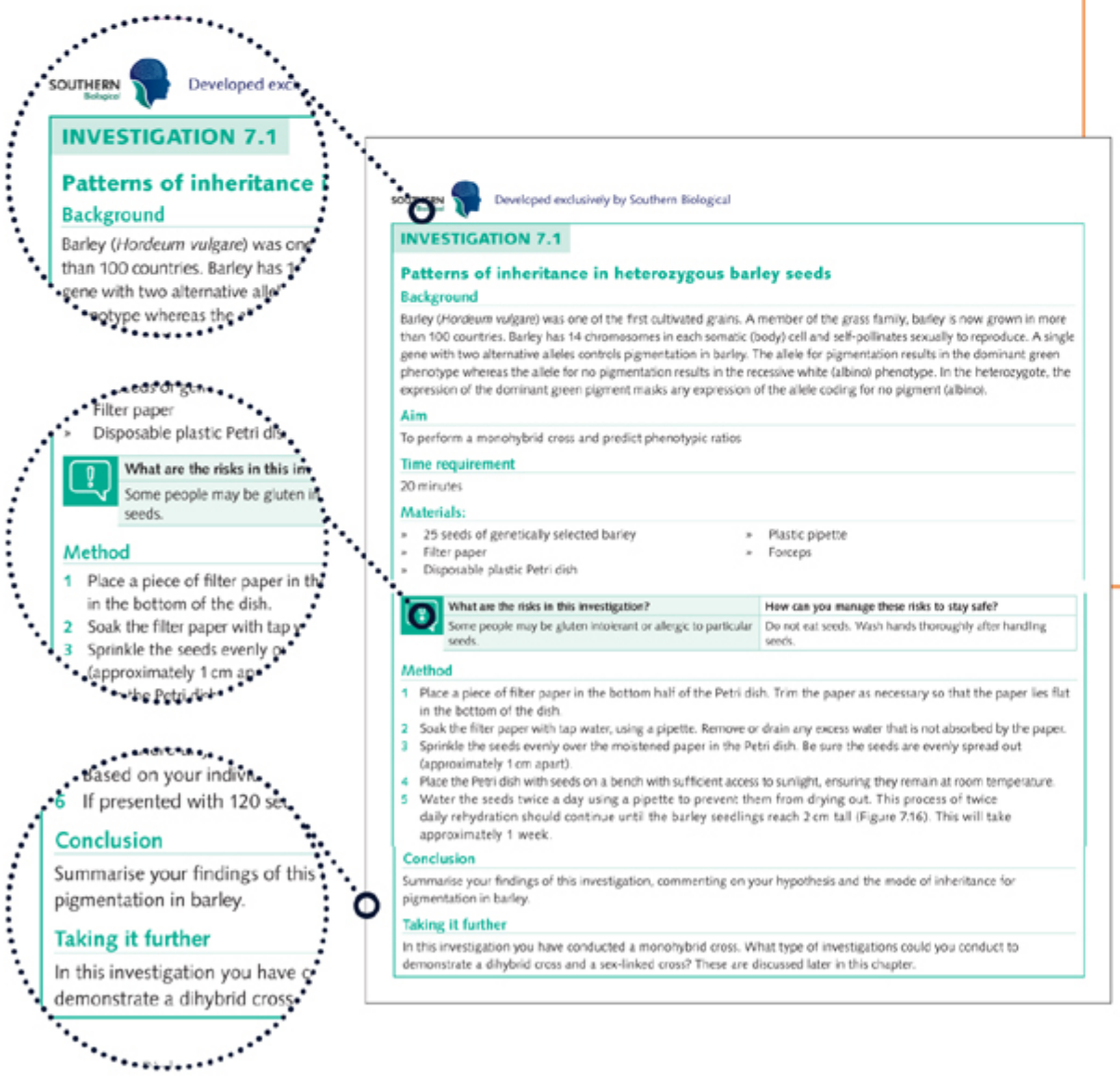
1 In the middle of an A3 piece of paper or other surface, draw a graphic depicting the c
graphic similar to Figure 2.3. Alternatively, you could create an infographic or digital p
2 Create four chromosomes from items such as beads, string, pipe cleaners or any othe

Explore key knowledge and develop, use and demonstrate the key science skills through the **Investigations**. Investigations provide:

- guided instruction on the materials
- method
- collection
- analysis of results
- discussion.

Investigations are not without risks and part of learning to work like a scientist is learning to work safely. **Risk assessment** tables highlight the risks of the investigation and provides suggestions on how you can minimise risks.

Taking it further questions found at the end of some investigations provide you with ideas on how you could extend or adapt the investigation for further study.



SOUTHERN Biological — Developed exc

INVESTIGATION 7.1

Patterns of inheritance

Background

Barley (*Hordeum vulgare*) was on
than 100 countries. Barley has 1
gene with two alternative alle
enotype whereas the

eeds of gi
Filter paper
Disposable plastic Petri di

What are the risks in this in
Some people may be gluten i
seeds.

Method

1 Place a piece of filter paper in th
in the bottom of the dish.
2 Soak the filter paper with tap
3 Sprinkle the seeds evenly o
(approximately 1 cm ap
the Petri dish

based on your indivi
6 If presented with 120 se

Conclusion

Summarise your findings of this
pigmentation in barley.

Taking it further

In this investigation you have c
demonstrate a dihybrid cross

Developed exclusively by Southern Biological

INVESTIGATION 7.1

Patterns of inheritance in heterozygous barley seeds

Background

Barley (*Hordeum vulgare*) was one of the first cultivated grains. A member of the grass family, barley is now grown in more than 100 countries. Barley has 14 chromosomes in each somatic (body) cell and self-pollinates sexually to reproduce. A single gene with two alternative alleles controls pigmentation in barley. The allele for pigmentation results in the dominant green phenotype whereas the allele for no pigmentation results in the recessive white (albino) phenotype. In the heterozygote, the expression of the dominant green pigment masks any expression of the allele coding for no pigment (albino).

Aim

To perform a monohybrid cross and predict phenotypic ratios

Time requirement

20 minutes

Materials:

- 25 seeds of genetically selected barley
- Filter paper
- Disposable plastic Petri dish
- Plastic pipette
- Forceps

What are the risks in this investigation?	How can you manage these risks to stay safe?
Some people may be gluten intolerant or allergic to particular seeds.	Do not eat seeds. Wash hands thoroughly after handling seeds.

Method

1 Place a piece of filter paper in the bottom half of the Petri dish. Trim the paper as necessary so that the paper lies flat in the bottom of the dish.
2 Soak the filter paper with tap water, using a pipette. Remove or drain any excess water that is not absorbed by the paper.
3 Sprinkle the seeds evenly over the moistened paper in the Petri dish. Be sure the seeds are evenly spread out (approximately 1 cm apart).
4 Place the Petri dish with seeds on a bench with sufficient access to sunlight, ensuring they remain at room temperature.
5 Water the seeds twice a day using a pipette to prevent them from drying out. This process of twice daily rehydration should continue until the barley seedlings reach 2 cm tall (Figure 7.16). This will take approximately 1 week.

Conclusion

Summarise your findings of this investigation, commenting on your hypothesis and the mode of inheritance for pigmentation in barley.

Taking it further

In this investigation you have conducted a monohybrid cross. What type of investigations could you conduct to demonstrate a dihybrid cross and a sex-linked cross? These are discussed later in this chapter.

Remember that investigations work hand-in-hand with your logbook, which is where you record all your:

- investigation observations
- ideas
- data
- analysis
- discussion and conclusions.

Your logbook is an important assessment and authentication tool.

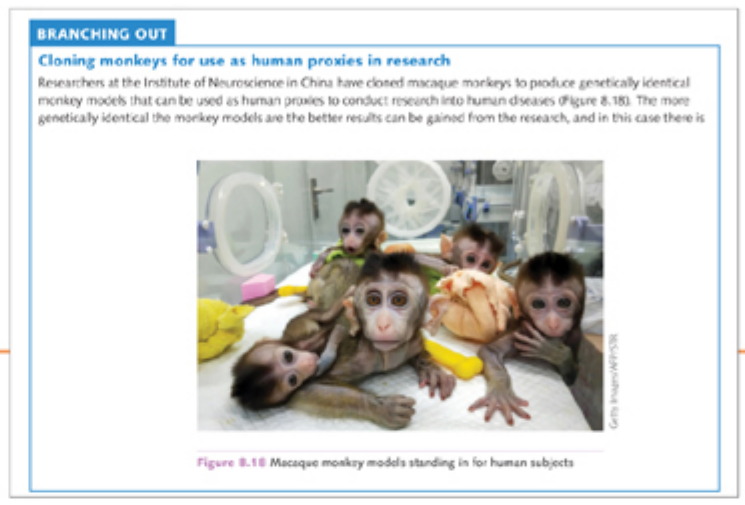
8 Prepare for tests and exams

The best way to prepare for exams is to use past exam questions. **Area of Study reviews** at the end of each Area of study allow you to check your knowledge by completing difficulty-graded exam-style questions. The answers to these are at the back of the book. Look for **tips** in the margin that point things to be aware of when answering particular types of exam questions.

EXAM TIP
Mechanical digestion decreases the size of the food; chemical digestion decreases the size of the molecules.

9 Extend yourself

At the end of each chapter you will find a **Branching out** activity. This material is extension and non-examinable. It examines possible careers and future applications of what you have just learnt.


BRANCHING OUT

Cloning monkeys for use as human proxies in research

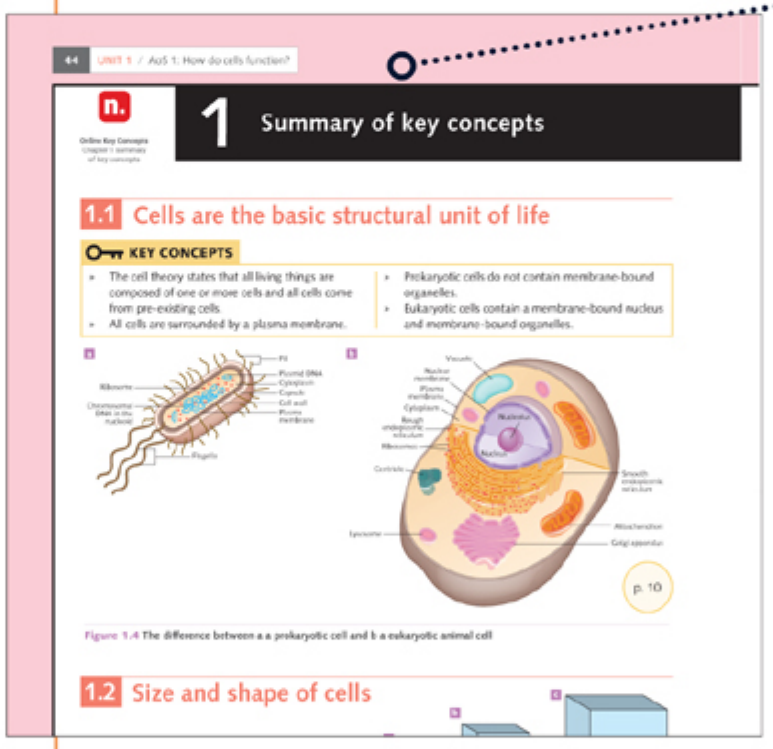
Researchers at the Institute of Neuroscience in China have cloned macaque monkeys to produce genetically identical monkey models that can be used as human proxies to conduct research into human diseases (Figure 8.18). The more genetically identical the monkey models are the better results can be gained from the research, and in this case there is

Figure 8.18 Macaque monkey models standing in for human subjects

10 Consolidate your learning

At the end of every chapter you can consolidate your knowledge. Here you will find:

- **summary of key concepts** that you have met throughout the chapter. You can download a copy of the concepts by accessing the worksheet icon on NelsonNet. Use this to assist you in revising and studying for internal and external assessments
- a **chapter glossary** of all the key terms for the chapter plus their definitions
- **chapter review** questions that will help you to recall, revise, understand and apply the concepts from the chapter. The questions are grouped under headings (**Remembering**, **Understanding**, **Applying**, **Analysing**, **Evaluating** and **Creating**) and reflect the level of thinking required to answer each question. These questions provide you with the practice needed to analyse and answer exam questions.


1 Summary of key concepts

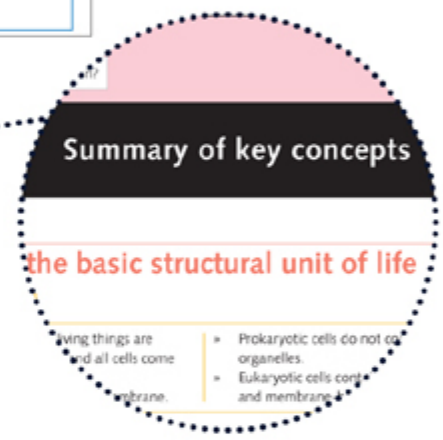
1.1 Cells are the basic structural unit of life

KEY CONCEPTS

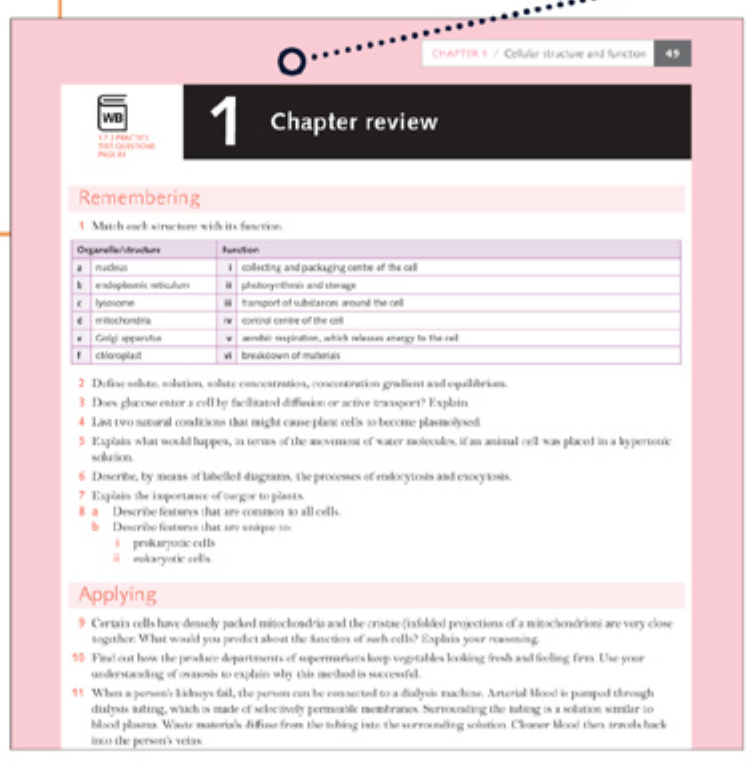
- The cell theory states that all living things are composed of one or more cells and all cells come from pre-existing cells.
- All cells are surrounded by a plasma membrane.
- Prokaryotic cells do not contain membrane-bound organelles.
- Eukaryotic cells contain a membrane-bound nucleus and membrane-bound organelles.

Figure 1.4 The difference between a a prokaryotic cell and b a eukaryotic animal cell

1.2 Size and shape of cells


Summary of key concepts

the basic structural unit of life


1 Chapter review

Remembering

1 Match each structure with its function.

Organelle/structure		Function
a	nucleus	i collecting and packaging centre of the cell
b	endoplasmic reticulum	ii photosynthesis and storage
c	lysosome	iii transport of substances around the cell
d	mitochondria	iv control centre of the cell
e	Golgi apparatus	v aerobic respiration, which releases energy to the cell
f	chloroplast	vi breakdown of materials

2 Define solute, solution, solute concentration, concentration gradient and equilibrium.
3 Does glucose enter a cell by facilitated diffusion or active transport? Explain.
4 List two natural conditions that might cause plant cells to become plasmolysed.
5 Explain what would happen, in terms of the movement of water molecules, if an animal cell was placed in a hypertonic solution.
6 Describe, by means of labelled diagrams, the processes of endocytosis and exocytosis.
7 Explain the importance of turgor to plants.
8 a Describe features that are common to all cells.
b Describe features that are unique to:
i prokaryotic cells
ii eukaryotic cells.

Applying

9 Certain cells have densely packed mitochondria and the cristae (infolded projections of a mitochondrion) are very close together. What would you predict about the function of such cells? Explain your reasoning.
10 Find out how the produce departments of supermarkets keep vegetables looking fresh and feeling firm. Use your understanding of osmosis to explain why this method is successful.
11 When a person's kidneys fail, the person can be connected to a dialysis machine. Arterial blood is pumped through dialysis tubing, which is made of selectively permeable membranes. Surrounding the tubing is a solution similar to blood plasma. Waste materials diffuse from the tubing into the surrounding solution. Cleaner blood then travels back into the person's veins.


Chapter review

Online Resources

nelson net.

FOR THE STUDENT

The NelsonNet website provides you with material that will help you understand, explore, engage and organise the key knowledge and key science skills you have learnt about in your textbook. You will find it at **www.nelsonnet.com.au** and once your registration is complete, you can access digital resources for each chapter to further reinforce your learning. Look on the back cover of this book to find out how to complete your registration.

You will find:

- **NelsonNetBook** with annotation capability
- **Weblinks** to more information, online interactives and videos
- **Worksheets** for some online videos
- **Downloadable versions** of each chapter map and summary of key concepts
- **Videos** explaining significant concepts
- **Play and say** to help you to pronounce and spell words in the key terms list
- **Flash cards** to assist remembering and revising of key terms and their definitions.

FOR THE TEACHER

Please note that complimentary access to NelsonNet and the NelsonNetBook is only available to teachers who use the accompanying student textbook as a core educational resource in their classroom.

Contact your sales representative for information about access codes and conditions.

To the teacher

The VCE Biology course comprises both key knowledge and key science skills. The *VICscience Biology* suite of products provides you with the perfect resource to teach all the key knowledge and key science skills in an integrated way and to prepare your students thoroughly for the school-based and external assessments.

1 Stick to the Study Design

This textbook has been written so all content closely aligns with the *VCAA VCE Biology Study Design* (2022–2026). It has been authored and reviewed by experienced biology teachers, academics and researchers to ensure up-to-date scientific and accurate content for students.

2 Access differentiated material

Differentiation is built into each chapter to assist you in helping those students that may struggle with content or skill development and extending those students who want to achieve at a higher level.

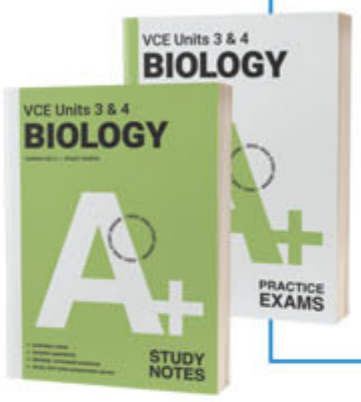
- **Chapter maps** provide students with a gentle and visual introduction to each chapter enabling students to engage with the chapter content prior to entering the chapter.
- **Key terms** at the beginning of each chapter present all the bolded key terms throughout the chapter in one place. Students can use the **flashcards** study tool to learn and review key terms with their definitions, and assist with pronunciation and spelling of key vocabulary.
- **Remember** provides students the opportunity to recall concepts previously learnt that will be revisited during the chapter.
- **Concept questions** are pitched to be lower-order questions to assist with learning consolidation but end with HOT Challenge questions are for those students who would benefit from answering higher-order questions.
- **Investigations** end with a **Taking it further** section, which provides ideas on how the investigation can be extended.
- **Weblinks** to external, vetted websites provide extra information; worksheets are provided for some weblinks.
- Each chapter finishes with a **Branching out** activity. This activity provides an extension activity for students who are looking for more information on a particular topic.

3 Prepare for the exam

Students of VCE Biology are working toward external assessment at the end of Units 3 & 4. To fully prepare for this exam, students require access to a large number of quality exam-style questions with answers. *VICscience Biology* gives you the full complement including the following.

- **Area of study reviews** at the end of each Area of Study provide students with difficulty-graded multiple-choice and short-answer questions that have been adapted from VCAA exam questions with answers provided at the back of the book.
- You will also find a full practice **end-of-year exams with answers**.
- *VICscience Biology VCE Units 1 & 2 Skills Workbook* provides students with difficulty-graded multiple-choice and short-answer exam questions that have been adapted from VCAA exam questions.

exam+



- **exam*plus*** simulates real exam-practice and comprises thousands of unseen exam-style and past VCAA exam questions with answers to use in your teaching. Simply select your questions for a quiz, topic test, or practice exam and **exam*plus*** generates a practice test or exam.
- Consider bundling ***A+ Study Notes*** and ***Practice Exams*** with your VICscience Biology booklist for the most economical solution for students' exam preparation and readiness.

4 Support for the teacher

There is a wealth of teacher support materials on the teacher NelsonNet site that accompanies this product. These include:

- **Cognero Assess** comprising 20 auto-correcting multiple-choice questions to be shared with your students for every chapter
- **answers** to all textbook questions, investigations and Branching out activities
- sample SACs with suggested marking schemes
- **practice end-of-year exams with answers**
- **teaching plans** for every chapter showing how all the components of the *VICscience Biology* suite are integrated to provide your students with a thorough and complete learning experience designed to prepare them for internal and external assessment
- support for the investigations provided through **Southern Biological**.

DEVELOPED EXCLUSIVELY BY SOUTHERN BIOLOGICAL

SOUTHERN Biological

ACCESS TO QUALITY INVESTIGATIONS

Practical work is a central component of the VCE Biology course and crucial in developing key science skills. The study design specifies the number of hours that students need to spend undertaking practical work. **Southern Biological and Cengage have partnered** to ensure that you and your students are provided with exciting and current practical investigations to introduce, reinforce and practise the key science skills listed in the *VCAA VCE Biology Study Design 2020–2026*, pages 7–8. Some of the investigations written by Southern Biological are exclusive to Cengage, and all investigations have been rigorously stress-tested by Southern Biological to ensure that they will work in your classroom.

Each investigation is accompanied by a risk assessment table that highlights risks to students or others posed by the materials or method. Teachers are expected to amend each table in the case of substitutions or in the case of any additional risks. This may mean obtaining and following Safety Data Sheets (SDS) for certain chemicals. All teachers are required to follow the safety guidelines of their specific school and associated government legislation when students are in their care.

Investigation support provided by Southern Biological include:

- **suggested answers** to investigation questions
- **videos to assist teachers** and laboratory technicians to prepare and deliver the investigations to students providing them with optimal hands-on experience
- **videos aimed at students** to assist with undertaking the investigations including suggested answers and hints
- **risk assessments** for investigations where applicable
- resourcing, safety and investigation **preparation sheets.**

Study design grid

Unit	Area of study	Chapters									
		1	2	3	4	5	6	7	8	9	10
How do organisms regulate their functions? 1.	**1: How do cells function?** Students examine the structure and functioning of prokaryotic and eukaryotic cells, and how the plasma membrane contributes to survival by controlling the movement of substances into and out of the cell. Students explore cellular growth, replacement and death. They become familiar with the key events and regulation of the cell cycle and the processes for cell division, including disruptions to the cell cycle and deviant cell behaviour. Students consider the properties of stem cells and their role in differentiation, specialisation and renewal of cells and tissues. (p.18 Study Design)	✓	✓	✓							
	2: How do plant and animal systems function? Students explore how systems function through cell specialisation in vascular plants and in digestive, endocrine and excretory systems in animals, focusing on regulation of water balance in plants, and temperature, blood glucose and water balance in animals. Students examine how homeostatic mechanisms in animals help maintain their internal environment within a narrow range of tolerance levels, and consider malfunctions in homeostatic mechanisms. (p. 23 Study Design)			✓	✓	✓	✓				
	3: How do scientific investigations develop understanding of how organisms regulate their functions? Survival of organisms requires control and regulation of factors within an organism and often outside an organism. Different types of cells and adaptations enhance an organism's survival in a particular environment, while homeostatic mechanisms maintain the internal environment. In this area of study students adapt or design and then conduct a scientific investigation to generate appropriate qualitative and/or quantitative data, organise and interpret the data, and reach a conclusion in response to the research question. The student-adapted or student-designed scientific investigation relates to knowledge and skills developed in Area of Study 1 and/or Area of Study 2. (p. 24 Study Design)					✓					

Unit	Area of study	Chapters									
		1	2	3	4	5	6	7	8	9	10
	1: How is inheritance explained? Students describe the production of gametes in sexual reproduction through the key events in meiosis. They explore the nature of chromosomes and the use of genetic language to read and interpret patterns of inheritance and predict outcomes of genetic crosses. Students explain how a characteristic or trait can be influenced by one gene, many genes acting together, and genes interacting with external environmental or epigenetic factors. They apply their genetic knowledge to analyse pedigree charts, determine patterns of inheritance and predict outcomes of genetic crosses. (p. 27 Study Design)						✓	✓			
	2: How do inherited adaptations impact on diversity? Students analyse the advantages and disadvantages of asexual and sexual reproduction and investigate the use and application of reproductive cloning technologies. Students explore the biological importance of genetic diversity and the structural, physiological and behavioural adaptations that enable species to survive in an ecosystem. Students explore the interdependencies between species, including the importance and impact of keystone species and top predators. They consider the contributions of Aboriginal and Torres Strait Islander knowledge and perspectives to the understanding of the adaptations of, and interdependencies between, species in Australian ecosystems. (p. 28 Study Design)								✓	✓	
	3: How do humans use science to explore and communicate contemporary bioethical issues? Students explore a contemporary bioethical issue relating to the application of genetic knowledge, reproductive science, inheritance or adaptations and interdependencies beneficial for survival. Examples of investigation topics include, but are not limited to: genomic and epigenetic research; cloning for agriculture, horticulture or other purposes; assisted reproductive technologies; prenatal and predictive genetic testing; strategies for maintaining genetic diversity within a species or population; the impact of introduced species; changes to specific keystone species on populations and ecosystems; or the use of biomimicry to solve human challenges or biopiracy of Indigenous knowledge.										
	How do humans use science to explore and communicate contemporary bioethical issues? **2.** Students may develop a research question related to the applications included above or, in conjunction with their teacher, they may develop their own research question related to Area of Study 1 and/or Area of Study 2. Possible starting points when developing a research question may include stimulus material such as announcements of recent discoveries, an expert's published point of view, a TED talk or a YouTube presentation, an article from a scientific publication, public concern about an issue, changes in government funding or new government initiatives. Analysing and synthesising secondary data, students demonstrate and apply their knowledge and relevant key science skills to: explain the biological concepts specific to the identified bioethical issue; consider different perspectives; outline social, economic, legal and/or political factors relevant to the selected issue; choose a position or course of action on the basis of reasoning and reflection; and communicate their findings. (p. 29 Study Design)										✓

Getty Images/Pimenta Gabriel

Unit 1

How do organisms regulate their functions?

Area of Study 1: How do cells function?

Area of Study 2: How do plant and animal systems function?

Area of Study 3: How do scientific investigations develop understanding of how organisms regulate their functions?

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1 Cellular structure and function

By the end of this chapter you will have covered the following material.

Key knowledge

Cellular structure and function

» cells as the basic structural feature of life on Earth, including the distinction between prokaryotic and eukaryotic cells, pp. 7–10

» surface area to volume ratio as an important factor in the limitations of cell size and the need for internal compartments (organelles) with specific cellular functions, pp. 11–17

» the structure and specialisation of plant and animal cell organelles for distinct functions, including chloroplasts and mitochondria, pp. 17–27

» the structure and function of the plasma membrane in the passage of water, hydrophilic and hydrophobic substances via osmosis, facilitated diffusion and active transport, pp. 27–42

Key science skills

Develop aims and questions, formulate hypotheses and make predictions

» identify, research and construct aims and questions for investigation, pp. 15–16

» identify independent, dependent and controlled variables in controlled experiments, pp. 15–16

» formulate hypotheses to focus investigation, pp. 15–16

» predict possible outcomes, pp. 15–16

Plan and conduct investigations

» design and conduct investigations; select and use methods appropriate to the investigation, including consideration of sampling technique and size, equipment and procedures, taking into account potential sources of error and uncertainty; determine the type and amount of qualitative and/or quantitative data to be generated or collated, pp. 15–16

» work independently and collaboratively as appropriate and within identified research constraints, adapting or extending processes as required and recording such modifications, pp. 15–16; 30–31

Comply with safety and ethical guidelines

» demonstrate safe laboratory practices when planning and conducting investigations by using risk assessments that are informed by safety data sheets (SDS), and accounting for risks, pp. 15–16; 30–31

» apply relevant occupational health and safety guidelines while undertaking practical investigations, pp. 15–16

» demonstrate ethical conduct when undertaking and reporting investigations, pp. 15–16

Generate, collate and record data

» record and summarise both qualitative and quantitative data, including use of a logbook as an authentication of generated or collated data, pp. 15–16; 30–31

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- » organise and present data in useful and meaningful ways, including schematic diagrams, flow charts, tables, bar charts and line graphs, pp. 15–16; 30–31
- » plot graphs involving two variables that show linear and non-linear relationships, pp. 15–16

Analyse and evaluate data and investigation methods

- » process quantitative data using appropriate mathematical relationships and units, including calculations of ratios, percentages, percentage change and mean, pp. 15–16
- » identify and analyse experimental data qualitatively, handing where appropriate concepts of: accuracy, precision, repeatability, reproducibility and validity of measurements; errors (random and systematic); and certainty in data, including effects of sample size in obtaining reliable data, pp. 30–31

Analyse, evaluate and communicate scientific ideas

- » use appropriate biological terminology, representations and conventions, including standard abbreviations, graphing conventions and units of measurement, pp. 15–16
- » discuss relevant biological information, ideas, concepts, theories and models and the connections between them, pp. 15–16; 30–31
- » analyse and explain how models and theories are used to organise and understand observed phenomena and concepts related to biology, identifying limitations of selected models/theories, pp. 30–31

To access resources below, visit www.nelsonnet.com.au

Online Chapter Map:
- Chapter 1 map (p. 4)

Online Key Terms:
- Chapter 1 flashcards (p. 6)

Weblinks:
- Amoeba sisters (p. 23)
- Cytoplasmic streaming (p. 24)

Online Worksheets:
- Introduction to cells: the grand cell tour (p. 23)
- Cytoplasmic streaming (p. 24)

Video:
- Why are our cells so small (p. 11)

Online Key Concepts:
- Chapter 1 summary of key concepts (p. 44)

Online Chapter Map
Chapter 1 map

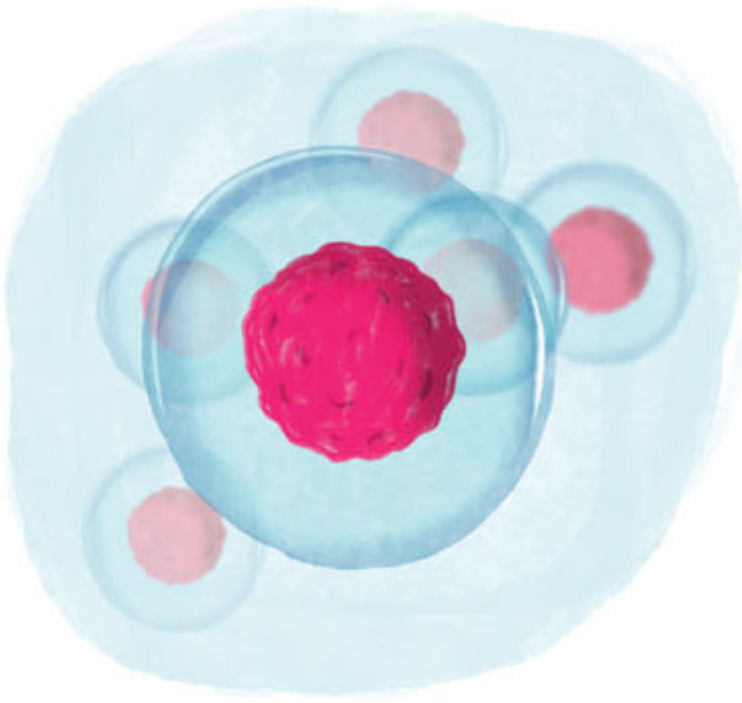
1 Cellular structure and function

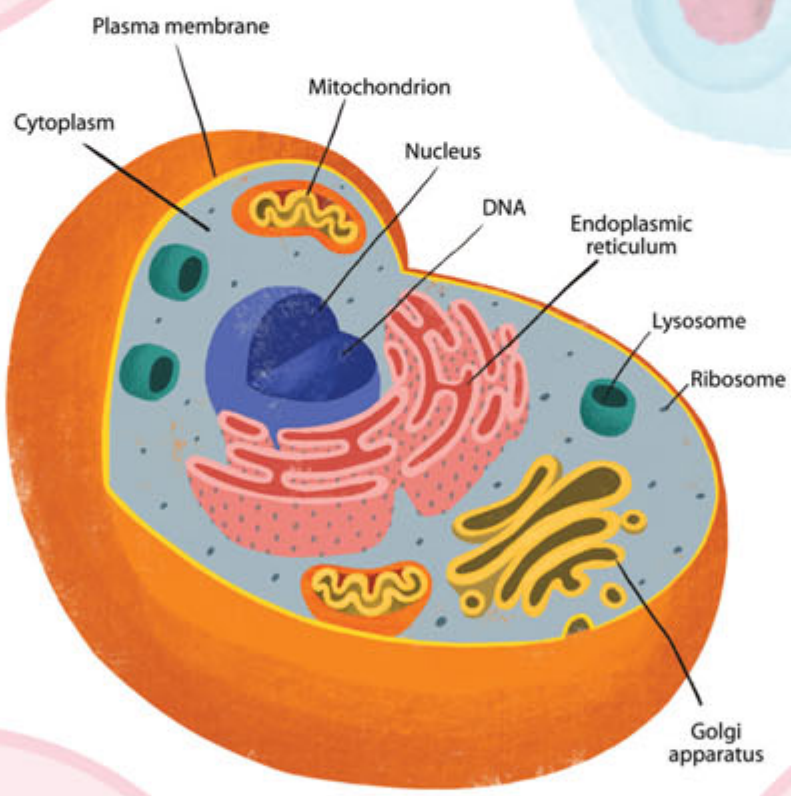
Every living organism is made up of one cell or many, even up to 30 trillion cells.
The basic structure and function become more specialised depending on what the cells do.

1.1 Cells are the basic structural unit of life

p. 7

Every organism is made of cells. Prokaryotic cells are simple in structure with no nucleus. Eukaryotic cells are more complex in structure with a nucleus and membrane-bound organelles.





1.2 Size and shape of cells

p. 11

Cells take in their requirements from the outside and release their waste through their plasma membrane. They need enough plasma membrane to service their cytoplasm – a balancing act called surface area to volume ratio.

1.3 What's inside a cell?

p. 17

Eukaryotic cells have a plasma membrane that encloses its cytoplasm. Within the cytoplasm, many different membrane-bound organelles, such as nuclei, mitochondria and chloroplasts, enable cells to perform many different functions at the same time.

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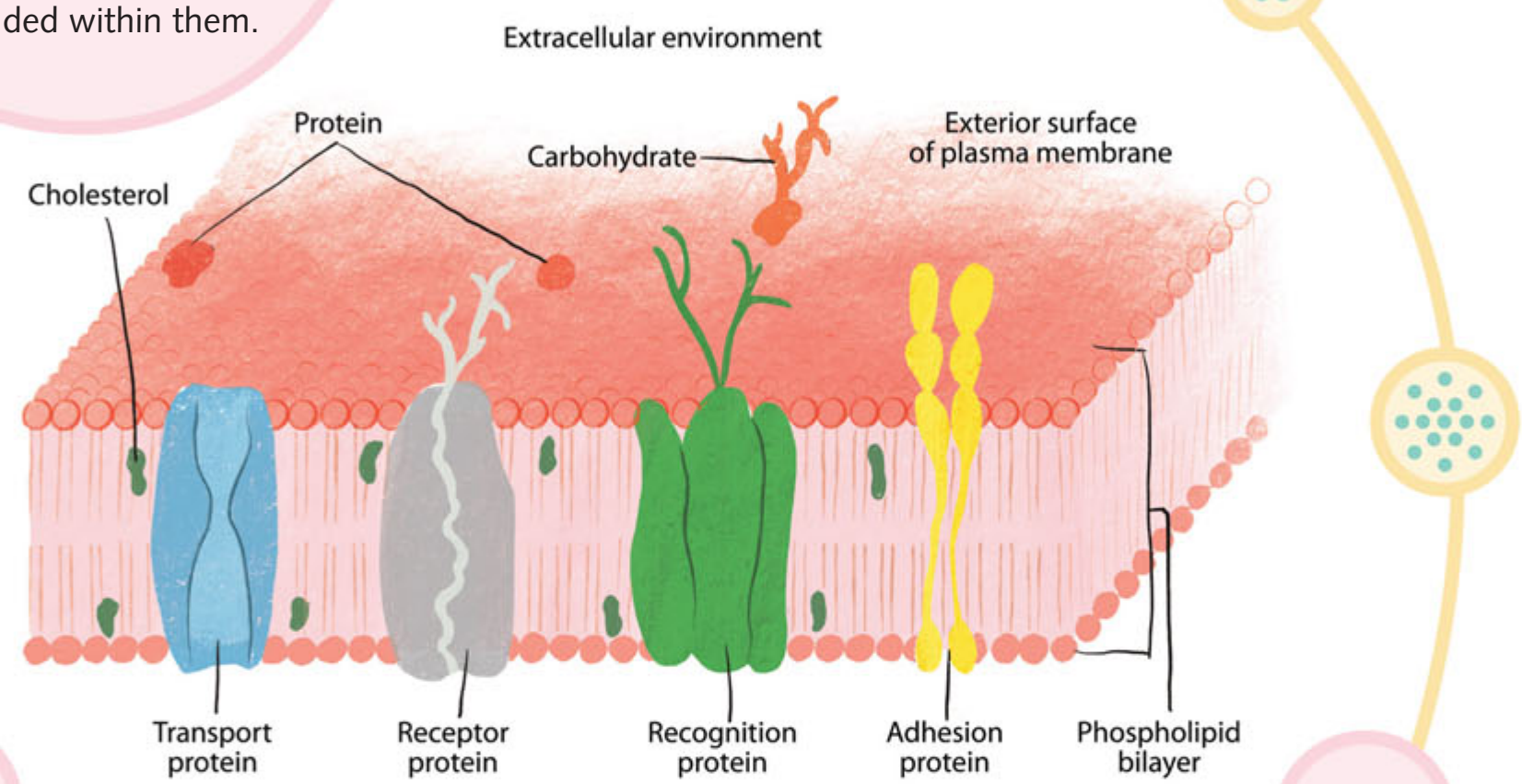
1.4 Plasma membrane

p. 27

The plasma membrane bounds the cell. It holds everything in, and controls what enters and leaves. It is made up of two layers of phospholipid molecules with proteins embedded within them.



1.6 Movement across membranes using energy

p. 39

Sometimes energy is required to pump certain substances in or out of the cell. This is because some substances are too big or are moving against a concentration gradient or are moved in bulk. Proteins come into action at this point.

1.5 Passive movement across the membranes

p. 32

Some materials can move across membranes without requiring energy to push or pull them across. This is passive movement. Diffusion and osmosis are passive movement processes.

The cell is the basic unit of biology. Ensure you have sound understanding of how a cell is structured and how it functions before you proceed in this course. It all comes back to the cell!

Online Key Terms
Chapter 1 flashcards

Know your key terms

active transport
adenosine triphosphate (ATP)
adhesion protein
amino acid
carrier protein
cell
cellular respiration
cellulose
centriole
channel protein
chlorophyll
chloroplast
cholesterol
chromosome
concentration gradient
contractile vacoule
crenation
cristae
cytoplasm
cytoplasmic streaming
cytoskeleton
cytosol
diffusion
deoxyribonucleic acid (DNA)
endocytosis
endoplasmic reticulum
enzyme
equilibrium
eukaryotic
exocytosis
external environment
extracellular
facilitated diffusion
flaccid
fluid mosaic model
glycoprotein
Golgi apparatus
grana
haemolysis
hydrophilic
hydrophobic
hypertonic
hypotonic
intercellular
internal environment
intracellular
ion
isotonic
lysosome
membrane
metabolism
microfilament
microtubule
mitochondria
mitochondrial matrix
multicellular
nanometre (nm)
nuclear envelope/membrane
nucleolus
nucleus
organelle
osmosis
passive transport
permeable
phagocytosis
phospholipid
phospholipid bilayer
photosynthesis
phytosterol
pinocytosis
plasma membrane
plasmolysis
plasmid
plastid
prokaryotic
receptor
receptor protein
recognition protein
ribosome
ribonucleic acid (RNA)
rough endoplasmic reticulum
selectively permeable
smooth endoplasmic reticulum
solute
solution
solvent
spindle fibres
stroma
surface-area-to-volume ratio (SA : V)
synthesise
thylakoid membrane
tonoplast
transmembrane protein
transport protein
turgid
unicellular
vacuole
vesicle

Remember

This chapter will build on the following concepts that you will have already met during your study of science. Take the time to refresh these concepts before you start this chapter.

WB
REMEMBER
PAGE 2

1 Cells are the basic units of living things.
2 Cells have specialised structures and functions.
3 Organisms can be single-celled (unicellular) or have many cells that work together (multicellular).
4 There are six kingdoms of living things: Plants, Animals, Fungi, Protista, Eubacteria and Archaeabacteria.
5 Enzymes are proteins that speed up chemical reactions.

All organisms are composed of the basic unit of living things – the **cell**. The organism could be made up of only one cell (**unicellular**) (Figure 1.1a) or many cells (**multicellular**) (Figure 1.1b) working together. Within the cell, many functions need to take place simultaneously for the survival of the cell and, if multicellular, the organism of which it is a part. These functions have their own inputs, outputs and processes that need to occur. It makes sense that these different processes are kept separate. It is a bit like making a two-course dinner with a friend in your home kitchen. Your friend prepares the dessert of cheesecake on the kitchen table while you prepare the main course of roast beef on the kitchen bench. You don't want the roast beef mixing with the cheesecake so you carry out your preparation in different areas. It is the same within cells. Cellular respiration occurs in one area of the cell and protein synthesis in another. Each area is kept separate from the other as they have different inputs, processes and outputs. This separation is achieved through **membranes** that act as a boundary around the individual compartments within the cell.

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Figure 1.1a Although a *Paramecium* is only a single cell it has complex internal structure. **b** A flame tree is made up of many cells and takes on a very different shape to a *Paramecium*.

1.1 Cells are the basic structural unit of life

Over the past 180 years we have come to understand that all organisms are made up of cells, the basic structural and functional unit of an organism. A cell's structure is highly organised and many chemical processes and reactions occur within it at the same time. Cells can be found in many shapes and sizes depending on whether the organism is unicellular or multicellular, where they are located individually in the environment or are part of a multicellular organism, and the function that they have to perform.

In 1665, Robert Hooke, an English natural philosopher using a very simple microscope, became the first person to make observations of the walls of empty plant cells. He coined the term 'cell' for the first time and described his observations of the walls of dead and empty plant cells. 'Cell' was roughly translated from the Latin word 'cellula' and means 'little compartment'. Five years later, a Dutch businessman and self-taught scientist, Antonie van Leeuwenhoek, made his own single-lensed microscope and started observing and recording the living cells that he called 'tiny animals'; these were the first bacteria to be observed and drawn. He was not only the first to observe and document bacteria, but he also made the first drawings of muscle fibres, spermatozoa and red blood cells.

In 1838, Matthias Schleiden saw that each individual cell within a whole plant developed as an independent unit. He thought that the obvious distinct area that we now know as the **nucleus** probably

had something to do with the development of each cell. In 1839, Theodor Schwann used his extensive knowledge of zoology and animal tissues to theorise that 'Animals as well as plants consist of cells and cell products – and even though the cells are part of a whole organism, they have, to some extent, an individual life of their own.'

These observations, along with microscopic examinations of a great variety of different materials, led Schleiden and Schwann to the belief that the majority of organisms are composed of cells. This belief is embodied in the cell theory, which was proposed by these two scientists in 1839. The cell theory states that all living things are composed of one or more cells. The cell is the smallest entity that retains the properties of life.

Cell division was described for the first time in 1849 and this led to more information being added to the cell theory. In later years, Rudolf Virchow proposed that all cells come from pre-existing cells. This had not been appreciated before. Schwann had thought that new cells arose from tiny particles in the fluid between cells.

WB
1.1.1 THE CELL THEORY PAGE 3

In summary these observations led to the cell theory, which states:

1. The cell is the basic structural and functional unit of an organism
2. All new cells are produced by pre-existing cells.

a

Getty Images Plus/iStock/ilviaggiatore

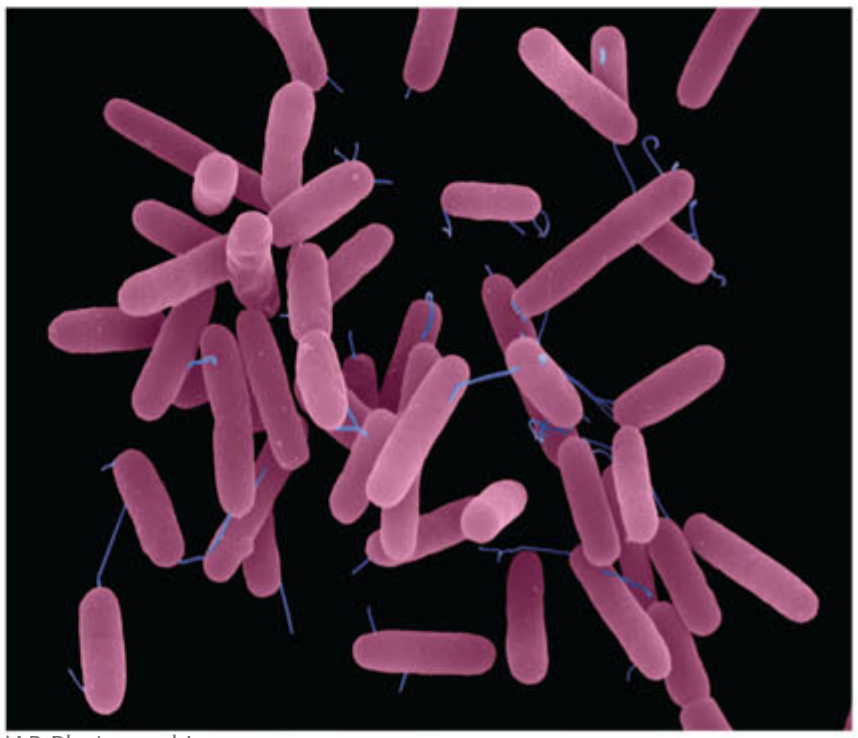
b

Shutterstock.com/Ma

c

Shutterstock.com/AB Photographie

d



Alamy Stock Photo/Sc

Figure 1.2 The various organisms on Earth can look very different but they are all made up of cells. **a** fern, **b** jellyfish, **c** giraffe and **d** bacteria

Prokaryotic versus eukaryotic cells

All living things are grouped into Kingdoms. These Kingdoms are called Animal, Plant, Fungi, Protista, Eubacteria and Archaebacteria. These groupings are initially based on cell structure. There are two different types of cell structure: prokaryotic and eukaryotic.

WB 1.1.2 PROKARYOTIC AND EUKARYOTIC CELLS PAGE 5

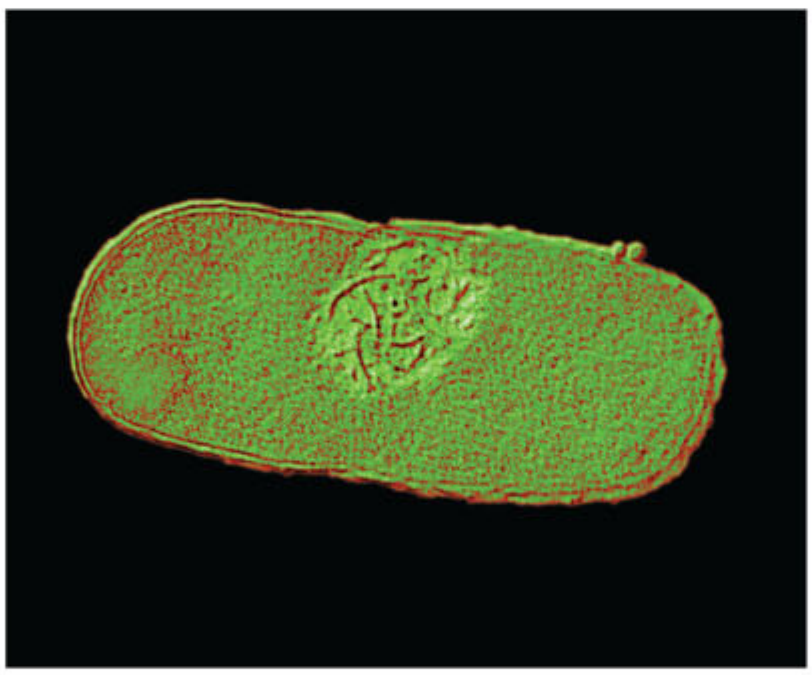
Prokaryotic cells

The cells with the simplest structure, called **prokaryotic** cells, are found in the Kingdoms Eubacteria and Archaebacteria. These are cells that have no internal membrane-bound structures or compartments, including no membrane-bound nucleus. These cells still contain genetic material but the **deoxyribonucleic acid (DNA)** is not contained inside a nucleus. Rather, it is packaged together with proteins in a region of the cell called a nucleoid and as extra-chromosomal DNA in circular **plasmids**. Prokaryotic cells are considered to be the oldest in evolutionary history.

Escherichia coli (*E. coli*) is a bacterium that inhabits the large intestines of humans. It is used as an indicator of faecal contamination at beaches. When you hear that a beach is unfit to swim in, it is usually because the *E. coli* count is over an accepted level. Being a bacterium, *E. coli* is prokaryotic in structure (Figure 1.3).

The term 'membrane' is often used to describe any thin layer, whether in relation to living things or not. The membrane that surrounds all cells is called the **plasma membrane**. As a protective boundary, the plasma membrane keeps internal contents confined in one area, preventing them moving away from each other. The plasma membrane is important in keeping out foreign molecules that could damage or destroy the cell's components.

EXAM TIP
Do not get plasmid confused with plastid. Plasmids are circular pieces of DNA found in prokaryotic cells. Plastids are membrane-bound organelles found in eukaryotic plant and some fungi cells.



Alamy Stock Photo/Science Photo Library

Figure 1.3 ***Escherichia coli*** **cell, showing internal structure. Note the nucleoid region in the top middle of the cell.**

Eukaryotic cells

More complex cells, called **eukaryotic** cells, contain membrane-bound **organelles** that are suspended in a fluid called the cytosol. Eukaryotic cells have DNA enclosed by a **nuclear envelope**, which is a double membrane, forming what is known as a true nucleus. DNA is the genetic material that codes information used in the synthesis of proteins. Members of the Animal, Plant, Fungi and Protista Kingdoms are all composed of eukaryotic cells. Yet even these types of cells differ in the types of organelles they possess (p. 27).

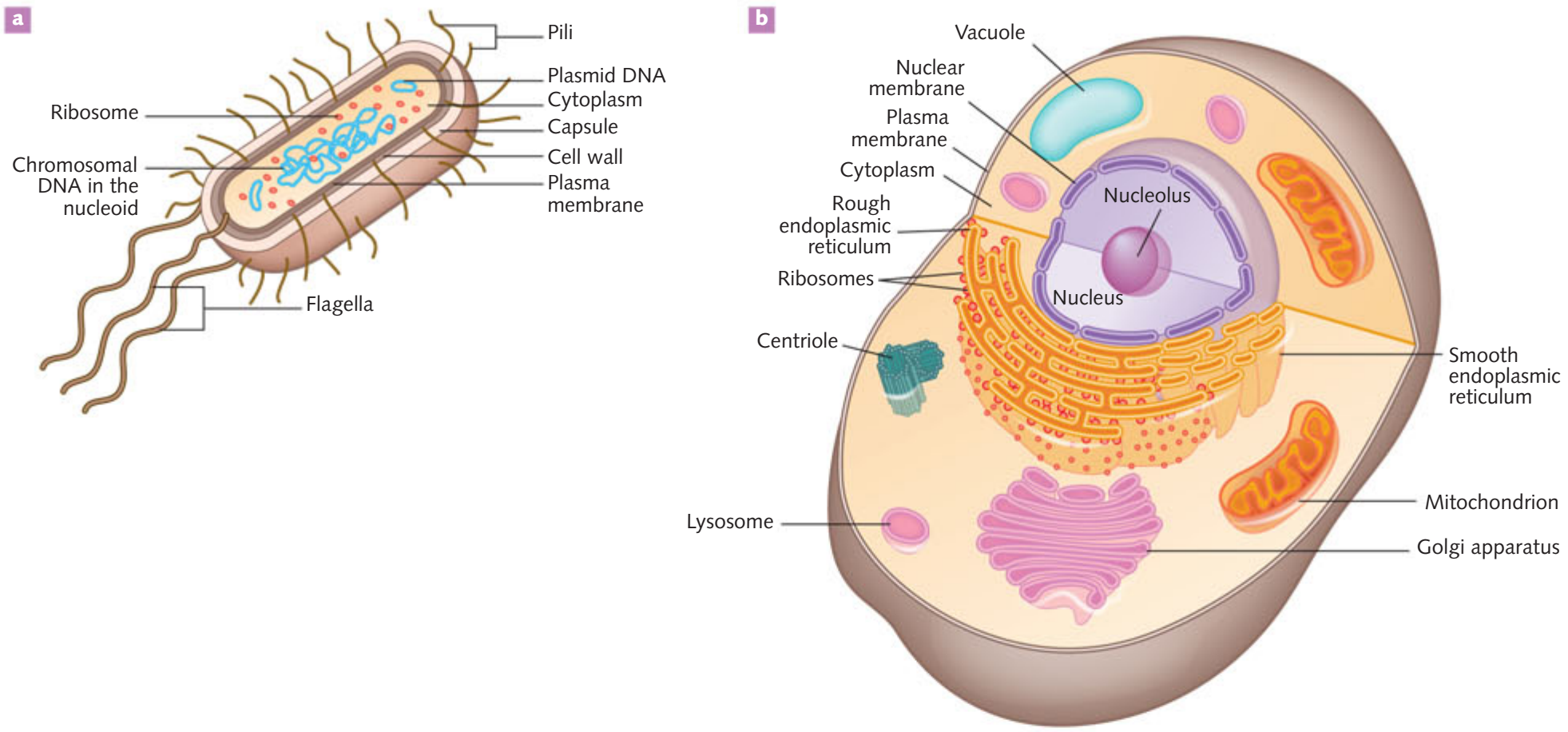


Figure 1.4 The difference between **a** a prokaryotic cell and **b** a eukaryotic animal cell

KEY CONCEPTS

- The cell theory states that all living things are composed of one or more cells and all cells come from pre-existing cells.
- All cells are surrounded by a plasma membrane.
- Prokaryotic cells do not contain membrane-bound organelles.
- Eukaryotic cells contain a membrane-bound nucleus and membrane-bound organelles.

Concept questions 1.1

1 List the characteristics that all living things have in common.

2 Living things are made up of cells and the products of cells. Explain what this means.

3 What is the cell theory?

4 What are the differences between prokaryotic cells and eukaryotic cells?

5 A student makes the statement that 'Prokaryotic cells probably evolved before eukaryotic cells'. Explain if this statement is supported or not.

HOT Challenge

6 **a** Kingdoms Eubacteria and Archaebacteria are made up of prokaryotic cells. Compare some of the characteristics of these organisms.

b Some Archaean species, for example, have the following properties: commensals, methanogens (methane-producing strains), inhabit the gastrointestinal tract in humans and ruminants, where their vast numbers aid digestion. Some can endure high temperatures and organic solvents (extremophiles). Rarely found to be pathogens.

A company is exploring whether such organisms might be useful to manufacture to sell to remote hot locations to help with sewage treatment and to produce biogas for onselling. What aspects of the listed properties make these Archaea a suitable candidate to be used in this way?

1.2 Size and shape of cells

It is not a coincidence that cells were first described with the invention of the microscope. They are not visible to the naked eye (unless it is the world's largest single-celled organism, an aquatic alga called *Caulerpa taxifolia*). The first living organisms to evolve on Earth were single celled. To thrive in the environment of early Earth, these cells needed to obtain requirements (nutrients and gases) and expel wastes. Being such a small size allowed nutrients, gases and wastes to cross their plasma membrane at a rate that sustained life within the cell. As organisms became larger, the cells did not get larger; rather, the cells divided and increased in number. Multicellular organisms became the next evolutionary step; however, unicellular organisms still persist.

CONNECT

Multicellular organisms and how they obtain their requirements are discussed in Chapters 3 and 4.

Unicellular organisms survive successfully as an independent single cell. All their waste products and input requirements pass across the plasma membrane. Complex multicellular organisms such as the plant in Figure 1.1b are made up of many different specialised cells, which may have different functions to keep the plant alive. Their requirements and waste products still need to pass across plasma membranes.

Surface-area-to-volume ratio

There is a delicate balance between the size of the cell and its ability to gain enough requirements and remove enough wastes across its plasma membrane to sustain life. It is important for the plasma membrane (the surface of the cell) to have a large enough area for this to happen in a manner that can sustain a healthy cell. All substances must be able to move to and from the inside of the cell (its volume) at a rate that ensures the survival of the cell. This can best be explained by comparing the volume of the cell to its external surface area.

Video
Why are cells so small?

This important concept relating to the exchange of materials across plasma membranes is the **surface-area-to-volume ratio (SA :V)**. It represents an important relationship between the surface area of the plasma membrane surrounding a cell and the volume of its contents. So, for example, if a cell has a surface-area-to-volume ratio of 3 : 1, this means that there are three parts of surface area of a cell servicing 1 part of volume of that cell. This is a much better ratio than 2 : 1 or 1 : 1.

1.2.1
SURFACE AREA TO VOLUME RATIO
PAGE 7

For a cell to be able to supply its contents with metabolic requirements and remove wastes, it needs a large surface area in relation to its volume.

As a cell grows larger, both its surface area and volume increase, but its volume grows faster than its surface area. This is shown in Figure 1.5. Cell A has a volume of 1.0 mm^3 and a surface area of 6mm^2 to service it. This is a surface-area-to-volume ratio of 6 : 1. Cell C, however, has a volume of 27 mm^3 and a surface area of 54mm^2 to service it, a surface-area-to-volume ratio of only 2 : 1.

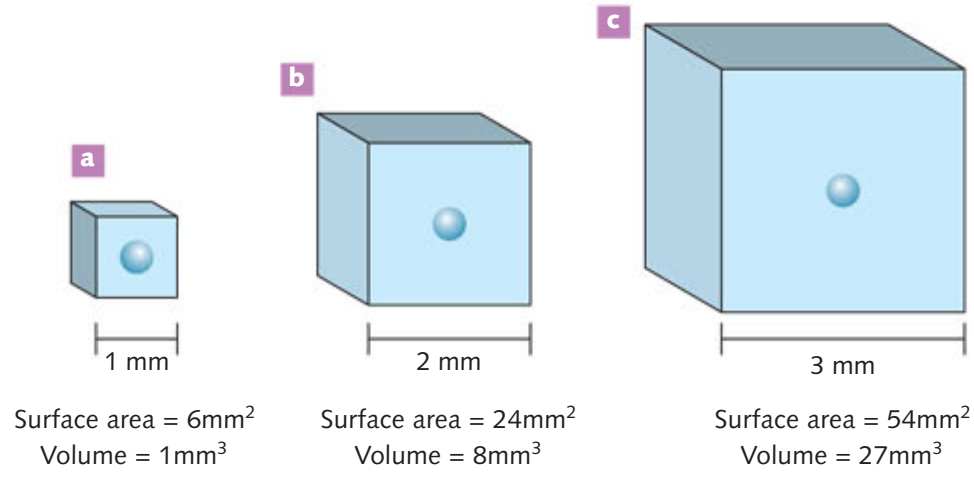


Figure 1.5 Three hypothetical cells. Cell A has a SA : V = 6 : 1, Cell B = 3 : 1 and Cell C = 2 : 1. Cell A is the smallest cell but has the largest SA : V and Cell C is the largest cell with the smallest SA : V. Note that the nucleus remains the same size in all three cells.

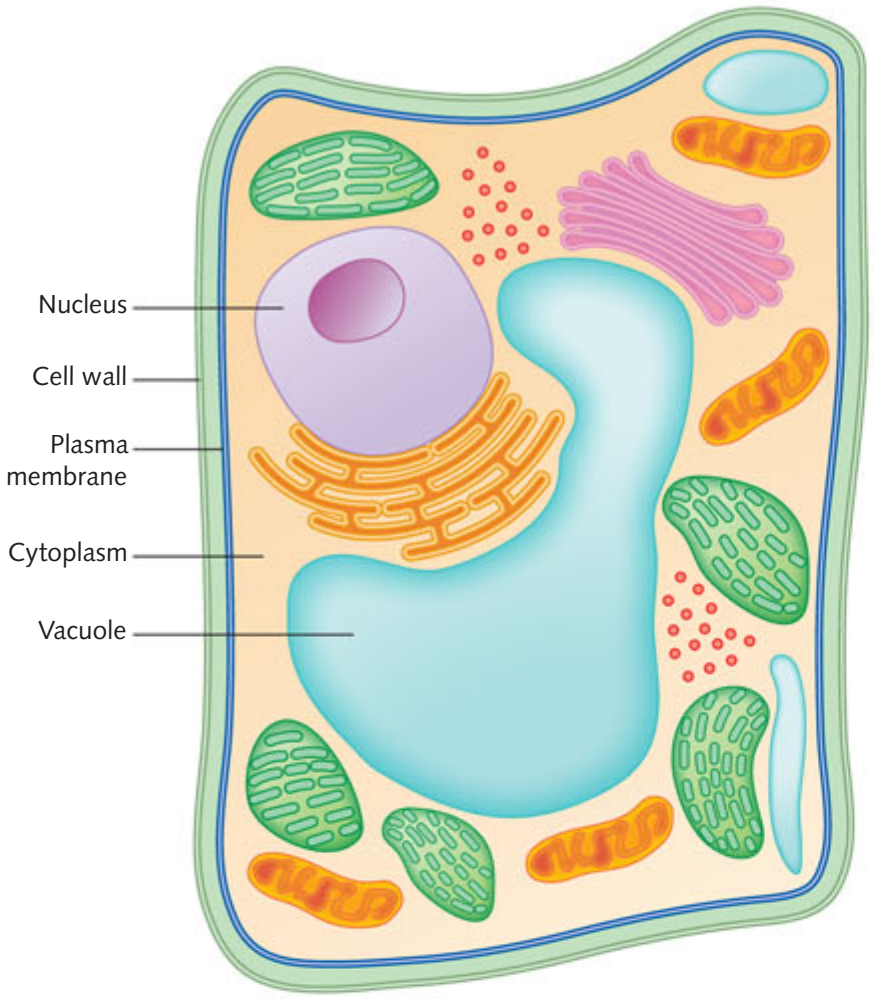


Figure 1.6 A large vacuole in plant cells reduces the volume of cytoplasm in the cell that has to be serviced by the surface area.

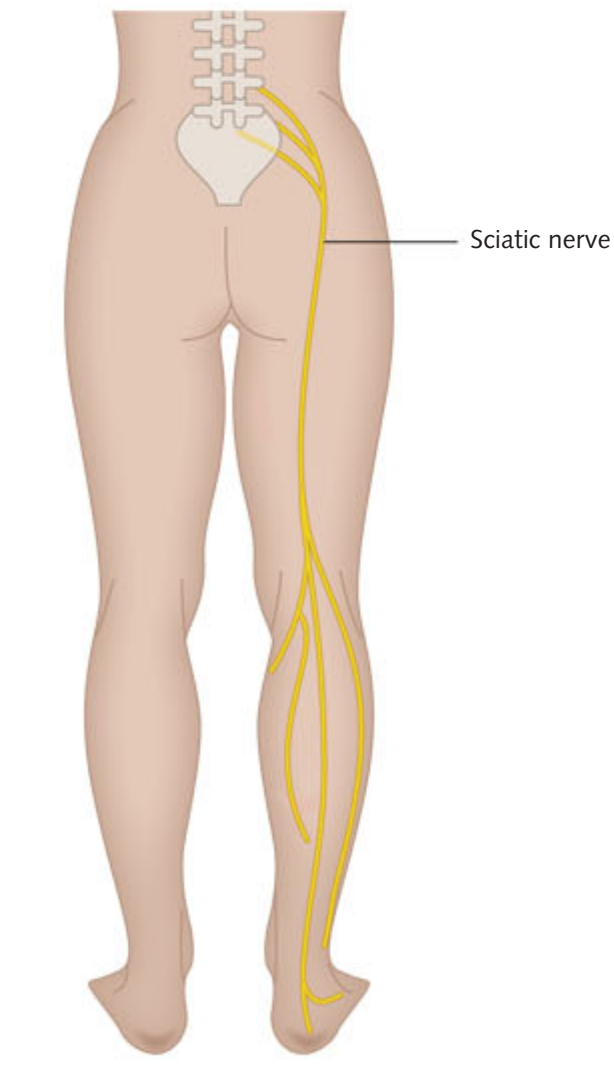


Figure 1.7 The nerve cells that connect your spinal cord to your toes are more than 1 m long.

As the size of a cell increases, the surface-area-to-volume ratio decreases. This means the efficiency with which a cell obtains its nutrients and removes its wastes is reduced as its size increases. A cell increasing in size reaches a point where the inward movement of essential substances and the outward movement of wastes across the surface area by **diffusion** are not efficient enough to service the increasing volume of the cell. For this reason, individual cells tend to be very small.

How big can cells grow?

Because of the restrictions of the surface-area-to-volume ratio, most cells are too small to see without the aid of a microscope. Red blood cells, for example, are about 8 millionths of a metre wide; approximately 2000 of them would fit across your thumbnail. However, some eukaryotic cells can be observed with the unaided human eye, such as the yolks of bird eggs, cells in some algae, and the eggs of fish and frogs (spawn).

Such cells have special ways to offset the low surface-area-to-volume ratio that comes from their large size. In giant algal cells, a **vacuole** fills most of the cell. This pushes the metabolically active cytoplasm towards the edges of the cell, just beneath the plasma membrane (Figure 1.6). This has two benefits. It means that the distance materials need to diffuse when moving into or out of the cell is much less. It also has the effect of reducing the active volume of the cytoplasm and so reducing the amount of exchange that must occur across the membrane.

Shape of cells

In a multicellular organism, some cells need to be of a certain size and shape in order to perform their specific function. For example, the nerve cells that connect your spinal cord to your toes run the full length of your leg and are more than 1 m long (Figure 1.7). To explain how they overcome issues associated with increased size, we need to look at the relationship between shape and surface-area-to-volume ratio.

The shape of an object can significantly change its surface-area-to-volume ratio. A sphere has the least surface area for the volume it encloses. This explains why soap bubbles are perfect spheres. The thin elastic membrane made by the soap mixture contracts to the smallest area that can enclose the volume of air blown into it when the bubble was made (Figure 1.8). Likewise, spherical cells have a relatively small surface-area-to-volume ratio when compared with cells of other shapes.

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Figure 1.8 Soap bubbles are perfect spheres because this is the smallest surface area that can contain the bubble's volume.

ACTIVITY 1.1

Can you make square soap bubbles?

Aim

To explore shape and surface area

You will need

- 250 mL beaker (or large glass)
- 2 × 30 cm pipe cleaners
- Liquid dishwashing detergent

What to do

1. Place approximately 200 mL of cold water into the beaker.
2. Add about 10 mL of detergent, being careful not to let it froth. If froth does appear, scrape it off.
3. Bend each pipe cleaner to form a square, one with sides 3 × 3 cm, the other 5 × 5 cm.
4. Dip the pipe cleaners into the soapy mixture and gently blow to form bubbles. Observe the shape changes that occur as the bubble forms and floats away.
5. Account for the shape of the bubble in terms of surface area and volume.

What did you discover?

1. Were you able to blow square bubbles?
2. Why do you think most animal cells are circular in shape.

Cells often have specific features that ensure they have the highest surface-area-to-volume ratio possible. Long, thin or flat cells have relatively more membrane for a certain volume compared with spherical cells. A good example is seen in the root hairs that cover the root tips of most plants. The long, thin extensions of the single cells that form root hairs are able to significantly increase the surface area over which water and mineral salts can be absorbed (Figure 1.9).

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Figure 1.9 Scanning electron micrograph of root hairs in oregano, *Origanum vulgare*. They greatly increase the surface area for absorption of water.

WORKED EXAMPLE 1.1

Calculate the surface-area-to-volume ratio of a cube 1 cm × 1 cm × 1 cm.

Answer	Logic
Surface area of a cube = number of sides × length of side^2	Use the correct formula to calculate surface area.
Surface area = 6 × 1 × 1	Insert numbers into formula.
= 6 cm^2	Calculate answer.
Volume of a cube = length × width × height	Use the correct formula to calculate volume.
Volume = 1 × 1 × 1	Insert numbers into formula.
= 1 cm^3	Calculate answer.
Surface area : volume ratio = 6 : 1	Calculate SA : volume ratio. Insert numbers into formula and calculate answer.

Try these yourself

1 Calculate the surface-area-to-volume ratio of a cube 4 cm × 4 cm × 4 cm.
2 Calculate the surface-area-to-volume ratio of a cube 6 cm × 6 cm × 6 cm.

Developed by Southern Biological

INVESTIGATION 1.1

Why are cells so small?

The relatively small size of cells allows molecules to pass through their membranes. If a cell gets too large then the centre of the cell cannot be serviced efficiently. As the size of an object increases, the volume increases at a greater rate than the surface area. For a cell, this means that efficiency of the exchange of materials across a membrane is reduced, and therefore the cell's ability to take in enough nutrients is reduced. In addition, toxins may be retained inside the cell for too long.

Using agar cubes with indicator, vinegar and some simple mathematics, we can see how much effect a small increase in surface area has on volume.

Aim

To determine the relationship between surface area to volume ratio and its relationship to diffusion rates

Time requirement

45 minutes

Materials

- Prepared agar cubes with bromothymol blue indicator (side lengths 1 cm, 2 cm and 3 cm)
- 150 mL vinegar (dilute acetic acid)
- 250 mL beaker
- Plastic or metal spoon
- Timer
- Ruler
- Calculator
- Paper towel
- Disposable gloves

What are the risks in this investigation?	How can you manage these risks to stay safe?
Glass beakers may break or have chipped edges.	Inspect and discard any chipped or cracked beakers, no matter how small the damage. Sweep up broken glass with a brush and dustpan; do not use fingers.
Disposable gloves may pose allergy risk.	Use a type of glove that removes allergy risk and is suitable for the chemicals being used.
Acetic acid may produce an irritant vapour.	Ensure the investigation is performed in a well-ventilated space.

Method

1. Form a hypothesis for this investigation. Remember that you must record all aspects of this investigation into your logbook.
2. Put on disposable gloves and measure the height (h), width (w) and length (l) of each cube to calculate surface area (SA) and initial volume (V_i). Copy Table A into your logbook and record this information in it.
3. Half-fill the beaker with vinegar, ensuring that the largest cube can be submerged, and place one cube of each size into the beaker (Figure 1.10).
4. Set a timer and remove the cubes after 4 minutes, pat them dry with a paper towel. Measure the portion of each cube that is still blue. Try to minimise the amount of time the cubes are out of the vinegar.
5. Replace the cubes in the vinegar and repeat step 4 several times until the cubes have been submerged for a total of 20 minutes.
6. Calculate the volume of the portion of the cube that is still blue (V_f) after each 4-minute interval and the percentage of the whole cube that the vinegar has penetrated (%P). Copy Table B into your logbook and record this information in it.

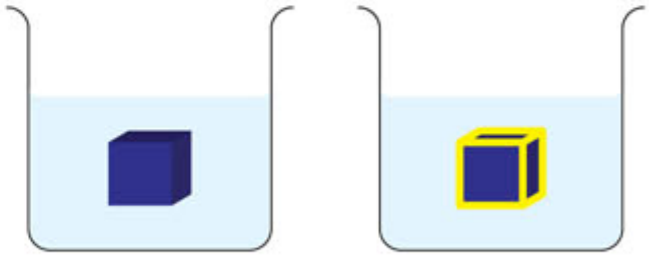

Figure 1.10 Initial colour of cube (left) and how it may appear after some time (right)

Results

Copy and complete Table A below, then copy and complete Table B for each cube.

Table A Initial measurements

Cube	Height (*h*) (cm)	Width (*w*) (cm)	Length (*l*) (cm)	SA (cm^2)	V_i (cm^3)	Ratio (SA : V) (cm^{-1})
A						
B						
C						

SA = surface area, V_i = initial volume

Table B Measurements over time: Cube (X)

Time (min)	Height (*h*) (cm)	Width (*w*) (cm)	Length (*l*) (cm)	V_f (cm^3)	$P(V_i - V_f)$ (cm)	% penetration $\left(\frac{P \times 100}{V_i}\right)$
0						
4						
8						
12						
16						
20						

P = penetration of the vinegar into the cube, V_i = initial volume (from table A), V_f = volume of the part of the cube that is still blue

Discussion

1. Explain why the agar cubes change colour when placed in the vinegar solution.
2. Describe the relationship between the size and surface area to the rate that diffusion occurs.
3. Using the same set of axes, create a graph of time in minutes (*x*-axis) against %*P* (*y*-axis) for each cube. Comparing them all on one graph will demonstrate the trends of each.

Conclusion

Summarise your findings, commenting on your hypothesis and explaining the advantages and disadvantages of cell size.

Taking it further

Create a graph of initial SA : V(*x*-axis) against the total time in minutes (*y*-axis) to demonstrate that, as the ratio increases, the time taken to completely penetrate the cube will decrease in a non-linear fashion.

KEY CONCEPTS

- Surface-area-to-volume ratio (SA : V) is a relationship between the size of the outside of an object and the amount of space enclosed within the object.
- Cells with a larger surface-area-to-volume ratio can obtain nutrients and remove wastes more efficiently.
- The shape of a cell can significantly change a cell's surface-area-to-volume ratio.

Concept questions 1.2

1 What is meant by surface-area-to-volume ratio when applied to a cell?

2 A round cell with a diameter of 2 cm has a greater chance of survival than a round cell with a diameter of 5 cm. Explain why this is so.

3 Observe the cell in Figure 1.11. List two substances that would move into the cell through the plasma membrane, and two substances that would move out of the cell through the plasma membrane.

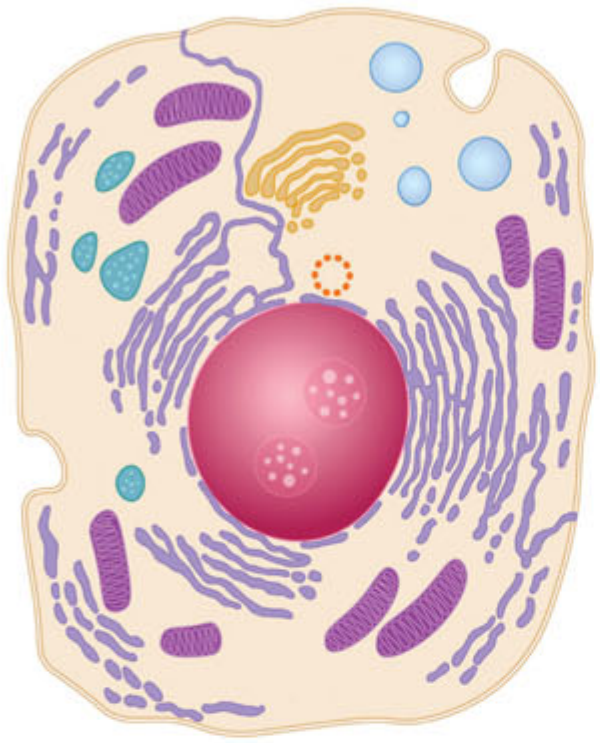

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Figure 1.11

4 Plant cells are generally large in comparison to animal cells. How do permanent vacuoles in large plant cells aid in diffusion of vital inputs into the cell to run its functions?

5 Heart muscle cells in animals have evolved to be long in shape, while fat cells (adipocytes) are roughly spherical. An adipocyte has a radius of approximately 50 micrometres (μm), while a type of heart muscle cell called a cardiomyocyte has a radius of about 15 μm. Explain why this evolutionary difference in cell size and shape may have evolved.

HOT Challenge

6 Figure 1.12 depicts three different types of cell arrangement.

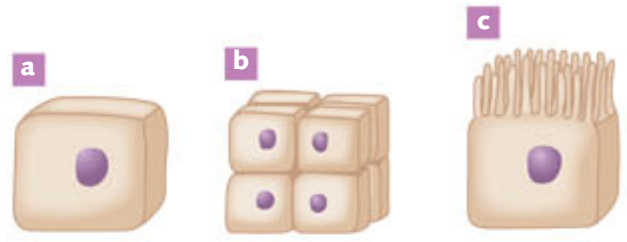


Figure 1.12 Three different eukaryotic cells a One large cell, b Eight small cells, c Cell with microvilli on one surface

a Which cell would have the smallest surface-area-to-volume ratio (SA : V)? Justify your choice.

b Describe how the specialised cell depicted in Figure 1.12c has evolved to increase the SA : V.

c The dimensions of the cell in Figure 1.12a are: height 10 μm, width 10 μm, depth 8 μm.

Using the above dimensions, what is the SA of the cell, the V of the cell and the SA : V?

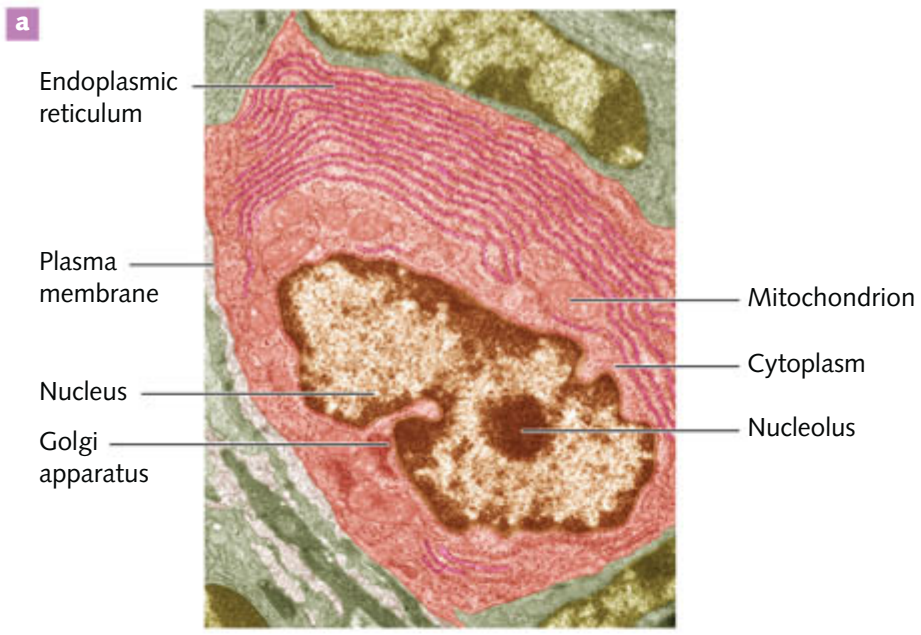
1.3 What's inside a cell?

WB
1.3.1 COMPARTMENTS IN CELLS PAGE 13

Unlike prokaryotic cells, eukaryotic cells are able to take on a range of functions. This is only made possible by compartmentalising within the cells, because eukaryotic cells are larger than prokaryotic cells.

The cell compartments, called organelles, can be clearly seen with the electron microscope (Figure 1.13). Cells that were formerly believed to have little or no structure have been shown to have an elaborate internal organisation. Organelles are bound by membranes to separate them off from other parts of the cell. This allows several activities to occur at the same time independently of each other. The organelles carry out specific functions within the cell, working together to ensure that all the cell's and hence the organism's needs are met.

The presence of these internal membrane-bound organelles also results in a greater surface area within the cell, allowing for more exchange of materials and therefore more cellular functions. Together, the total surface area of a cell's internal membranes far exceeds that of its plasma membrane.



Science Photo Library/Steve Gschmeissner

Science Photo Library/Dr. Martha Powell, Visuals Unlimited

Figure 1.13a Eukaryotic animal cell showing its plasma membrane and other organelles **b** a typical line drawing of an animal cell **c** eukaryotic plant cell showing its plasma membrane, cell wall and other organelles **d** a typical line drawing of a plant cell

External cell boundary: plasma membrane

EXAM TIP

Remember the difference between cytoplasm and cytosol. Cytoplasm = the cytosol + organelles (not the nucleus); cytosol = the gel-like fluid in which organelles are suspended.

Each cell is an independent unit, separated from other cells and its environment by the plasma membrane (or cell membrane), the outermost barrier of a cell. The plasma membrane is composed of lipid molecules that are interspersed with tiny protein channels. It is mainly through the protein channels that nutrients and water enter a cell and wastes are released. The structure of the plasma membrane will be discussed in more detail on page 27.

Cytoplasm

The plasma membrane encloses a gel-like fluid in which substances are dissolved and organelles are suspended. This fluid is called the **cytosol**. The **cytoplasm** is comprised of the cytosol plus all the organelles, with the exception of the cell nucleus. All the chemical reactions that are required to enable a cell to live occur within the cytoplasm.

Coordinating cell activities: nucleus

Cells carry out many and varied tasks, usually at the same time. To be efficient, a cell needs to have some way of coordinating all of these activities. This is a main function of the nucleus. The nucleus is one of

the most noticeable features you can observe in a eukaryotic cell. It is clearly visible using both light and electron microscopes, as shown in Figure 1.14.

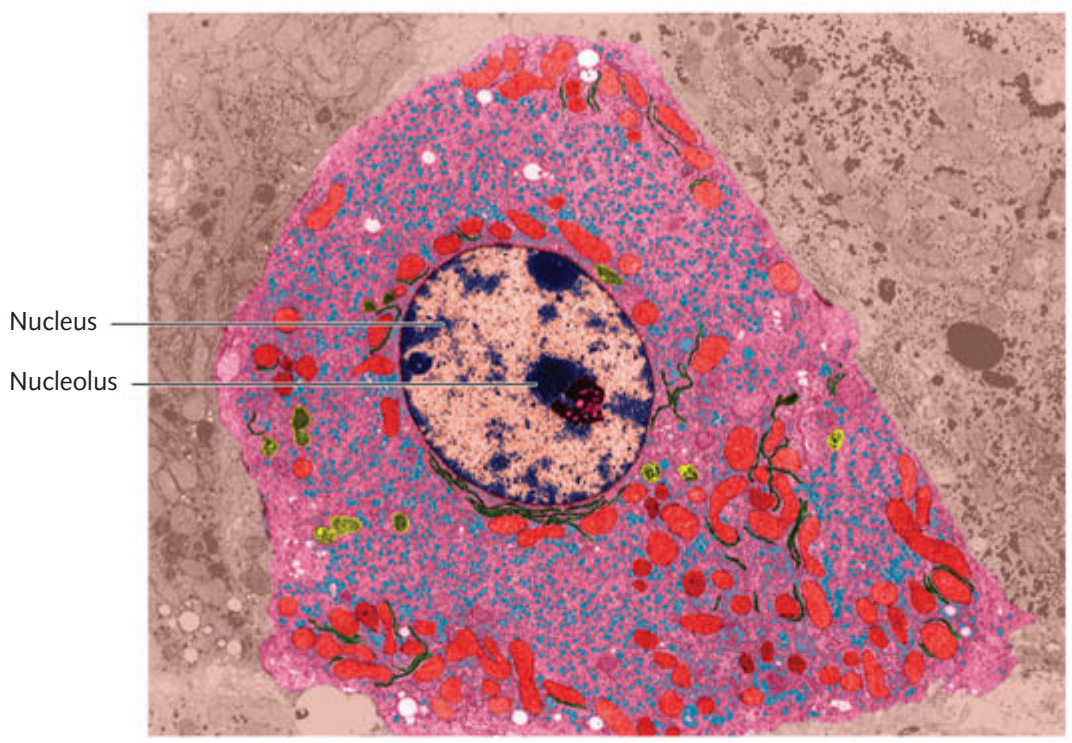


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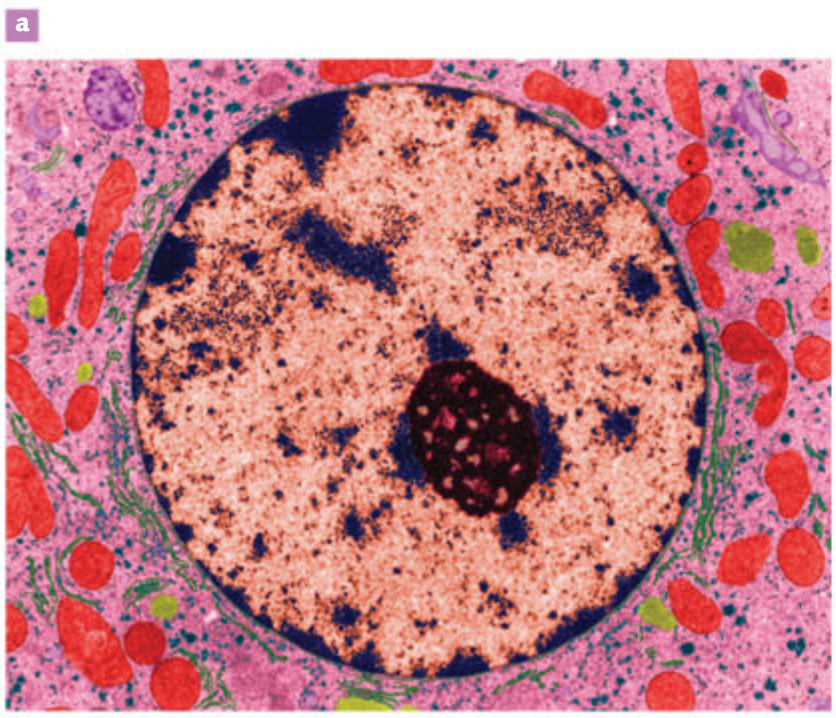
Figure 1.14 Transmission electron micrograph of the nucleus of a liver cell (1240 ×)

The nucleus is said to be the control centre of the cell. DNA (deoxyribonucleic acid) is the main molecule found within the nucleus. DNA is tightly coiled and wound around proteins to make up **chromosomes**. Chromosomes can be seen when the nucleus is actively dividing (Figure 1.15a). DNA codes for the production of proteins that carry out a variety of activities within the cell. By coding for different proteins at different times, depending on the function of the cell, the nucleus can coordinate the activities of the cell and hence the organism.

CONNECT

How DNA codes for proteins and how proteins are produced is covered in Unit 3.

The nucleus is separated from the rest of the cell by the porous **nuclear membrane** (or envelope). It is composed of a fatty substance (lipid) with small holes or pores within it (Figure 1.15b). This allows charged particles (**ions**) and small water-soluble molecules to move freely across it. The membrane around the cell nucleus keeps the DNA of eukaryotic cells separate from the chemical reactions occurring in the cytoplasm.



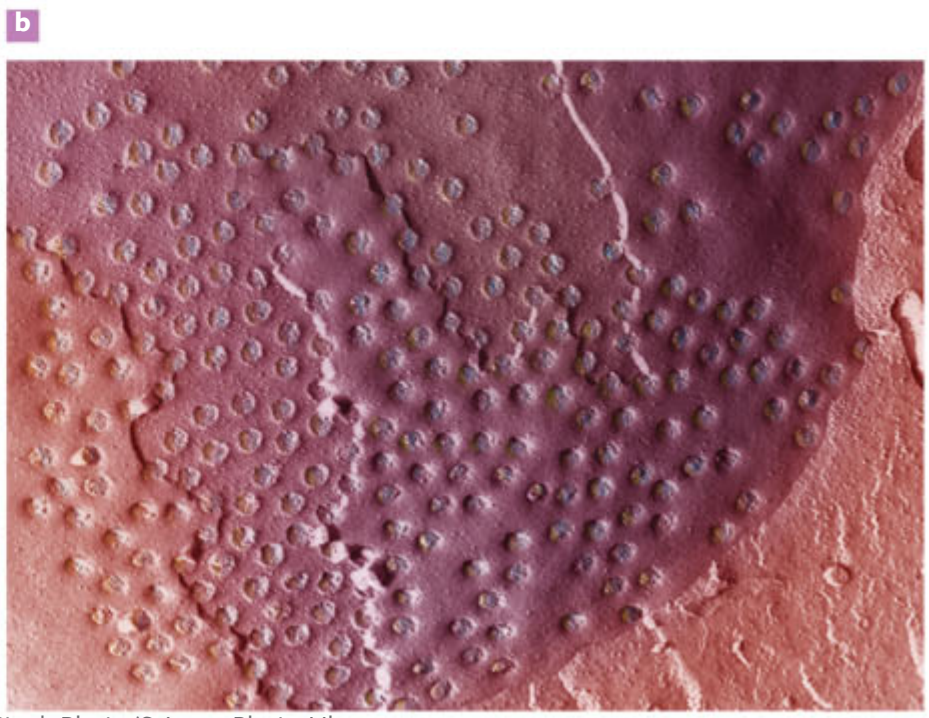


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Figure 1.15a Chromosomes within the nucleus **b** Scanning electron micrograph (SEM) of the surface of the porous nuclear membrane

A dark-staining structure within the nucleus is called the **nucleolus** . One or more of these can be seen in cells when they are not dividing. The nucleolus is made of densely packed protein and a type of nucleic acid called ribosomal **ribonucleic acid (RNA)**. Nucleoli are the sites of **ribosome** synthesis in the cell. Ribosomes are found in the cytoplasm and are involved in protein synthesis, as explained below.

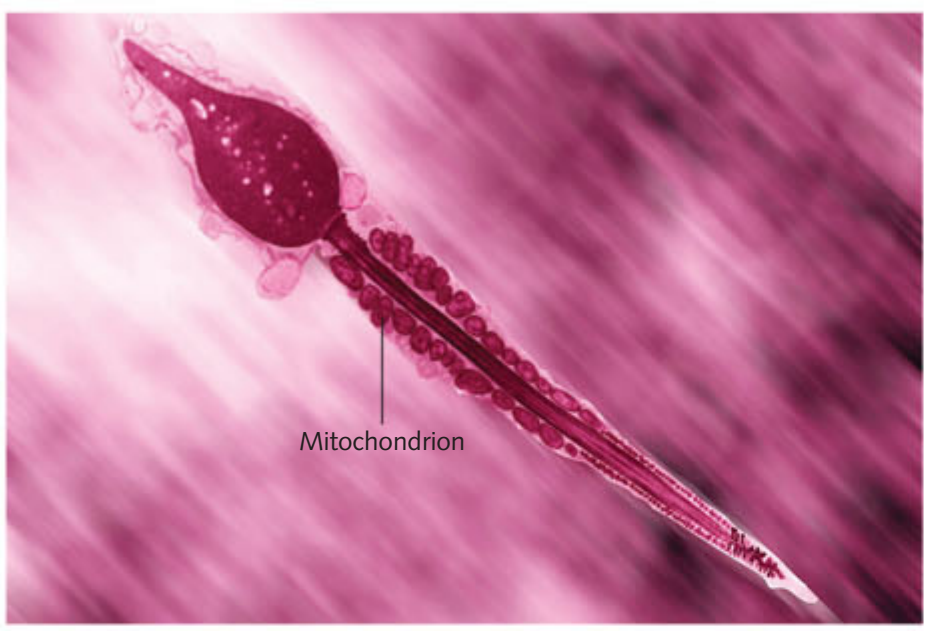

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Figure 1.16 **Human sperm cell showing tightly packed mitochondria behind the head**

The power supply: mitochondria

All cells need a source of energy so they can perform functions – move, make substances, communicate and reproduce. The energy source is provided by the **metabolism** of glucose molecules which diffuse into the cytoplasm of the cell.

The male reproductive system has an organ that produces the male sex cell, sperm. The task of the sperm cell is to fertilise the egg in the reproductive tract of a female. In order to get there the sperm cell must swim – very fast. To do this, it needs a lot of energy.

If you could zoom in on an individual sperm cell you would see that in the mid piece just behind the head of the cell there are many tightly packed organelles called **mitochondria** (Figure 1.16). The rest of the tail thrashes rapidly to propel the sperm cell forward. Mitochondria are found in the cytoplasm and are the sites of aerobic **cellular respiration**. Cellular respiration is a series of chemical reactions in which glucose is metabolised in the presence of oxygen to produce carbon dioxide, water and heat energy.

During certain stages of these chemical reactions, energy is released and this is used to join inorganic phosphate onto adenosine diphospate (ADP) molecules to form **adenosine triphosphate (ATP)** molecules. ATP is an energy storage molecule that is used by the cell to power cellular processes. Energy is released from ATP when the bond in the final phosphate is broken to form ADP. In the example of the sperm cell, this energy is used to move the tail and make the sperm cell move forward.

Mitochondria are small, oval-shaped organelles found scattered throughout the cytoplasm of a cell. Each mitochondrion consists of a smooth outer membrane and a highly folded inner membrane (Figure 1.17). The folds in the inner membrane are called **cristae** and they protrude into the inner space of the mitochondrion, a protein-rich fluid called the **mitochondrial matrix** .

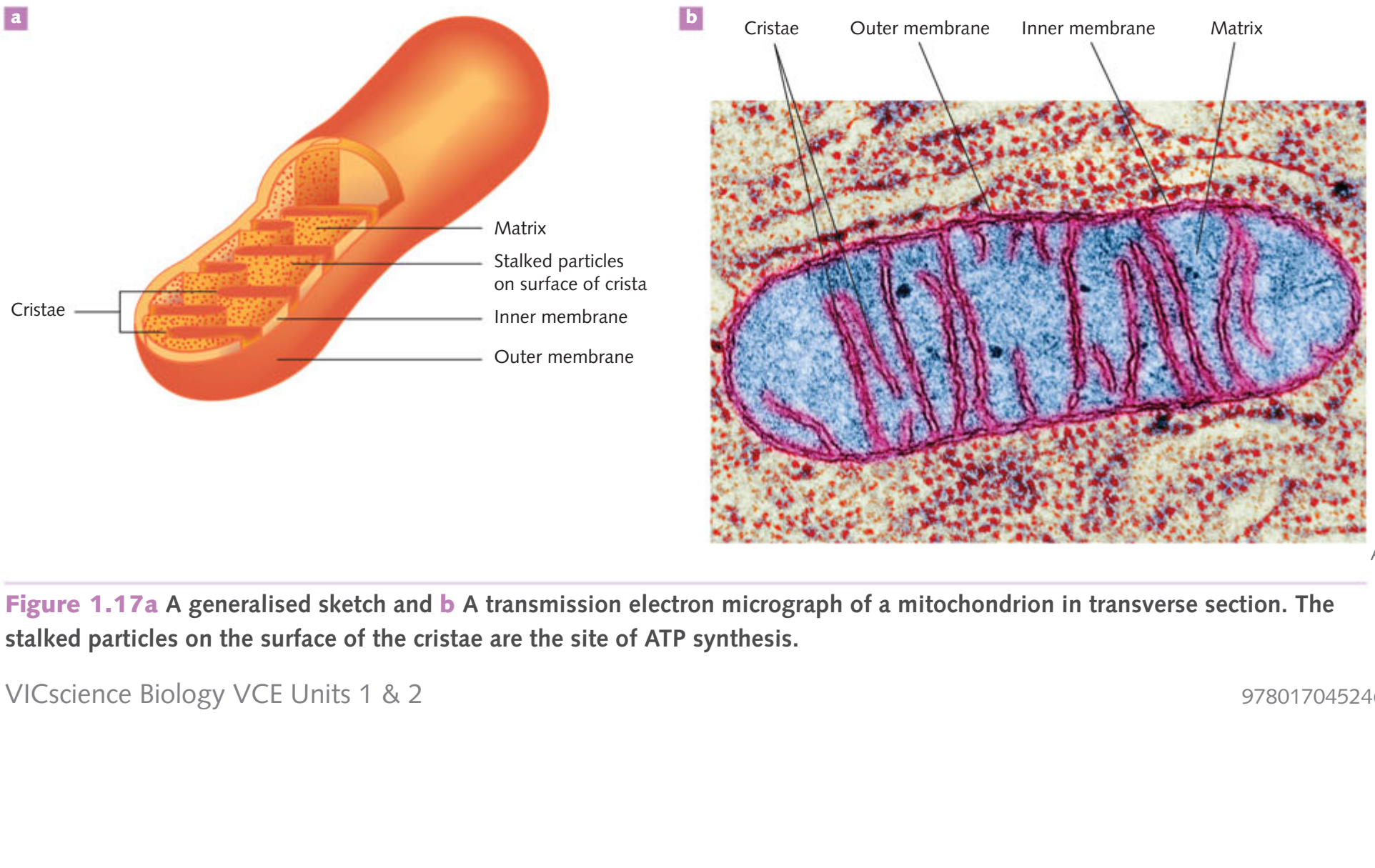

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Figure 1.17a **A generalised sketch and b A transmission electron micrograph of a mitochondrion in transverse section. The stalked particles on the surface of the cristae are the site of ATP synthesis.**

KEY CONCEPTS

- Cell organelles carry out specific functions within a cell.
- The cytoplasm makes up the bulk of a cell.
- The nucleus coordinates cell activities.
- Mitochondria are the sites of cellular respiration.

Concept questions 1.3a

1. How is the cytosol similar to the cytoplasm and how is it different? Describe the relationship between the cytoplasm and cytosol.
2. State where in cells you would find the cytoplasm.
3. Name the organelle that controls the functioning of eukaryotic cells. Describe the main molecule found in this organelle and explain how it controls the cell's functioning.
4. Draw a labelled diagram of a mitochondrion.
5. Sperm cells contain high levels of mitochondria. Explain how this is relevant to:
   a ATP production
   b motility

HOT Challenge

6. Why do you think it might be important for the porous double nuclear membrane to keep the DNA of eukaryotic cells separate from the chemical reactions occurring in the cytoplasm?

Building cell structures: ribosomes

WB 1.3.2 ORGANELLES PAGE 14

Both prokaryotic and eukaryotic cell types contain very small structures called ribosomes. You would not be able to see these clearly by using a light microscope. They are too small. You would need to make an image of a cell with an electron microscope before the ribosomes could be seen.

All cell types contain ribosomes, so they must be very important for cell functioning. Furthermore, some types of cells contain more ribosomes than others. Cells producing large amounts of proteins have the greatest numbers of ribosomes. This observation can be explained when we realise that ribosomes build up (**synthesise**) proteins from their building blocks, **amino acids**. Although your body produces most of the amino acids required for protein synthesis, some need to be supplied in the food you eat. It is the role of the digestive system to break down the proteins taken in as food into the amino acid building blocks. Proteins are needed for cell growth, repair and general cell functioning.

Transport within the cell: endoplasmic reticulum

How do proteins produced in ribosomes move to other parts of the cell? Even though many substances move around the cell in the cytoplasm, other substances are able to move around the cell through the **endoplasmic reticulum**. The endoplasmic reticulum is an interconnecting system of thin membrane sheets dividing the cytoplasm into compartments and channels as shown in Figure 1.18. The membrane of the endoplasmic reticulum is able to pinch off into small sacs called **vesicles** and deliver proteins to all parts within the cell. The endoplasmic reticulum is therefore an **intracellular** transport system.

Most of the endoplasmic reticulum in cells is studded with ribosomes and is known as **rough endoplasmic reticulum** (Figure 1.18). Proteins produced by ribosomes on the rough endoplasmic reticulum can move directly into the endoplasmic reticulum internal compartment where they can have modifications added, and they can be transported about the cell. Proteins produced in the rough endoplasmic reticulum can also be secreted from the cell. Such proteins include enzymes and hormones. Therefore, the endoplasmic reticulum also acts as an **intercellular** transport system, helping to move proteins from one cell to another.

In certain parts of some cells, the endoplasmic reticulum has no ribosomes attached to it and is known as **smooth endoplasmic reticulum**. The amount and function of this smooth endoplasmic reticulum depends on the type of cell it is located in. Its main role is to transport proteins, synthesise lipids and assist in the manufacture of plasma membranes. In liver cells it also detoxifies drugs and in adrenal cortical cells it produces the steroid hormones. Some carbohydrates are produced on smooth endoplasmic reticulum. Smooth endoplasmic reticulum is a place for storage of calcium ions, which are necessary for muscle contraction and interactions between some membrane proteins.

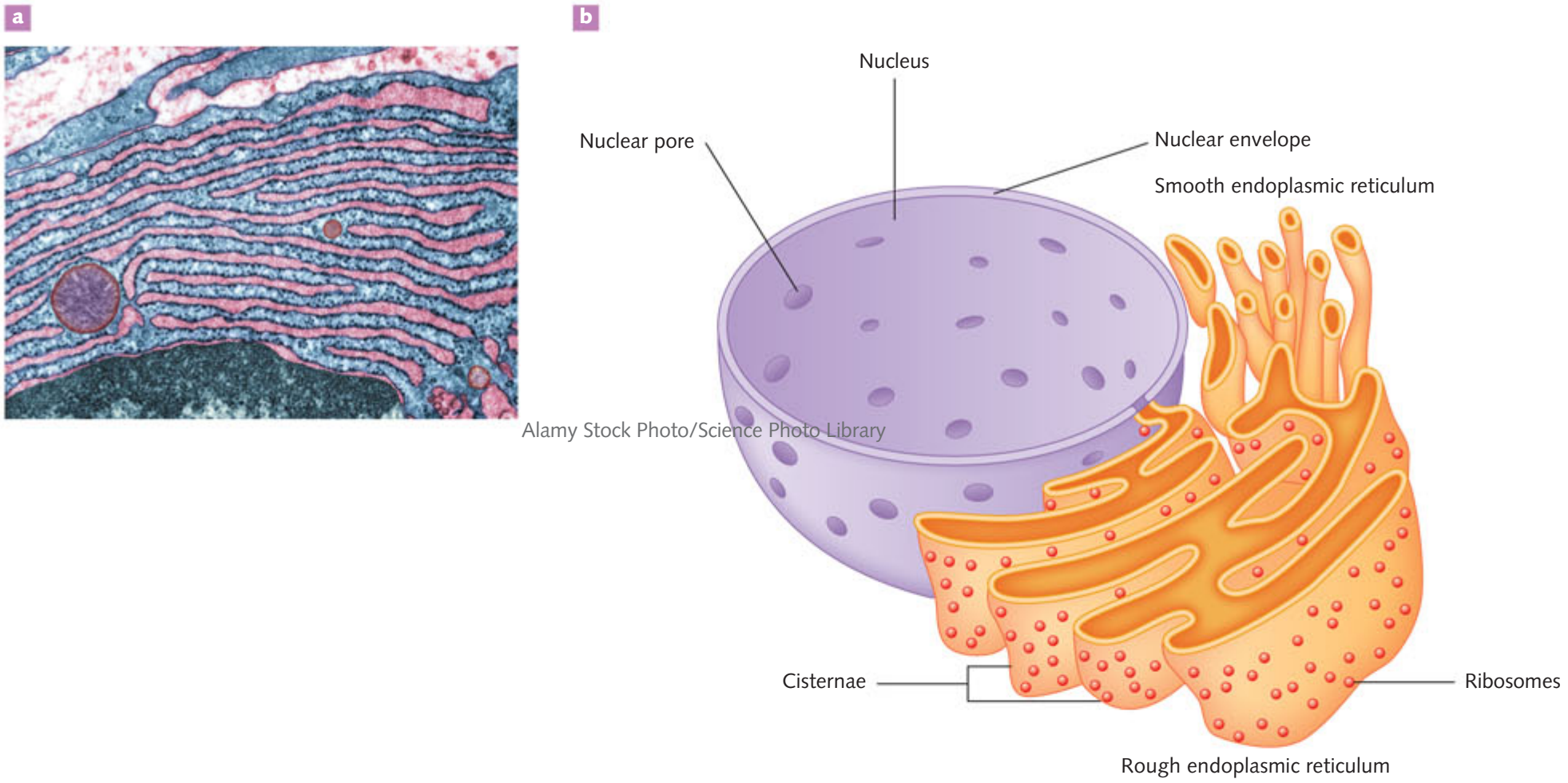

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Figure 1.18a Transmission electron micrograph (TEM) of rough endoplasmic reticulum studded with ribosomes **b** illustration showing endoplasmic reticulum in relation to the nucleus

Packaging and distribution: Golgi apparatus

The **Golgi apparatus** (also known as Golgi body) consists of a system of membranes within the cytoplasm. Parts of the Golgi apparatus membrane can pinch off into small vesicles (Figure 1.19). These vesicles move to the plasma membrane, where they join to the membrane and discharge their contents to the outside of the cell.

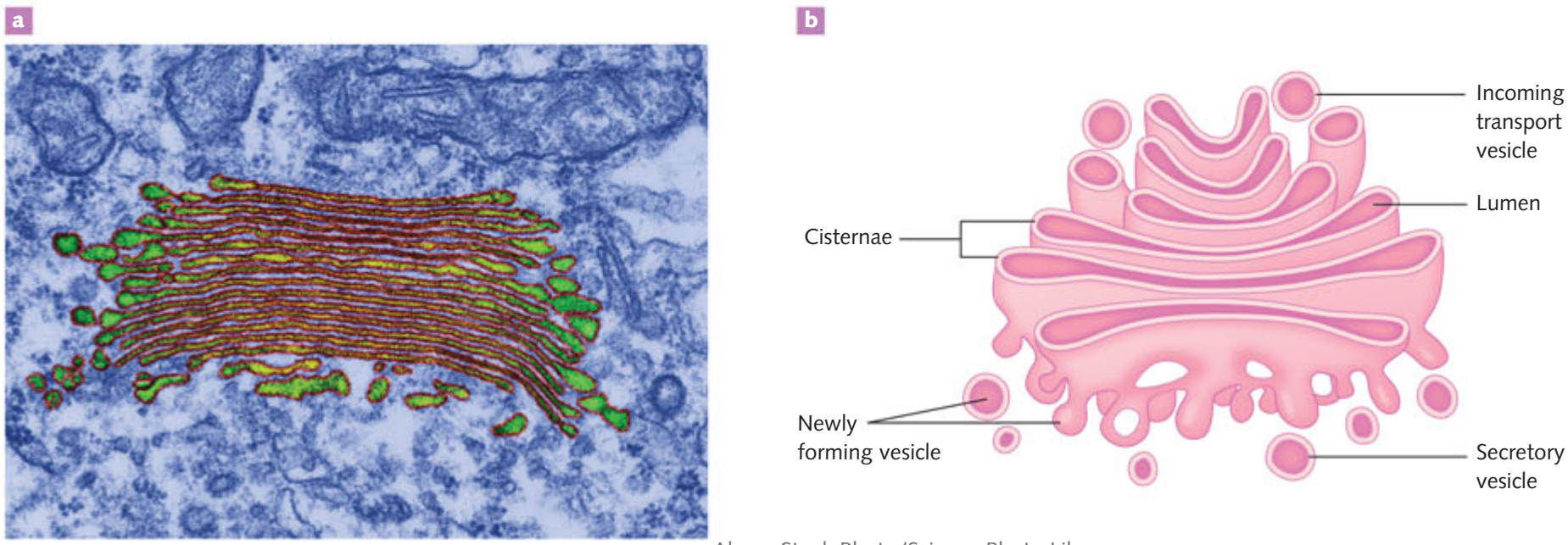

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Figure 1.19a Transmission electron micrograph of the Golgi apparatus **b** scientific illustration of the Golgi apparatus showing the ends pinched off into vesicles

Consider a grass-eating animal such as a kangaroo. The cells in grass have a tough outer cell wall. In order to be able to digest and absorb the nutrients from inside the grass cell, the cell wall must be broken down by enzymes. Cells in the digestive glands of the kangaroo produce such enzymes. **Enzymes** are types of proteins, and the digestive enzyme is produced initially by the ribosomes on the rough

endoplasmic reticulum. It moves through the channels within the endoplasmic reticulum where it buds off into a vesicle. The vesicle moves to the Golgi apparatus and fuses to it, releasing the vesicle contents into the Golgi apparatus. Different enzymes put the final touches to the digestive enzyme, and then it is packaged and stored before being secreted from the cell to move into the intestines of the kangaroo (Figure 1.20). This is where it can begin its work of digesting the cellulose in the cell wall of the grass.

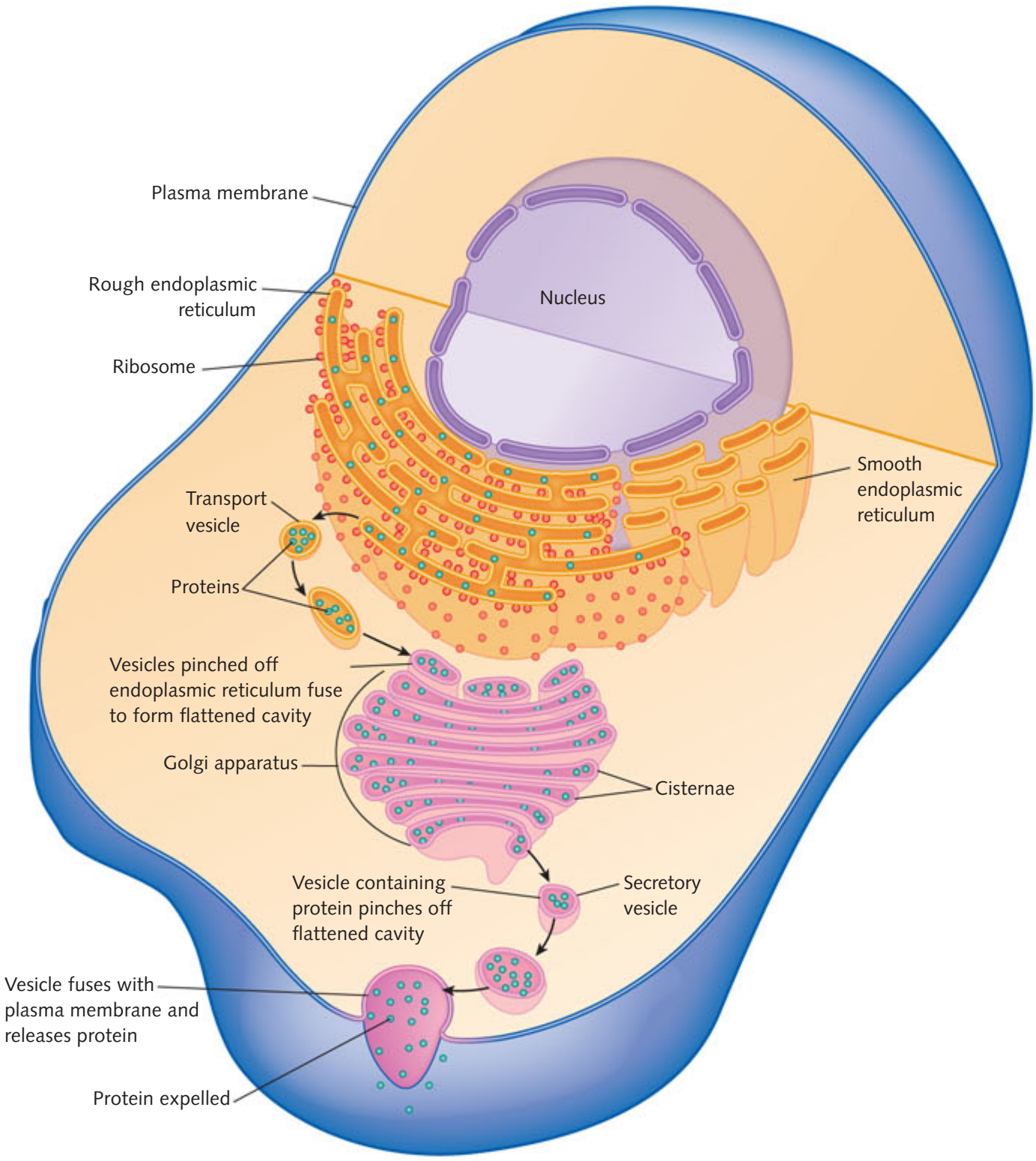


Figure 1.20 How the Golgi apparatus removes and secretes a protein from a cell

Weblink
Amoeba sisters
Watch the Amoeba sisters introduce the difference between prokaryotic cells and eukaryotic cells, the functions of the structures within each cell type and the basis of the cell theory.

Recycling and reuse: lysosomes

Inevitably, organelles within the cytoplasm of cells reach their 'use-by' date and wear out. Instead of wasting the raw materials that make up these organelles, the cell has a clever method of recycling and reuse. This is the job carried out by **lysosomes** ('lysis' = to break apart), another type of organelle found within the cytoplasm of animal cells. Lysosomes are formed by the Golgi apparatus. They are highly acidic and contain digestive enzymes that are responsible for splitting complex chemical compounds into simpler ones, such as when proteins are broken down into amino acids. These simpler compounds can then be used as building blocks for new compounds and organelles. Lysosomes can also digest substances brought into the cell from the external environment.

Online Worksheet
Introduction to cells: the grand cell tour

KEY CONCEPTS

- All cell types contain ribosomes, which build up amino acids into proteins.
- Some substances are moved around the cell in the endoplasmic reticulum.
- The Golgi apparatus packages and stores substances in vesicles in preparation for their release from the cell.
- Lysosomes are formed by the Golgi apparatus and contain digestive enzymes that break complex chemical compounds into simpler ones.

Concept questions 1.3b

1. State the function of ribosomes. Explain why you would expect to find more ribosomes in a cell that produces larger amounts of protein.
2. Describe the main roles of the endoplasmic reticulum.
3. Explain the role of the Golgi apparatus in the transport of materials out of the cell.
4. Vesicles are small transport sacs that can have multiple functions determined by where they are and what they are carrying. They are formed by 'pinching off' pieces of membrane. Both the endoplasmic reticulum and the Golgi apparatus can form vesicles. Compare these two types of vesicles in terms of where they form, what they carry, how they move around a cell and how they discharge their contents.
5. Do the rough endoplasmic reticulum and smooth endoplasmic reticulum perform the same functions? If not, how are they different in form and function?
6. Explain why lysosomes can be described as recyclers.

HOT Challenge

7. Which of the following biomolecules are not synthesised by the endoplasmic reticulum?
   - **a** proteins
   - **b** lipids
   - **c** nucleic acids
   - **d** cholesterol

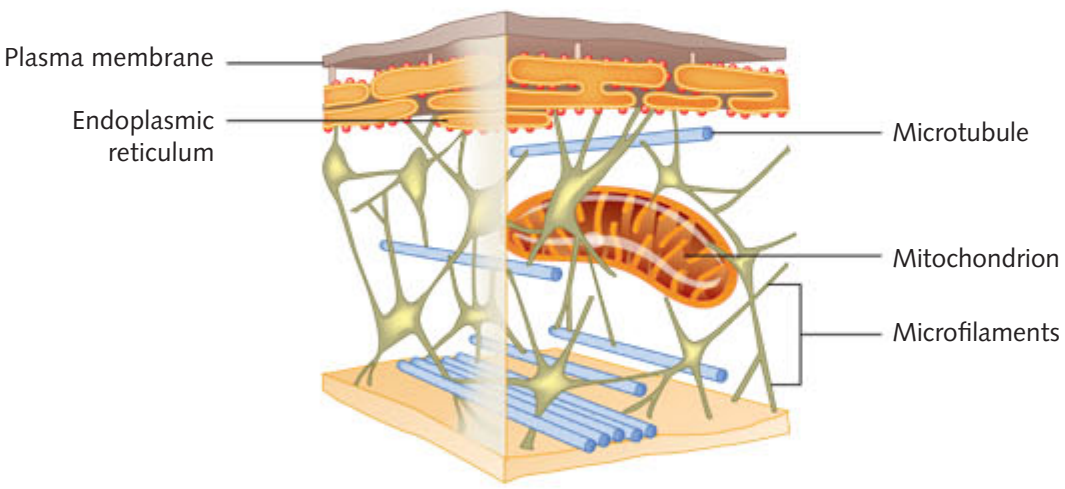


Figure 1.21 The cytoskeleton of a cell

Supporting cell structure: cytoskeleton

If a cell is essentially a fluid-filled sac, what stops it from being flattened, ruptured and squashed? This doesn't happen because eukaryotic cells have an internal skeletal structure called a **cytoskeleton**, as depicted in Figure 1.21. The cytoskeleton is a three-dimensional structure that occurs in the cytoplasm and provides shape to the cell. The 'bones' of the cytoskeleton are structures called **microtubules** and **microfilaments**, which are made of the proteins actin and tubulin.

Microtubules are hollow, cylindrical tubes approximately 20 **nanometres (nm)** in diameter. They act as a scaffold to determine cell shape. They also provide a set of 'rails' for the cell organelles to travel around the cytoplasm. This allows the constant mixing and movement of the cytoplasm known as **cytoplasmic streaming**. This can be seen in a living *Elodea* leaf under the light microscope. The **chloroplasts** can be seen to be slowly moving around the vacuole and other cell structures (see weblink) as they are carried along in the moving cytoplasm.

Weblink
Cytoplasmic streaming

Online Worksheet
Cytoplasmic streaming

One of the more remarkable properties of microtubules is the apparent ease with which they come apart and reassemble. They can be assembled in one part of the cell where they are needed, then taken apart and reassembled later in another part of the cell.

Animal cells contain two rod-like structures that are located at right angles to each other. These structures are called **centrioles**. One of the roles of centrioles is to organise and produce microtubules. Centrioles are very prominent in animal cells that are about to divide. They replicate to produce two pairs just before cell division begins. They give rise to the **spindle fibres**, collections of microtubules onto which chromosomes attach. When the spindle fibres contract during mitosis, the attached chromosomes can be moved around the cell.

Microfilaments are contractile proteins about a quarter of the diameter of microtubules. They are solid and not tubular. Like microtubules, they can be readily assembled and disassembled. They occur in bundles in the cytoplasm and when they contract they can cause the cell to change shape; this is especially apparent in the contraction of muscle cells.

Prokaryotic cells also contain a cytoskeleton which supports their shape and plays a role in binary fission. The cytoskeleton is made of proteins similar to the actin and tubulin found in the eukaryotic cytoskeleton.

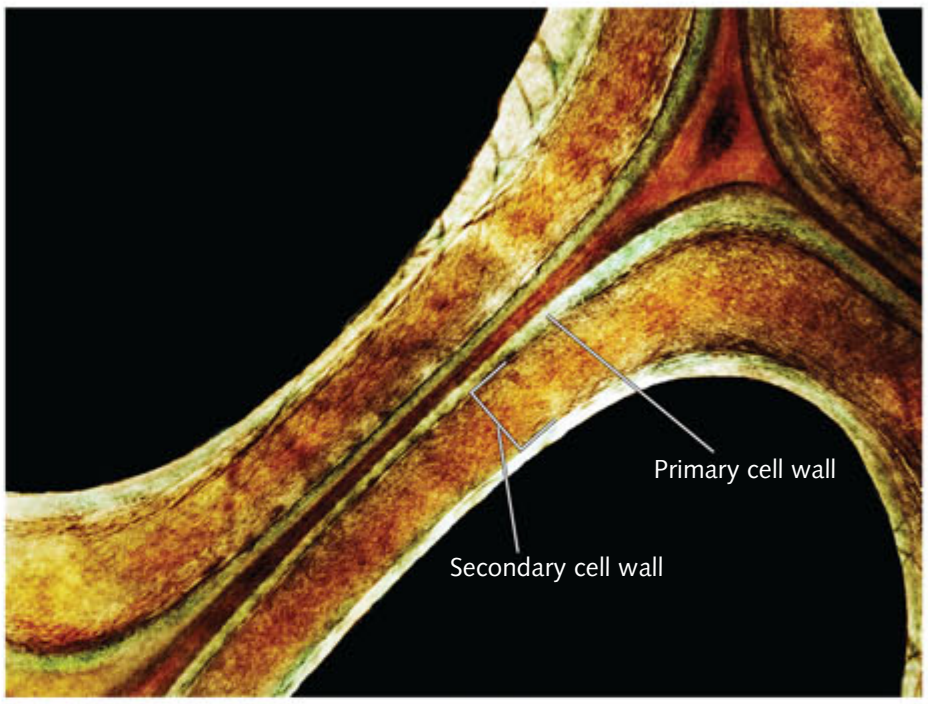
CONNECT

Binary fission and mitosis are discussed in Chapter 2.

Support and protection: cell walls

Animal cells are surrounded by a plasma membrane. The cells found in plants, bacteria, fungi and most algae have an additional external cell wall that surrounds the plasma membrane and provides extra support and protection to these cells.

The cell wall in plant cells is composed of **cellulose**, a complex carbohydrate molecule. Some cells have a single cell wall, known as a primary cell wall. If extra support is needed, very rigid additional or secondary cell walls can be found (Figure 1.22). A tree trunk has the function of supporting the whole leaf canopy of the tree. The cells that make up the tree trunk therefore have to be very strong. These cells have a plasma membrane, a primary cell wall and a secondary cell wall. As these cells age, they die and lose their contents and plasma membrane, leaving only the cell walls intact. This creates long tube-like cells (called xylem), ideal for carrying water from the roots to the leaves.



Science P

Figure 1.22 A plant cell of the Canadian yew showing the primary and secondary cell walls

Table 1.1 Comparison of organelles in eukaryotic cells and prokaryotic cells.

Feature	Eukaryotic cell	Prokaryotic cell
Membrane-bound nucleus	present	absent
Membrane-bound organelles	present	absent
Ribosomes	present	present
Cytoskeleton	present	present
Plasma membrane	present	present
Mitochondrion	present	absent

CONNECT

Water transport in plants is discussed further in Chapter 3.

Making and storing food: plastids

The Australian eucalypt is found in various forms across the continent. The majestic river red gum with its green-grey leaves lines the banks of the Murray River. The smaller, shiny green-leafed snow gum graces our Alps. The stunted red Mallee gum, so-called because of its newly grown red leaves, grows in scrub regions. Many eucalypts have spectacular flowers of red, pink, yellow or cream (Figure 1.23).

The colourful presentation of the leaves and flowers of these trees is caused by a group of organelles called **plastids**. Plastids are organelles that contain coloured pigments. The three general types of plastids are chromoplasts (red), leucoplasts (colourless) and chloroplasts, which will be discussed below.

Getty Im

Figure 1.23 Plastids are responsible for the flower colours of this eucalypt

Chloroplasts

Eucalypts, like all other plants, produce their own simple sugars through the chemical reactions that make up photosynthesis. **Photosynthesis** is the process by which plants convert light energy to chemical energy (sugars) to fuel cellular activities. The energy that they need to power photosynthesis comes from the Sun. How do plants utilise this energy source when it is so far away? Plants have leaves and sometimes stems whose cells contain chloroplasts. These are oval-shaped organelles containing green pigment called **chloroplasts**.

CONNECT

The process of photosynthesis is explained in detail in Unit 3 of this course.

Chlorophyll is able to absorb light energy and make it available for use in photosynthesis. Photosynthesis is a series of chemical reactions that occur in the **stroma** and **thylakoid membrane** system of the chloroplast (Figure 1.24). The internal thylakoid membranes of the chloroplast are folded many times to provide more surface area for chemical reactions of photosynthesis to occur. They are also associated with the enzymes necessary to speed up the chemical reactions involved.

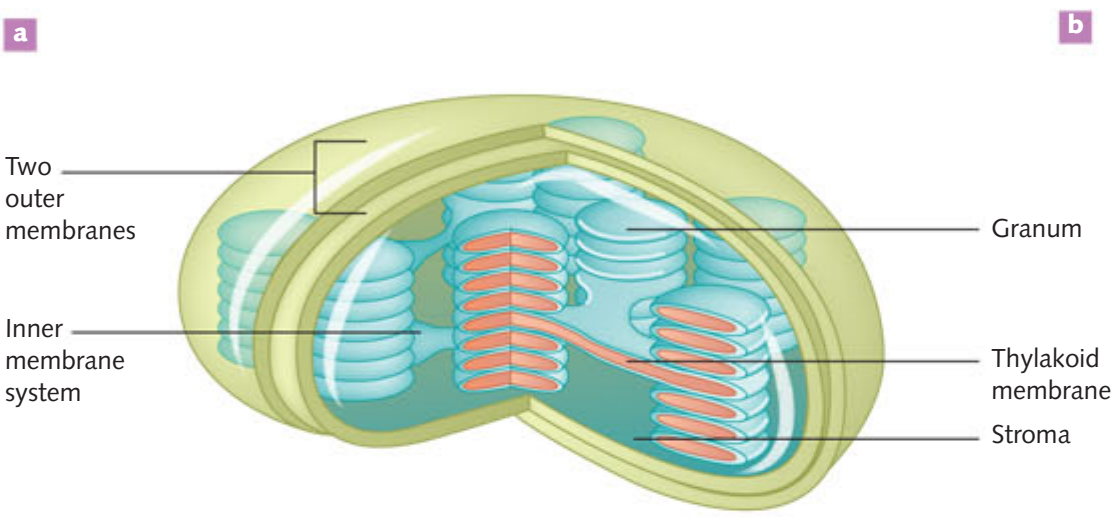


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Figure 1.24a Generalised sketch showing the grana and stroma of a chloroplast **b** False colour transmission electron micrograph of chloroplasts with a large starch granules (black) (magnification 5000×).

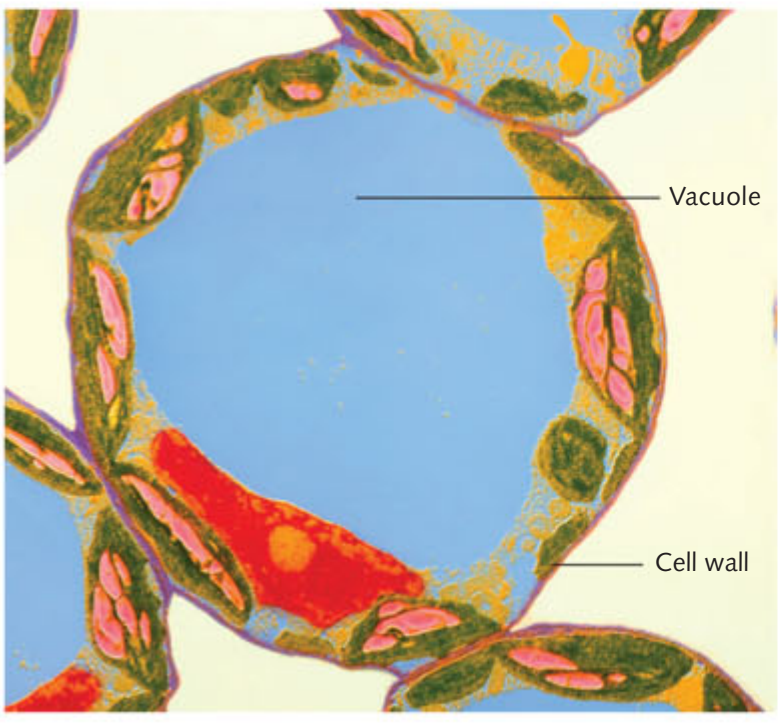

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Figure 1.25 Plant cell showing vacuole (in blue). Notice how the cell wall is extended.

Storing fluid: vacuoles

A large part of the cytoplasm in mature plant cells is composed of a fluid-filled space called a vacuole. The fluid in the vacuole serves as a storage space for sugars, minerals, proteins and water. The vacuole can expand, often taking up 50–90% of the volume of the cell. As the size of the vacuole increases, more and more pressure is exerted on the cell wall. This forces the flexible cell wall to bulge, thus increasing the size of the whole cell. As the size of the vacuole increases, the remaining cytoplasm becomes a narrow band between the plasma membrane and the vacuole, as shown in Figure 1.25.

Vacuoles are much more prominent in plant cells but animal cells contain numerous small vacuoles.

Table 1.2 Plant and animal cell organelles.

Organelle	Plant cell	Animal cell
Plasma membrane	✓	✓
Cytoplasm	✓	✓
Nucleus	✓	✓
Nucleolus	✓	✓
Mitochondria	✓	✓
Ribosome	✓	✓
Endoplasmic reticulum	✓	✓
Golgi apparatus	✓	✓
Lysosome	✓	✓
Cytoskeleton	✓	✓
Chloroplast	✓	✗
Large vacuole	✓	✗
Cell wall	✓	✗

KEY CONCEPTS

- The cytoskeleton provides shape to the cell.
- Microtubules and microfilaments are structures of the cytoskeleton.
- A cell wall, composed of cellulose, provides extra support and protection to some types of cells.
- Chloroplasts contain chlorophyll, a green pigment that absorbs light energy. They are the site for photosynthesis.
- The vacuole serves as a storage space for sugars, minerals, proteins and water.

Concept questions 1.3c

1 Name the components of the cytoskeleton and state what each component is made of.
2 Describe the function of the cell wall.
3 What is found inside a chloroplast?
4 Where are centrioles found and what is their function?

HOT Challenge

5 **a** Plastids in the main are found in plants and algae. The main function of chloroplasts is concerned with photosynthesis. What are the functions of chromoplasts and leucoplasts?
b Some marine molluscs live in an endosymbiotic relationship with algae. Why might this be useful, particularly to the marine molluscs?

1.4 Plasma membrane

The plasma membrane plays a vital role in the life of cells. Both the physical and chemical properties of the plasma membrane enable it to control the exchange of materials and messages. Many factors both within the cells and in their environment affect this sensitive balance.

In both multicellular and unicellular organisms, each cell is an independent unit enclosed by a plasma membrane. The plasma membrane forms the boundary between the **internal environment** of the cell, the cytoplasm and its **external environment**.

Animal cells are surrounded by a plasma membrane. Cells of plants, bacteria, fungi and most algae have a plasma membrane as well as a cell wall. The cell wall surrounds the plasma membrane and adds strength and support. The cell wall is **permeable**, allowing the passage of almost all materials. It is the **selectively permeable** plasma membrane that controls the movement of substances into and out of all cells.

Structure of the plasma membrane

WB 1.4.1 STRUCTURE OF PLASMA MEMBRANE PAGE 21

What makes up the plasma membrane to allow it to act as a regulatory boundary between the inside of the cell and the outside? How is material selected to move across the membrane? How does it reseal a puncture? To answer these questions, we need to look at the properties of the chemicals that make up the plasma membrane.

One remarkable property of the plasma membrane is its ability to change shape, expand and contract. During cell division and vesicle formation, the membrane can break and reassemble itself. This is because the membrane is actually a two-dimensional fluid, constantly flowing and changing shape. The plasma membrane and all membranes surrounding organelles within the cell are made up of many small phospholipid molecules and this gives the membrane great flexibility.

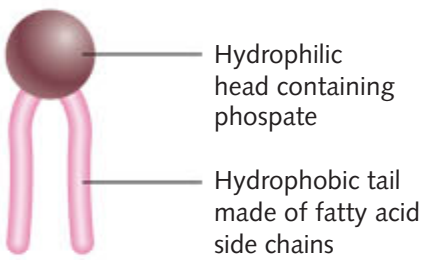


Figure 1.26 A phospholipid molecule. The hydrophilic head is attracted to water and the hydrophobic tails repel water.

The plasma membrane is composed of a double layer of **phospholipid** molecules, each of which can be represented by a head and two tails, as shown in Figure 1.26. The head is a **hydrophilic** (able to allow water soluble substances to move through) phosphate group and the tail is a **hydrophobic** (allowing water insoluble substances to pass through) fatty acid. This means that the head can remain in water, whereas the tails are repelled from the aqueous intracellular (internal) and **extracellular** (external to the cell) solutions. This forces them to face inwards towards each other, forming a **phospholipid bilayer** (Figure 1.27).

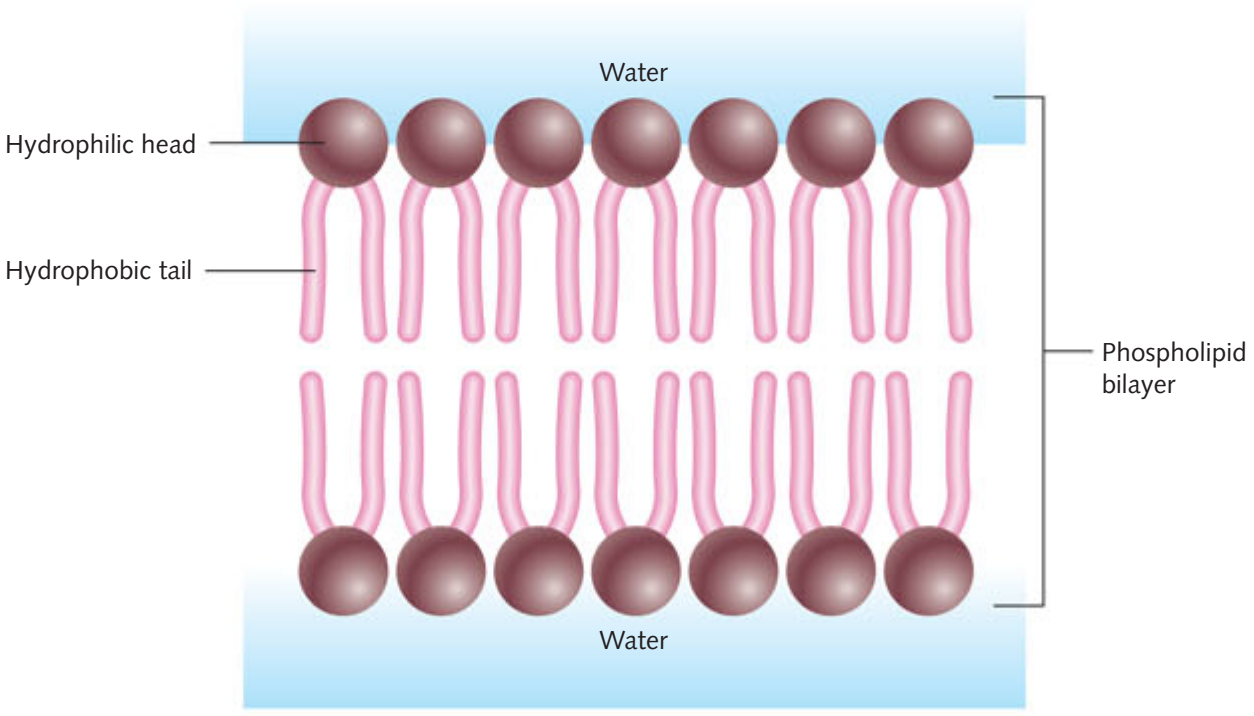


Figure 1.27 Representation of the way phospholipids form a bilayer in membranes

Individual phospholipid molecules are capable of sideways movement and are highly mobile within the membrane. The lipid bilayer of the membrane is like a liquid crystal, neither solid nor liquid. A single lipid molecule can travel rapidly from one place to another. For instance, one lipid molecule in a bacterium can move from one end to the other (approximately 3.5 μm) in a second. This feature gives the membrane important flexibility, allowing the cell to change shape easily and to expand and contract without losing integrity.

Specialised protein molecules are also embedded in the bilayer in various patterns, forming 'mosaics'. Some of these proteins can move laterally (sideways), but others are fixed in position. Proteins and lipids can also flip

around in the membrane. The structure of the plasma membrane can be understood by using a **fluid mosaic model** (Figure 1.28).

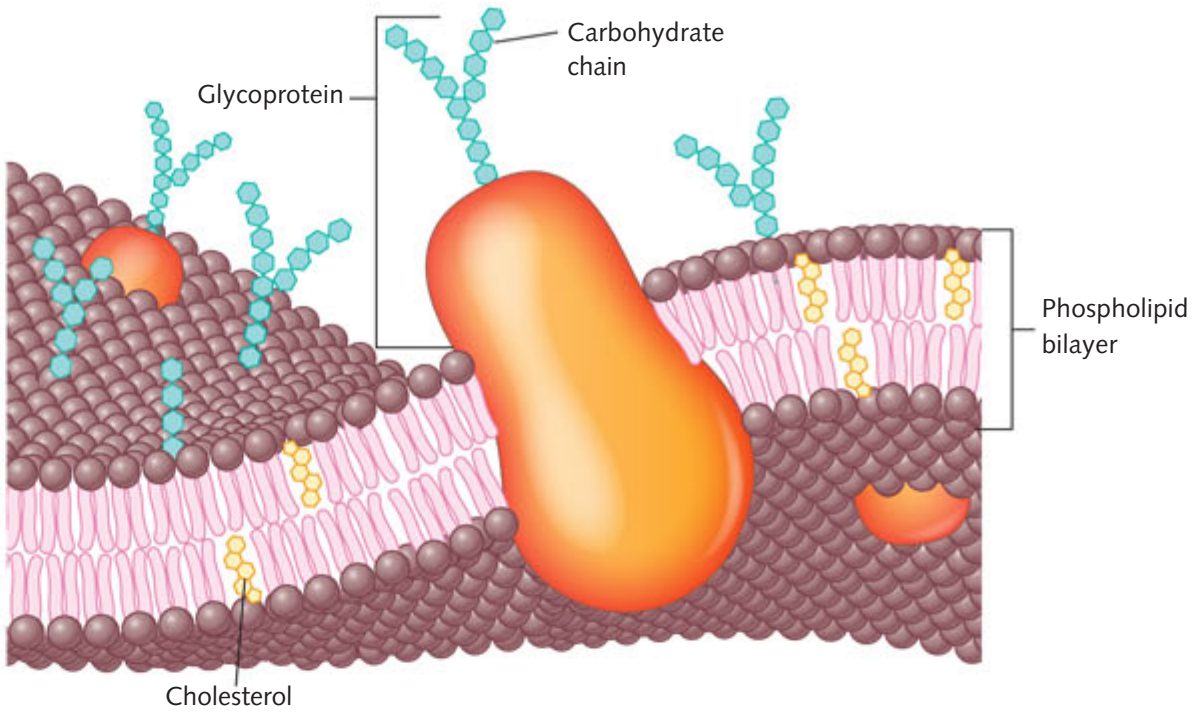


Figure 1.28 Three-dimensional view of a plasma membrane based on the fluid mosaic model

Sterols increase flexibility

Phospholipids alone do not provide the flexibility required in membranes. Strong inflexible bonds naturally form between the lipid tails. In animal cells, another type of lipid called **cholesterol** is interspersed among the phospholipid molecules. Cholesterol interferes with interactions between the lipid tails, making the membrane more flexible. In plants and bacteria, it is **phytosterol** (not cholesterol) that increases membrane flexibility.

Cholesterol has an interesting effect on membrane fluidity that depends on the temperature. At low temperatures, the phospholipid molecules in the membrane cluster together more closely because they do not have as much energy to move around. Fluidity is reduced because of this. When cholesterol is inserted between some of the phospholipid molecules, fluidity increases due to the greater distance between the molecules and their increased freedom of movement.

At high temperatures, there is more space between the phospholipid molecules because of their greater energy level. Fluidity is increased. When cholesterol is inserted between some of the phospholipid molecules in this case, the motion of the phospholipid molecule tails is reduced. This in turn decreases fluidity. Cholesterol therefore regulates plasma membrane fluidity and acts as a buffer against fluctuations in temperature.

Membrane proteins

Associated with each membrane is a set of membrane proteins that enable the membrane to carry out its distinctive activities. The types of proteins attached to a membrane vary depending on the cell type and its location. Even the two surfaces of the same bilayer, that is, the interior and exterior surfaces, differ considerably. There is also variety in the way proteins are associated with the membrane. Some proteins are bound only to the membrane surface whereas others are embedded in the phospholipid bilayer, with many penetrating from one side to the other (Figure 1.29). Different types of cells have different **receptor proteins**, enabling them to carry out different functions. The specific set of receptor proteins that a cell carries are determined by the genes the cell expresses – since receptors are proteins, they are genetically encoded. Surface proteins enable cell–cell interaction and communication and the exchange of substances with the external environment. Proteins on the external plasma membrane surface can be involved in signalling and communication between cells and can help to keep a cell anchored in its appropriate place. Proteins that span the membrane are called **transmembrane proteins** and they can regulate the movement of substances across the membrane.

Membrane proteins are essential for regulating cell behaviour and the organisation of cells in tissues. Proteins are also important for cellular communication. Some proteins, collectively called **receptors**, have receptor sites on their surface that detect molecules such as hormones. Each receptor is specific for a single molecule or a small number of molecules with a complementary structure to which the receptor binds.

Some membrane receptor proteins carry a carbohydrate molecule, giving them their collective name of **glycoproteins**. The addition of the carbohydrate group can give the receptor protein its particular function. It can also protect the protein core to increase the longevity of the protein in the rough extracellular environment.

Membrane **recognition protein** molecules act as markers that identify the cell as a normal body cell belonging to the individual. This is in contrast to a cell that has become cancerous, belongs to an invading microorganism, or a transplant from an unrelated individual. In multicellular organisms, **adhesion proteins** link cells together to maintain both the three-dimensional structure and the normal functioning of tissues. Most adhesion proteins are distributed uniformly along the plasma membranes that contact other cells.

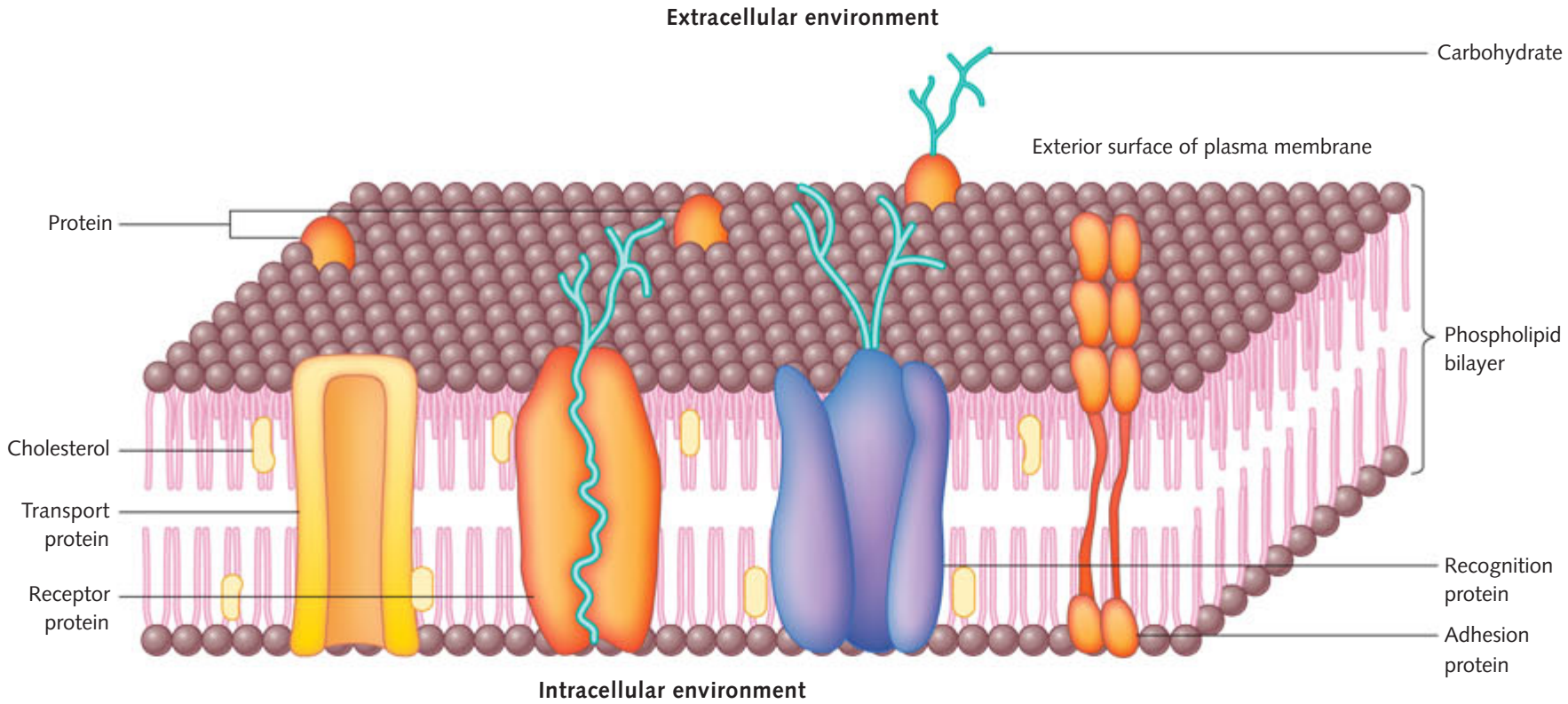


Figure 1.29 Examples of proteins associated with plasma membranes

SOUTHERN Biological Stress-tested by Southern Biological

INVESTIGATION 1.2

Modelling the fluid mosaic membrane

Models are useful in science if they simplify a concept or make a visual representation of something that is difficult to see.

Aim

To model the structure and function of the fluid mosaic model of the plasma membrane

Materials

Structure

- Rectangular cake or polystyrene block approx. 20 cm × 10 cm × 10 cm
- Knife
- Icing sugar/food colouring or fondant or buttercream
- Marshmallows
- Liquorice or modelling chocolate
- Selection of lollies
- Labels/toothpicks

Function

- 2 tea strainers
- Icing sugar
- Lollies (such as M&Ms)
- Elastic band
- Coloured paper
- Salt
- Sugar granules
- Tea leaves

What are the risks in doing this investigation?	How can you manage these risks to stay safe?
Knife has a sharp blade and can cut fingers.	Use the knife with care and keep fingers away from the sharp edge.
Science laboratory benches usually have chemicals on them that could harm you.	Do not eat the cake if you are working in the laboratory. If you want to eat the cake after you have made the model, work in a food preparation area.

Method

Structure

1 Trim the cake or polystyrene block to approximately the suggested size.
2 Using fondant/icing, completely coat the surface of the cake or block.
3 Place marshmallows to completely cover the top surface of the cake or block.
4 Place one line of marshmallows along the bottom of all sides of the cake, aligned with the marshmallows on the top edge of the cake.
5 Using liquorice or modelling chocolate, make 'tails'. Stick two of these tails onto the side of the cake leading from each marshmallow to the mid-line.
6 Using modelling chocolate or lollies, construct 'proteins' that penetrate the whole plasma membrane layer, and those that are only partially embedded in the membrane.
7 Attach lollies/modelling chocolate to some of these 'proteins' to represent the glycoproteins.
8 Use lollies/modelling chocolate to represent cholesterol/phytosterols.
9 Attach labels to all parts of the model using the toothpicks and labels.

Function

10 Place two teaspoons of icing sugar and two teaspoons of lollies into one of the tea strainers.
11 Tie the handles of the tea strainers together with the elastic band.
12 Shake the tea strainer over a piece of coloured paper.
13 Copy the table below and record which substances pass through.
14 Repeat this process using a variety of other substances (those on the material list or others).

Results

Structure

1 Draw a diagram or take a photo of your model.
2 Copy the tables into your logbook and complete them to indicate what each part of your model represents in the fluid mosaic model. Add more rows as required.

Structure in fluid mosaic model	Representation in your model
Phospholipid	

Function

Substances in mixture	Substances that passed through holes in tea strainer
Icing sugar and lollies	

Discussion

In terms of structure and function

1 Outline the purpose of your model.
2 What are the benefits of your model of the fluid mosaic model of the plasma membrane?
3 Discuss the limitations of your model.
4 Justify the validity of your model. See page 197 for a discussion of validity.

Conclusion

How did modelling the fluid mosaic model in this way give you a greater understanding of its structure and function?

KEY CONCEPTS

- The plasma membrane forms the boundary between the internal environment of the cell and its external environment.
- The plasma membrane is selectively permeable in that it controls the movement of substances into and out of cells.
- The plasma membrane is composed of a double layer of phospholipid molecules. The head is hydrophilic and the tail is hydrophobic.
- The structure of the plasma membrane can be understood by using a fluid mosaic model.
- Embedded in the plasma membrane are a variety of membrane proteins that enable the membrane to carry out its distinctive activities.
- Membrane proteins allow cells to function appropriately, respond to chemical messages and recognise each other.

Concept questions 1.4

1 Distinguish between permeable and selectively permeable.
2 List the components of the plasma membrane.
3 Explain why unicellular organisms are more likely to experience bigger changes in their external environment than are cells in multicellular organisms.
4 What is the difference between 'hydrophilic' and 'hydrophobic'?
5 The fluid mosaic model of the plasma membrane of a cell depicts a phospholipid bilayer with transmembrane proteins, glycoproteins, receptor proteins and cholesterol molecules within it. Describe the general structure and function of each of these components.

HOT Challenge

6 Polar charged particles are able to move through hydrophilic parts of the plasma membrane but do not move easily through hydrophobic parts of the membrane. Explain why.

1.5 Passive movement across membranes

Some materials can move across membranes without using energy but others require energy to move.

Movement that does not require energy is called **passive transport**. A simple analogy is riding a bicycle. Riding uphill requires you to use energy in your leg muscles to pedal hard. You are actively pedalling. Once you are at the top, you can move passively down the hill, without using any energy to move the pedals. Many molecules move across the plasma membrane passively, without using energy. This type of movement relies on a process called diffusion.

Diffusion

WB 1.5.1 DIFFUSION PAGE 22

Why does a spoonful of sugar dissolve rapidly in a cup of tea, even when it is not stirred? Why can you smell gas escaping from a gas stovetop? Part of the reason is that the particles of sugar and gas are constantly moving in a process called Brownian motion.

If you were to drop a crystal of potassium permanganate ($KMnO_4$) into a beaker of water, and you did not stir or move the beaker, what would happen? You will find that, over time, the purple colour of the permanganate spreads through the water until eventually it is evenly distributed. As the crystal dissolves, the potassium and the permanganate particles separate from the crystal and move through the water (Figure 1.30).

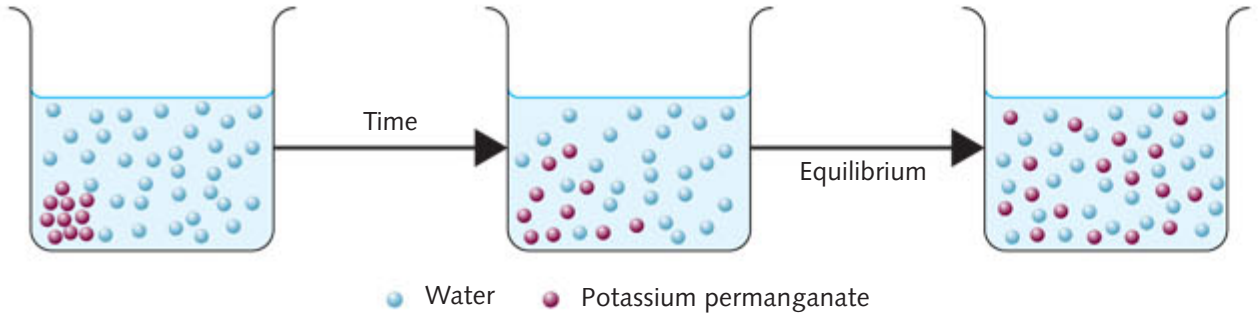


Figure 1.30 Diffusion of potassium permanganate in water over a period of time

What causes the particles in the potassium permanganate crystal to behave in this way? The particles

dissolving from the crystal are in a state of continual random motion. They can move in any direction. To start with, there are far more of them near the crystal, increasing the probability that they will move away from the crystal. This causes a net (overall) movement of potassium permanganate particles away from the crystal. This is the process of diffusion.

Diffusion is the net movement of particles from a region of high particle concentration (the crystal of potassium permanganate) to a region of lower particle concentration (the water in the beaker). The difference in particle concentration between the two regions is called the **concentration gradient**. Diffusion always takes place wherever such a gradient exists and it continues until the particles are distributed evenly throughout the system. When that happens, **equilibrium** is said to be reached. Particles will continue to move randomly, but at equilibrium they move at equal rates in all directions.

Diffusion is a passive process and does not require additional energy to make it happen. It takes place in gases and liquids, in both living and non-living systems. Increasing the concentration gradient or heating the particles to make them move faster will increase the rate of diffusion. The particle theory (also referred to as the kinetic theory of matter) says that the particles that make up matter are in constant motion and the higher the temperature, the faster the particles are moving.

ACTIVITY 1.2

Observing diffusion

Aim

To explore the movement of particles within a liquid

You will need

- A glass jar or tall beaker
- Warm water
- Tea bag
- Stirring rod

What to do

1. Fill the beaker with warm water. Let it sit for 5 minutes.
2. Tie a tea bag to the stirring rod and place the rod across the top of the beaker. Place the tea bag so that it enters the water with minimal disturbance.
3. Record the changes you observe in the water over the next 10 minutes.

What did you discover?

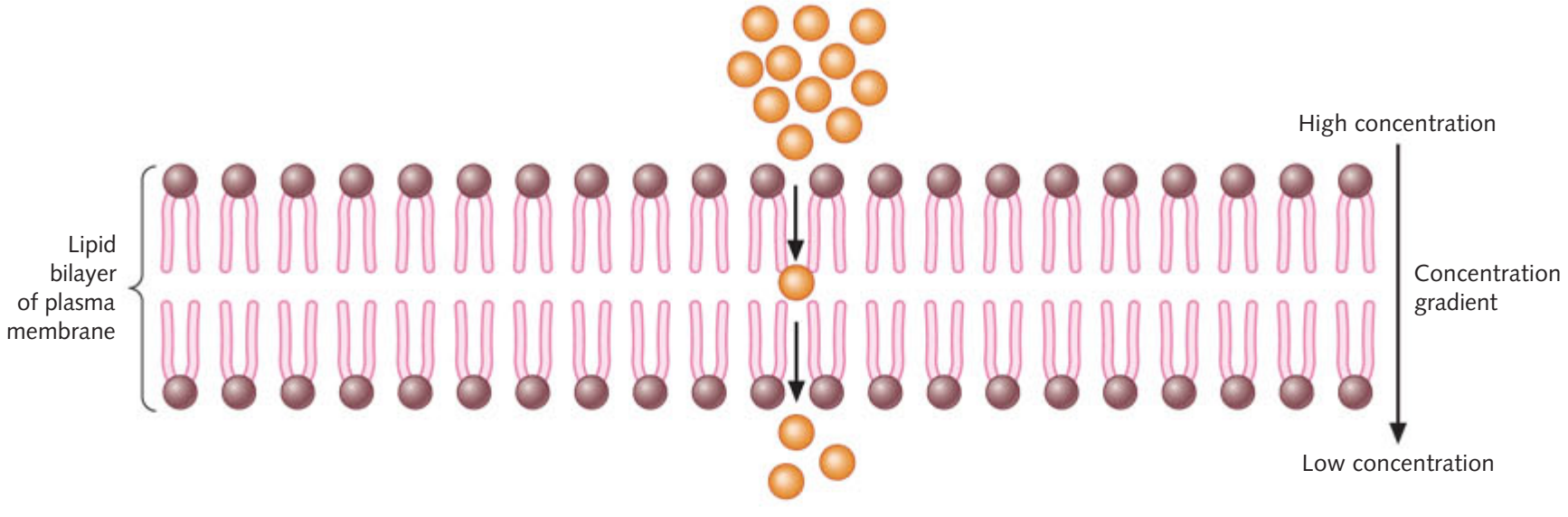
1. Describe the change in colour of the water over the 10 minutes.
2. Explain your observations, ensuring you use the term ‘concentration gradient’.

Extension

Predict what difference you would observe with hot and cold water rather than warm water. If you have time, test this prediction.

Diffusion across membranes

Hydrophobic molecules such as oxygen and carbon dioxide and other small, uncharged particles such as water move easily through the plasma membrane of a cell by simple diffusion. Figure 1.31 shows these particles passing between the phospholipid molecules from a high to a low concentration. Oxygen always tends to diffuse into cells because their use of oxygen in cellular respiration maintains a low concentration in the cytoplasm.



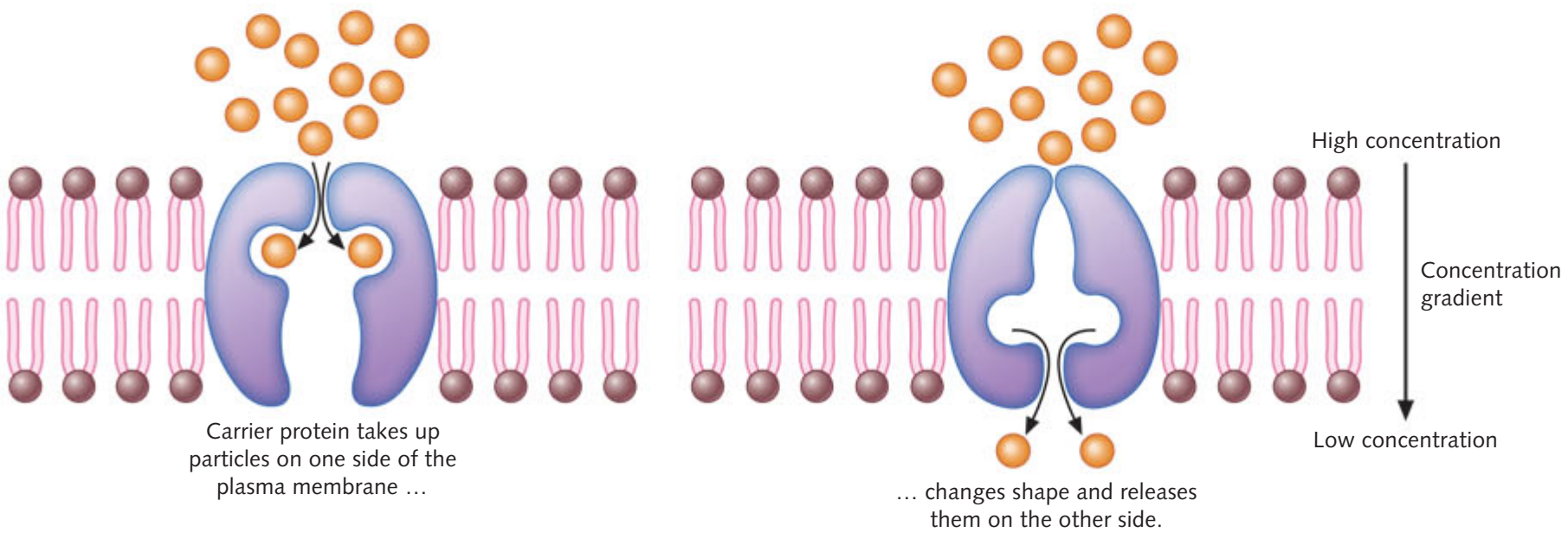
Robertis, M. & Biology W. (2003)

Figure 1.31 **Simple diffusion of small molecules through the plasma membrane is dependent on the concentration gradient.**

Facilitated diffusion

Charged particles (such as sodium (+) and chloride (–) ions) and relatively large molecules (such as glucose and amino acids) are repelled by the hydrophobic tails and so do not pass through the phospholipid bilayer readily. There must be some way to help them enter the cell. In the plasma membrane, certain proteins shield these materials from the repulsive force of the hydrophobic tails and assist such particles to diffuse into the cell. This process is called **facilitated diffusion** .

Two types of protein are involved in facilitated diffusion: **carrier proteins** and **channel proteins**. Carrier proteins bind to specific molecules on one side of the membrane, change shape and release the substance on the other side (Figure 1.32). An example is the glucose transporter protein, which is located in the plasma membrane of all mammalian cell types and carries glucose in either direction, depending on the direction of the concentration gradient.



Robertis, M. & Biology W. (2003)

Figure 1.32 **Facilitated diffusion using a carrier protein in the plasma membrane of a cell moves particles such as glucose down the concentration gradient.**

Channel proteins form narrow passageways through which water-soluble substances diffuse rapidly from an area of high concentration to a lower concentration (Figure 1.33). The inner boundaries of the protein channel contain layers of water so that larger water-soluble (hydrophilic) substances are able to move rapidly into the cell by passive means. Only ions of a specific size and shape can pass through a particular channel protein.

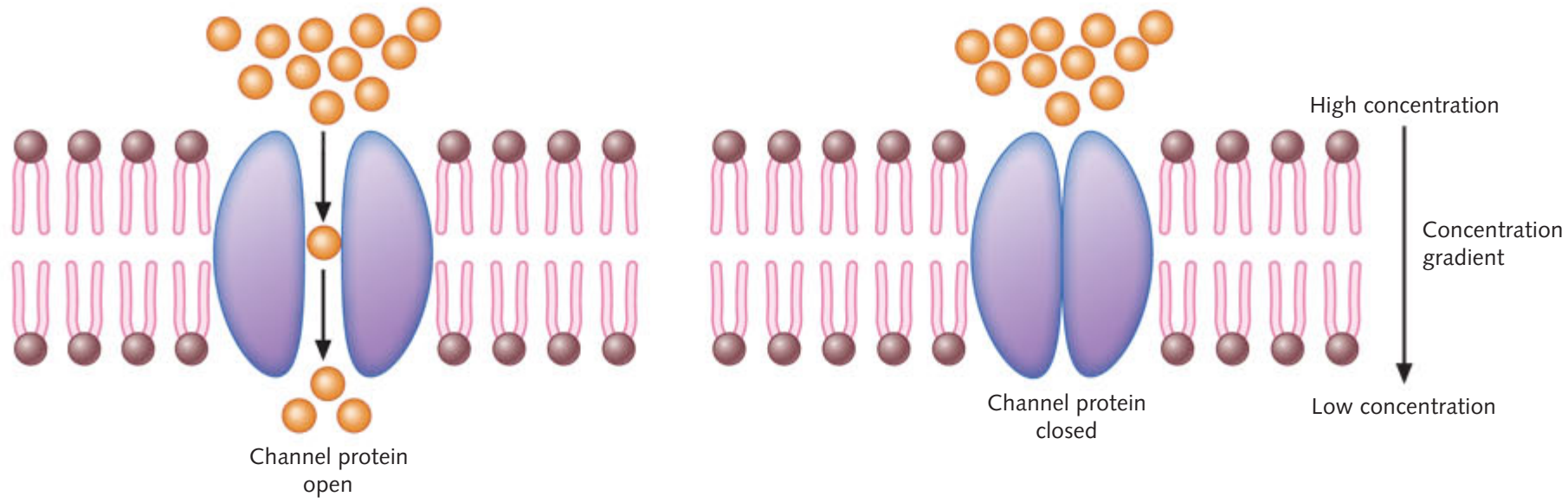


Figure 1.33 Facilitated diffusion through a channel protein in the plasma membrane of a cell. Movement is always down the concentration gradient.

KEY CONCEPTS

- Diffusion is the movement of particles down a concentration gradient, from where they are in high concentration to where they are in low concentration until equilibrium is reached.
- Diffusion is a passive process.
- The greater the concentration gradient of a substance across a membrane, the faster it will diffuse.
- Carrier proteins and channel proteins assist particles to diffuse into a cell. This process is called facilitated diffusion.

Concept questions 1.5a

1. Define diffusion.
2. List two factors that increase the rate of diffusion.
3. Explain how carrier proteins and channel proteins assist in facilitated diffusion.
4. Simple diffusion and facilitated diffusion are described as passive forms of cellular transport. What does the term 'passive' mean in this context?
5. Why is facilitated diffusion faster than simple diffusion when solute concentration is low?

HOT Challenge

6. It was once thought that water molecules simply passed through plasma membranes easily via diffusion (a special type of diffusion called osmosis) because they were small in size. However, although osmosis is important it does not account for the rapid and large amount of water movement into and out of cells during various processes. Protein channels called aquaporins are now known to facilitate the passage of water molecules. Research how this rapid water diffusion works.

Osmosis: a special type of diffusion

WB 1.5.2 OSMOSIS: A SPECIAL TYPE OF DIFFUSION PAGE 24

Without water, no life can survive, although some organisms can survive with very little water for longer than others. Water is the medium in which biochemical processes take place. Water also transports materials in **solution**, helps keep cells in shape and forms the fluid that bathes tissues. Water is described as the universal **solvent**, in that it dissolves most substances. If you add sugar or salt to water, you are adding **solute** to solvent and making a solution. A dilute solution has a relatively high concentration of water molecules (solvent) compared to solute particles dissolved in it, while a concentrated solution has a low concentration of solvent molecules and a high concentration of solute particles (Figure 1.34).

Plasma membranes are selectively (or differentially) permeable, meaning that water molecules pass through them easily but solutes do not. If the concentration of water molecules inside a cell is lower than the concentration outside, more water will diffuse into the cell than leave the cell until a balance or equilibrium is reached (net movement of water is into the cell). This process is called **osmosis**. By

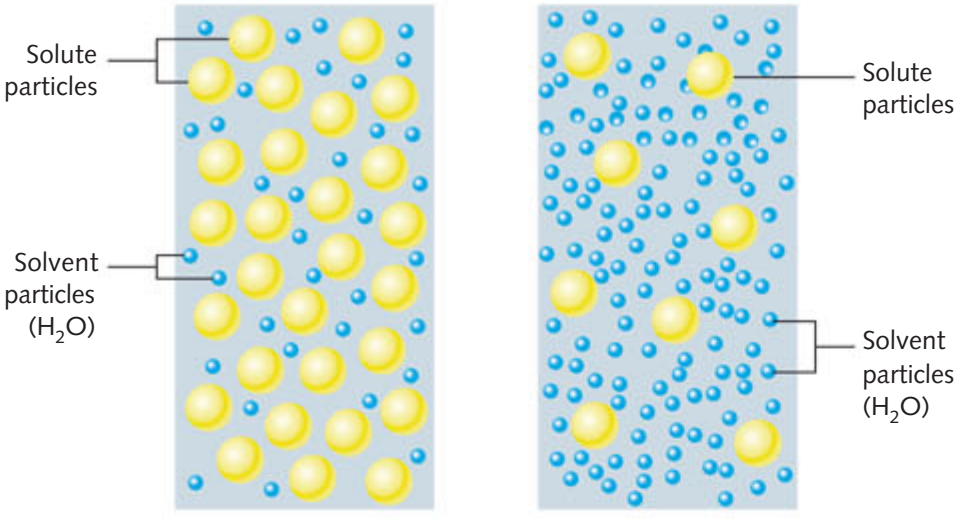


Figure 1.34 Making solutions: **a** a concentrated solution and **b** a dilute solution

definition, osmosis is the diffusion of water (or the movement of the solvent) across a selectively permeable membrane from an area of high water concentration (low solute) to an area of low water concentration (high solute). Osmosis is a special type of diffusion. Similar to diffusion, osmosis requires no input of energy because water is moving down its concentration gradient (Figure 1.35).

If the fluids inside and outside a cell are of equal solute concentration, the external solution is said to be **isotonic** ('iso' = same) to the cells; water molecules jostle on both sides of the membrane, moving in both directions equally. When cells are surrounded by a solution that contains a lower solute concentration than their cytoplasm, the external solution is said to be **hypotonic** ('hypo' = lower) to the cells. Water molecules will move by osmosis through the membrane into the cells. The reverse applies if the cells are surrounded by a solution of higher solute concentration; the external solution is **hypertonic** ('hyper' = higher) to the cells and so water molecules will move by osmosis out of the cells.

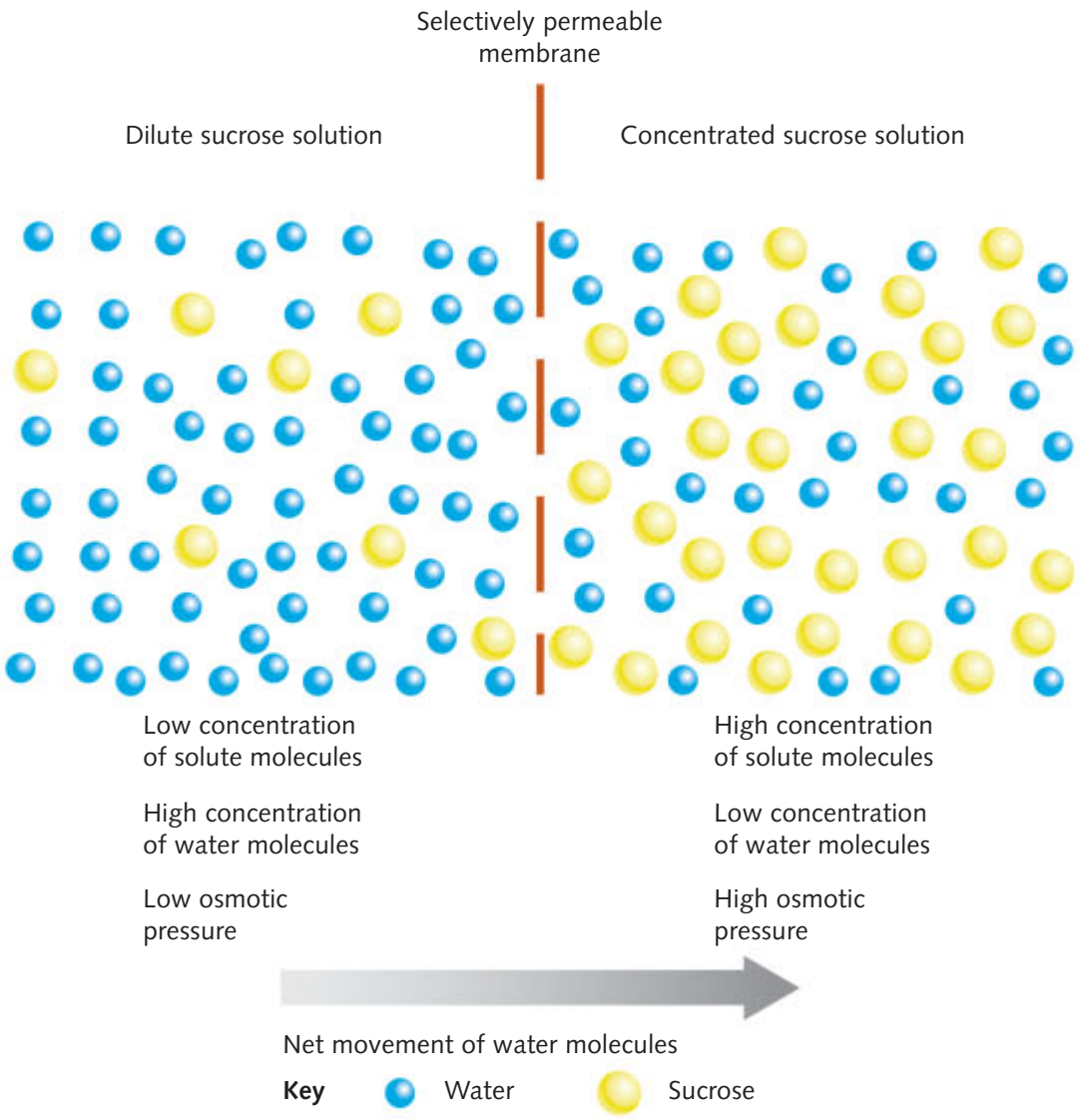


Figure 1.35 Summary of the conditions on the two sides of a selectively permeable membrane

Osmosis in animal cells

The cells of unicellular eukaryotes and multicellular organisms such as animals are surrounded by only a plasma membrane. Hypotonic solutions, such as fresh water, pose a special problem for these organisms. Water moving through the fluid plasma membrane into their cells by osmosis could cause

the cells to swell and eventually burst or lyse, killing the organism. Unicellular organisms such as *Amoeba* that live in fresh water have important regulatory mechanisms to combat these problems. They can remove excess water by forming pools of water in cytoplasmic organelles called **contractile vacoule** (Figure 1.36). When these vacuoles stretch to a certain point, they contract and expel the water to the external environment.

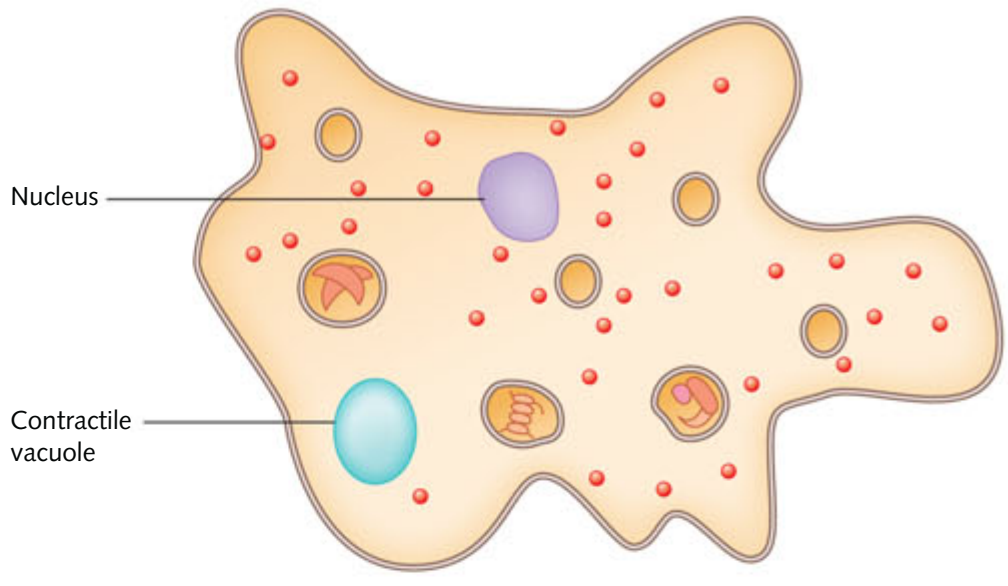


Figure 1.36 **Amoebas are able to remove fresh water using organelles called contractile vacuoles.**

In multicellular animals, cells are bathed in isotonic extracellular fluid. This means that cells can function efficiently because water diffuses equally in both directions, resulting in no net movement of water into or out of cells. To keep the internal environment of your body in isotonic balance, the solute concentration in the extracellular fluid is controlled by the concentration of solutes in blood plasma, which in turn is controlled by the kidneys.

You may have been in hospital and seen patients hooked up to an intravenous drip. This drip is connected directly to their circulatory system, adding fluid to their blood plasma. It is important that fluid in the drip has a solute concentration equal to blood plasma (isotonic). In this situation, water will enter and leave blood cells at the same rate, maintaining their ideal water concentration.

What will happen if the intravenous drip contains salty water? If the plasma surrounding blood cells becomes hypertonic, water will move out of the cells by osmosis and, in a process called **crenation** , they will shrink and become crinkled (Figure 1.37). The resulting small, shrunken blood cells tend to stick together, clogging small veins and arteries, and preventing oxygen reaching body tissues. If enough blockages occur, the results may be fatal.

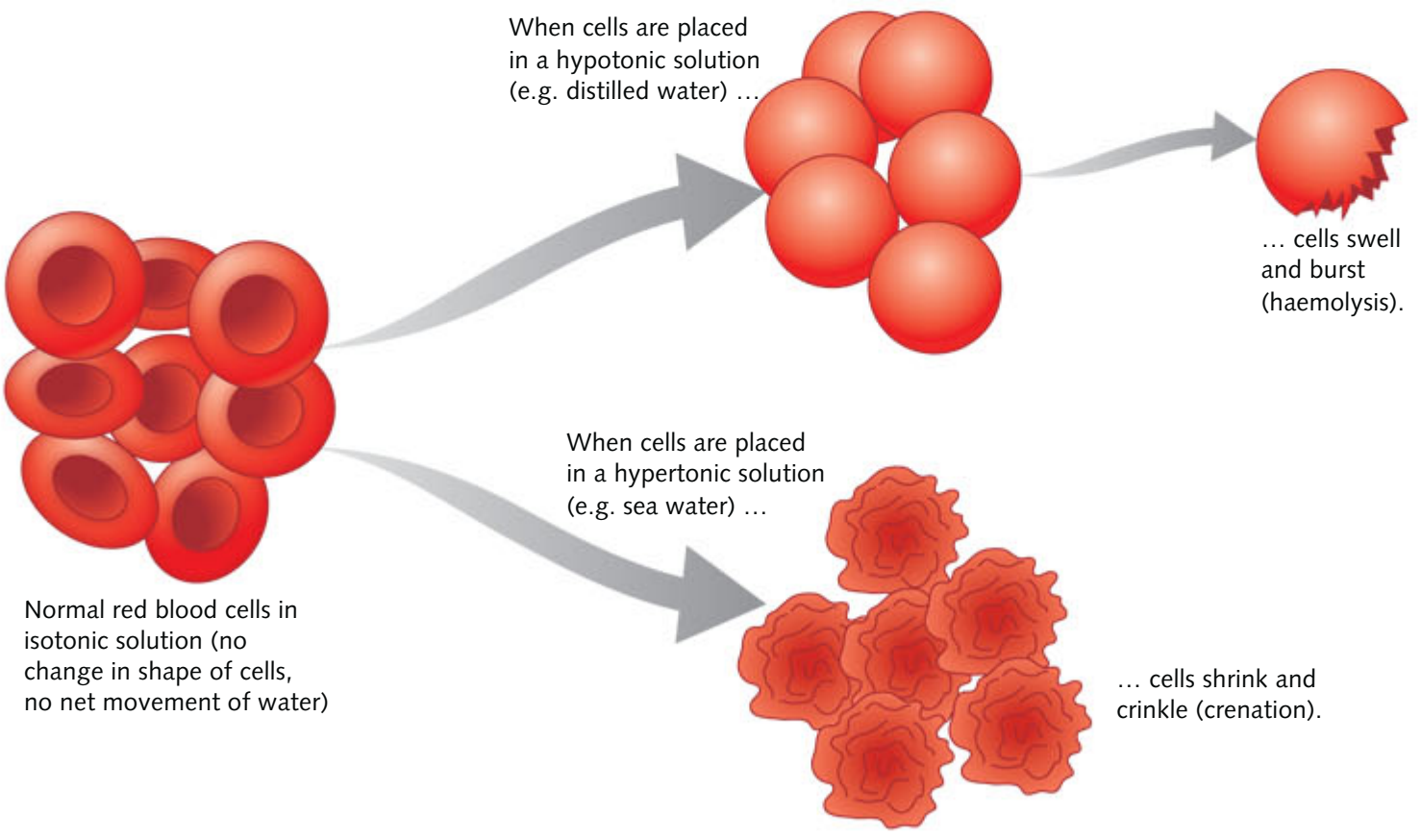


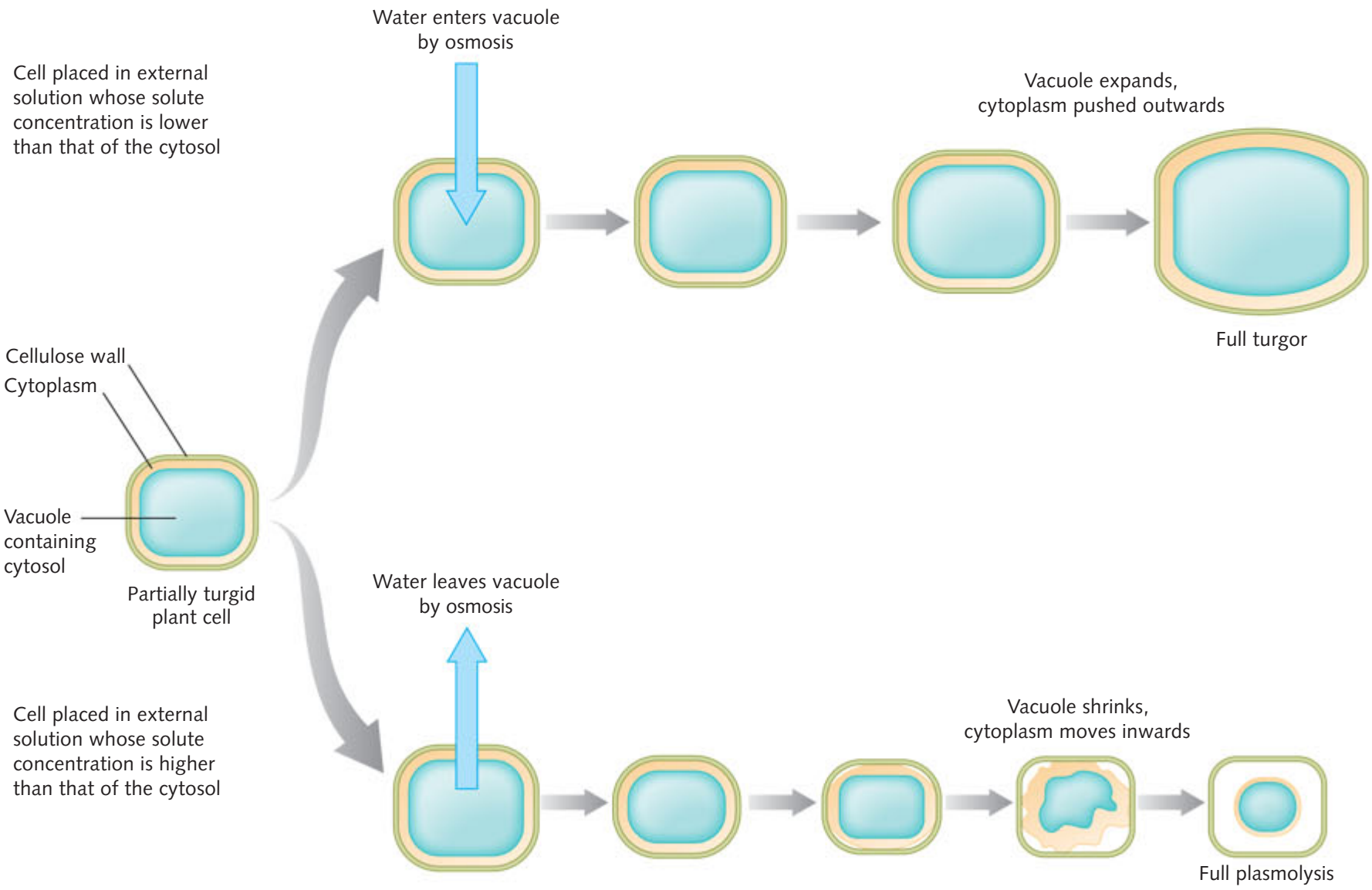
Figure 1.37 **Human red blood cells swell or shrink in solutions of varying solute concentrations.**

It is equally dangerous for an intravenous solution to be hypotonic. If the blood plasma is diluted by water, the blood cells will swell and burst. This condition is called **haemolysis** and it can seriously reduce the amount of oxygen being transported to body tissues. Because of these effects of osmosis on animal cells, it is important that the solute concentration of blood plasma is regulated by the kidneys (Chapter 3).

Osmosis in plants

Did you know that soaking limp vegetables like celery in water restores their crispness? Unlike animal cells, the celery cells will not burst when soaked in fresh water (hypotonic solution), even though water moves into the plant by osmosis. How can you explain this difference?

Think about the differences in plant and animal cell structure. Animal cells lack cell walls and rarely contain large vacuoles. Plant cells commonly have large, fluid-filled vacuoles and firm but permeable cell walls that surround the plasma membrane. Like the plasma membrane, the vacuole membrane (**tonoplast**) is differentially permeable. Plant cell vacuoles contain fluid that is rich in solutes: a solution of high concentration. When a hypotonic solution surrounds a plant cell, water molecules diffuse by osmosis, first into the cytoplasm and then into the vacuole. The vacuole swells, pushing the cytoplasm and plasma membrane against the cell wall. The tough cell wall prevents the cell from bursting. When the cell wall stretches as much as possible, no more water can enter and the cell is said to be **turgid** (Figure 1.38).



Roberts, M., Reiss, M

Figure 1.38 The effect of immersing a partially turgid plant cell in pure water and a high solute concentration.

Turgor is very important for plants. It supports them and maintains their shape and form. The stems of non-woody plants are kept erect by the turgid, tightly packed cells that fill them. Turgor is also responsible for holding leaves in a flat, opened-out position. Certain plant cells are able to undergo quite rapid changes in their solute concentration with consequent changes in turgor. This allows such cells to change their shape. Stomatal guard cells behave this way (Chapter 4), as do cells responsible for the rapid leaf movements of insectivorous plants such as the Venus flytrap.

On a hot, dry day, you may see some plants wilting. When significant quantities of water evaporate from the plant, the external concentration of water molecules becomes less than in the vacuole. Water molecules diffuse out, reducing the volume of the vacuole and causing the cells to become limp or **flaccid** and the plant to wilt. If enough water is lost, the plasma membrane pulls away from the cell wall in a process called **plasmolysis** (Figure 1.39).

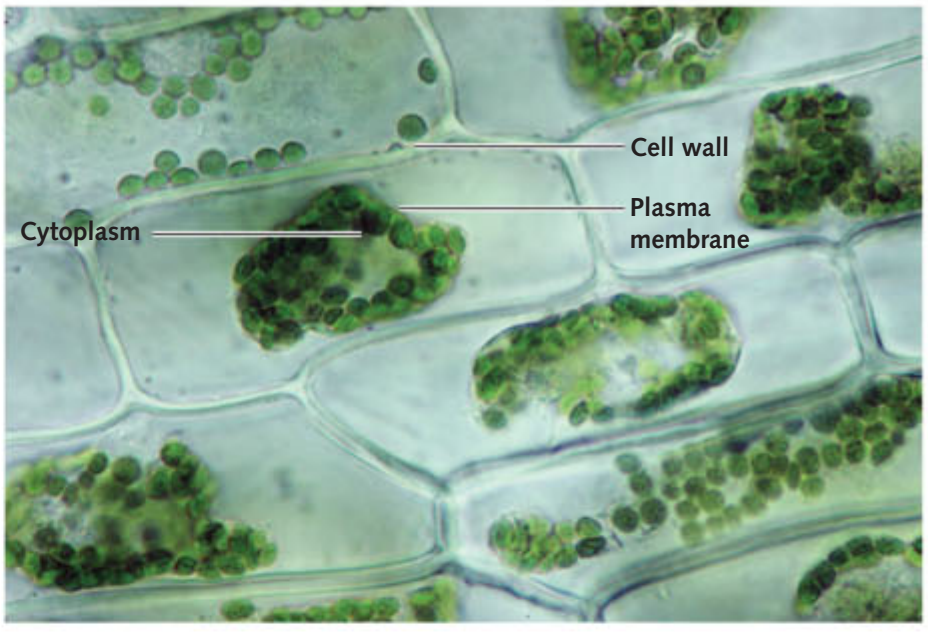


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Figure 1.39 Plasmolysis in *Elodea* cells. Water has diffused out of the cells, causing the volume of cytoplasm to shrink. Gaps between the cytoplasm and the cell wall are filled with external solution.

KEY CONCEPTS

- Simple diffusion, facilitated diffusion and osmosis are ways that molecules can cross membranes by passive transport (does not require energy).
- Osmosis is the diffusion of water across a selectively permeable membrane from an area of high water concentration (low solute) to an area of low water concentration (high solute).
- When a large amount of water enters an animal cell it will burst. When water enters a plant cell it becomes turgid because of the presence of a cell wall.

Concept questions 1.5b

1. A salt solution is a mixture of salt and water. Which of these is the solvent and which is the solute?
2. Give one reason why plant cells do not burst when placed in a hypotonic solution.
3. Explain why red blood cells are stored in saline (salt) solution rather than pure water.
4. If salad greens such as lettuce are left for a period of time, they become limp. To restore their crispness they can be soaked in cold water. Explain the reason for this.
5. What do hypotonic, isotonic and hypertonic mean in terms of water solutions in a cell and its surrounds?

HOT Challenge

6. Haemolysis can occur to red blood cells, as can crenation. Discuss what each of these occurrences is, how they may happen, and what part osmosis plays in the processes.

1.6 Movement across membranes using energy

The processes of diffusion and osmosis do not require the input of energy. However, there are occasions when energy is needed to move substances across membranes. **Active transport** and bulk transport are some examples where movement of substances requires energy from the cell.

Active transport

After you eat a meal, nutrients such as glucose are absorbed into the cells lining the inside of the small intestine. If diffusion alone were involved, once the concentrations of glucose inside and outside the cell became equal, there would be no net movement. Some of the glucose available from digestion would be excreted along with wastes and undigested food. This is not the case. Glucose continues to move into

WB
1.6.1 ACTIVE TRANSPORT PAGE 26

cells lining the small intestine even when its concentration is higher inside the cell. Cells appear to pump glucose in through their plasma membranes.

In this and other similar situations, molecules or ions move up their concentration gradient, from a region where they are in a low concentration to a region of higher concentration. As this movement of molecules or ions through a membrane against a concentration gradient requires the input of energy, it is called active transport.

How does active transport take place? Membrane **transport proteins** , similar to those responsible for facilitated diffusion, use energy from the small molecule adenosine triphosphate (ATP) to move molecules or ions up their concentration gradient (Figure 1.40). Adenosine triphosphate (ATP) is the main cellular source of chemical energy, and powers almost all of the processes within a cell. It acts as the energy source for the membrane transport protein to pump ions against their concentration gradient. As the membrane carrier proteins work in only one direction, they effectively act as one-way valves. The importance of these pumps becomes apparent in people who cannot produce them in adequate amounts, such as those suffering from the disease cystic fibrosis.

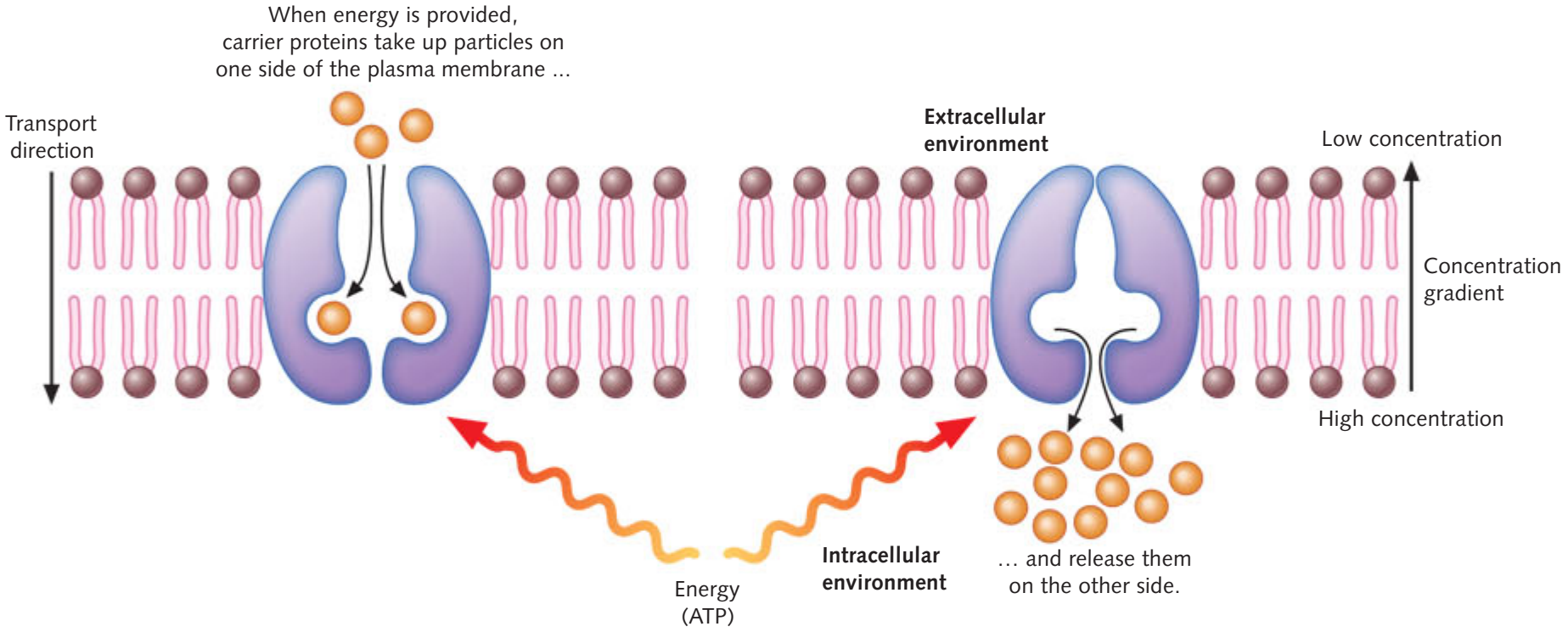

Figure 1.40 Active transport via a carrier protein in the plasma membrane of a cell. Energy is transferred to the carrier protein, enabling it to move the particles against a concentration gradient.

The energy demands of this process is significant. It has been estimated that while a person sleeps, as much as 40% of the total energy budget is used for active transport. Cells engaged in active transport have huge numbers of mitochondria. These organelles build up the ATP from ADP and inorganic phosphate that is used as the energy source in these cells.

WB
1.6.2 BULK TRANSPORT: MOVEMENT OF LARGE MOLECULES ACROSS MEMBRANES PAGE 28

Bulk transport: movement of large molecules across membranes

At times, very large particles have to be moved into a cell across its plasma membrane. In other circumstances, relatively large molecules have to be exported from a cell. The large size of these particles makes their movement through the membrane by diffusion or active transport impossible. In these cases of bulk transport, membranes and cytoplasmic vesicles have an important role to play in **endocytosis** and **exocytosis**. These are active processes, requiring energy in the form of ATP to move vesicles around the cytoplasm and to change the shape of the cell.

Endocytosis

Figure 1.41 shows a unicellular *Amoeba* (right) feeding on a smaller organism (bottom left), illustrating the process of endocytosis. The *Amoeba* changes shape by sending out projections or pseudopods that surround the prey. When the plasma membranes of the projections meet, membrane fusion occurs. This results in the formation of a vesicle, which then stores or transports the material within the cytoplasm (Figure 1.42). The two types of endocytosis discussed in this chapter are named according to the type of material consumed. The process that engulfs solids, like an *Amoeba* eating, is called **phagocytosis**, and the other process that takes in droplets of liquid is called **pinocytosis**.

Alamy Stock Photo/blickwinkel

Figure 1.41 A scanning electron micrograph of an *Amoeba* surrounding its prey (*Tetrahymena*) for ingestion

WB
1.6.3 COMPARING AND CONTRASTING DIFFUSION, OSMOSIS AND ACTIVE TRANSPORT PAGE 29

Human white blood cells are called phagocytes because, in defending the body against disease, they engulf bacteria by phagocytosis (Figure 1.43).

Pinocytosis occurs when the plasma membrane engulfs extracellular fluid in much the same way as phagocytosis (Figure 1.44). Fat droplets found in the small intestine after a meal move into cells by means of pinocytosis.

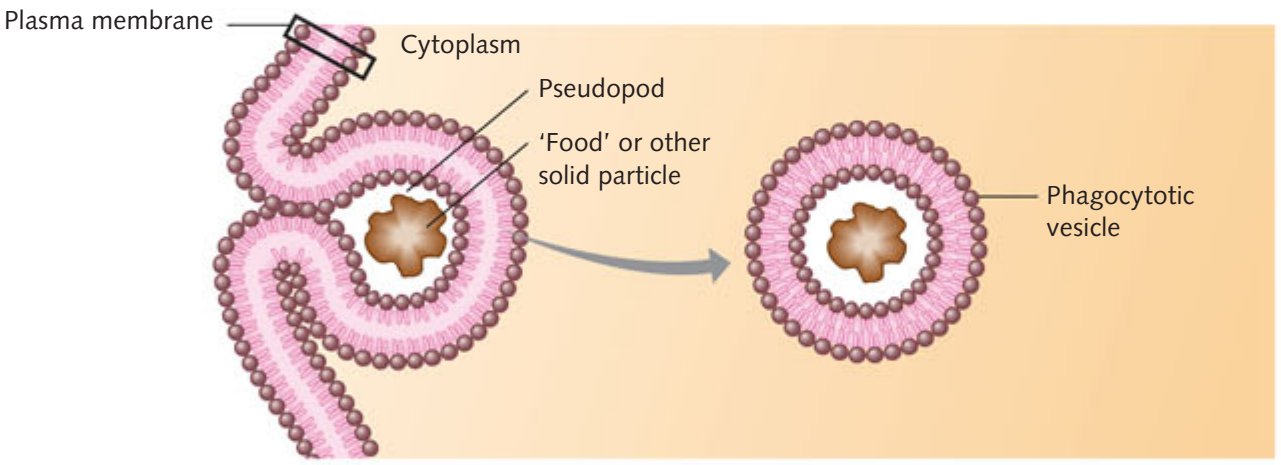

Figure 1.42 The process of phagocytosis

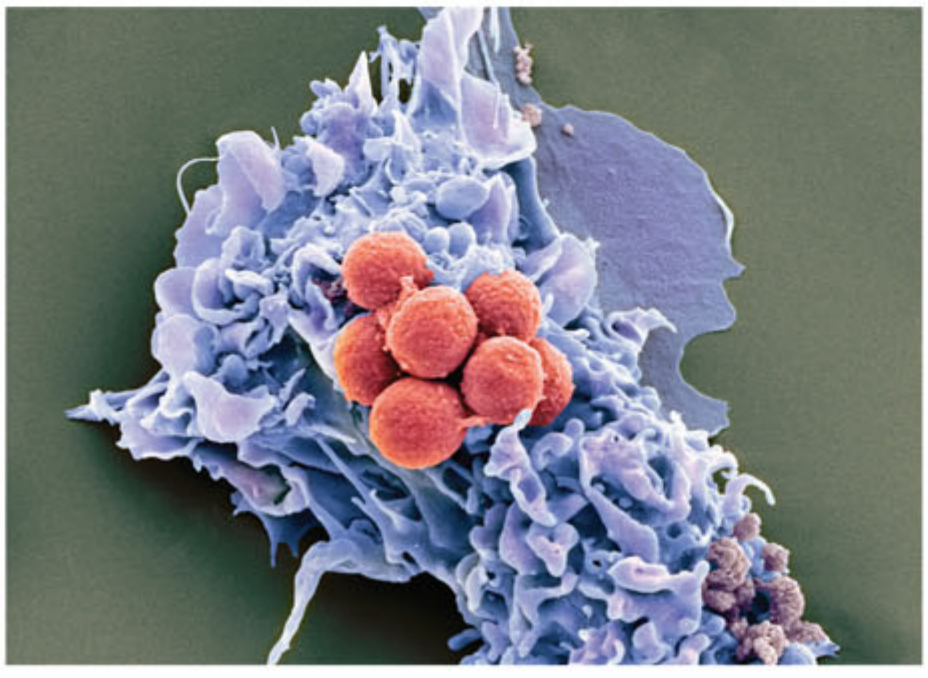

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Figure 1.43 A macrophage engulfing cells by phagocytosis

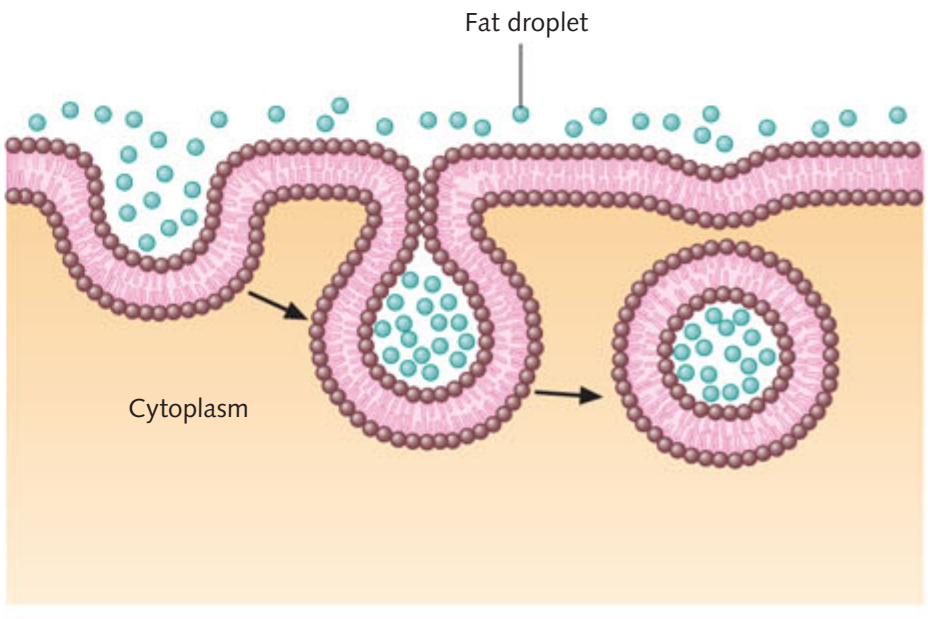


Figure 1.44 The process of pinocytosis

Exocytosis

Specialised animal cells produce a variety of substances, such as hormones, mucus, milk proteins and digestive enzymes, which have important functions elsewhere in the organism. This is also true for plants, where particular cells are specialised to produce products that need to be relocated. These include growth regulators, toxins to ward off predators and macromolecules for use elsewhere. In all these cases, exocytosis is involved.

Exocytosis is the process by which large molecules held in vesicles within the cell are transported to the external environment. It is essentially the reverse of endocytosis. During exocytosis, a membrane-bound vesicle moves to the plasma membrane, fuses with it and then releases its contents to the exterior of the cell (Figure 1.45).

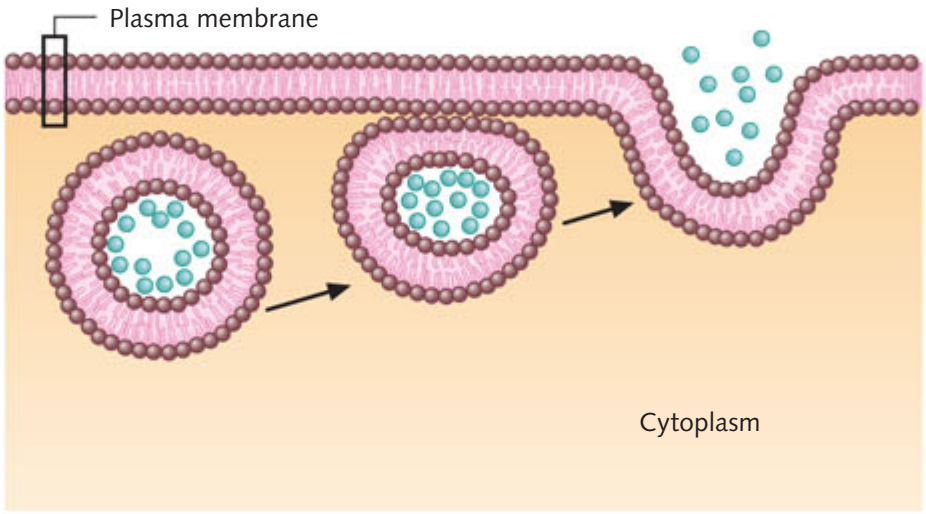


Figure 1.45 The process of exocytosis

KEY CONCEPTS

- Movement of particles up a concentration gradient, from where they are in low concentration to where they are in high concentration, is active and requires energy.
- Energy from ATP is used to move substances across membranes by active transport and bulk transport.
- Endocytosis and exocytosis are active processes that move large substances or large volumes of molecules into and out of cells.
- The two types of endocytosis are phagocytosis which takes in large particles, and pinocytosis which takes in liquid droplets.

Concept questions 1.6

1. Distinguish between active transport and simple diffusion.
2. Compare and contrast the passive and active cellular uptake of ions and glucose molecules.
3. Explain how the plasma membrane is involved in the processes of endocytosis and exocytosis.
4. Phagocytosis is a very important process in all cells, particularly in the immune system of organisms. Large white blood cells called phagocytes utilise this process to do what?

HOT Challenge

5. Pinocytosis is a common process in cells of gymnopserms such as pine trees. What characteristic property of pines might make this process common?

BRANCHING OUT

Scientists create an artificial cell that makes its own energy by photosynthesising

Artificial cells created inside the lab have taken another major step forward, with scientists developing cells that are able to produce their own chemical energy and synthesise parts of their own construction. That makes these artificial cells a lot more like real, biological cells – cells that can construct and organise their own building blocks naturally.

Not only could this help us understand how real cells work and come into being in the first place, it could also be vital for a host of other areas of research – such as ongoing efforts to produce artificial organs and other body tissue to fight back against disease.

'I have been trying for a long time to construct a living artificial cell, especially focusing on membranes,' says lead researcher Yutetsu Kuruma from the Tokyo Institute of Technology in Japan.

'In this work, our artificial cells were wrapped in lipid membranes, and small membrane structures were encapsulated inside them. In this way, the cell membrane is the most important aspect of forming a cell.'

The lipid membranes contained the proteins ATP synthase and bacteriorhodopsin, purified from living cells. These were designed to work in tandem, to use light energy to create an energy difference inside the cell, and then to use that energy difference to construct more molecules and more protein.

During the experiments, the photosynthesis process happened as the scientists had hoped. The artificial cells mimicked real cells by making messenger RNA (mRNA) from DNA, and then making protein from mRNA.

The key feature here is the cells' ability to produce that energy and do their own synthesising, potentially leading to the creation of independent artificial cells that can be sustained on their own.

While the study wasn't able to duplicate the full range of proteins that an actual cell can, the researchers think this might be within reach with an upgraded setup.

The scientists say their work could also be important in the study of protocells, which are thought to have come before modern cells. How did these protocells produce energy to create their own metabolism? This new type of artificial cell might tell us.

If two membrane proteins can produce enough energy to drive gene expression, as this study shows, then protocells might have been able to use sunlight to evolve into what we know as modern cells.

As the research continues, we might be able to reach and observe the cell development tipping point that happened on the early Earth. Other benefits of the research could cover everything from drug delivery to the development of super-smart sensors, and there's lots more to come yet.

'Our artificial photosynthetic cell system paves the way to construct an energetically independent artificial cell,' write the researchers.

Questions

1 List two major steps forward that have been achieved with this artificial cell.
2 From a scientific point of view, what is the point in trying to create an artificial cell?
3 '… the cell membrane is the most important aspect of forming a cell.' Explain what the researcher meant by this statement.
4 What new question arises from this work?
5 How could scientists use this work in the future?

Online Key Concepts
Chapter 1 summary of key concepts

1 Summary of key concepts

1.1 Cells are the basic structural unit of life

KEY CONCEPTS

p. 7

- The cell theory states that all living things are composed of one or more cells and all cells come from pre-existing cells.
- All cells are surrounded by a plasma membrane.
- Prokaryotic cells do not contain membrane-bound organelles.
- Eukaryotic cells contain a membrane-bound nucleus and membrane-bound organelles.

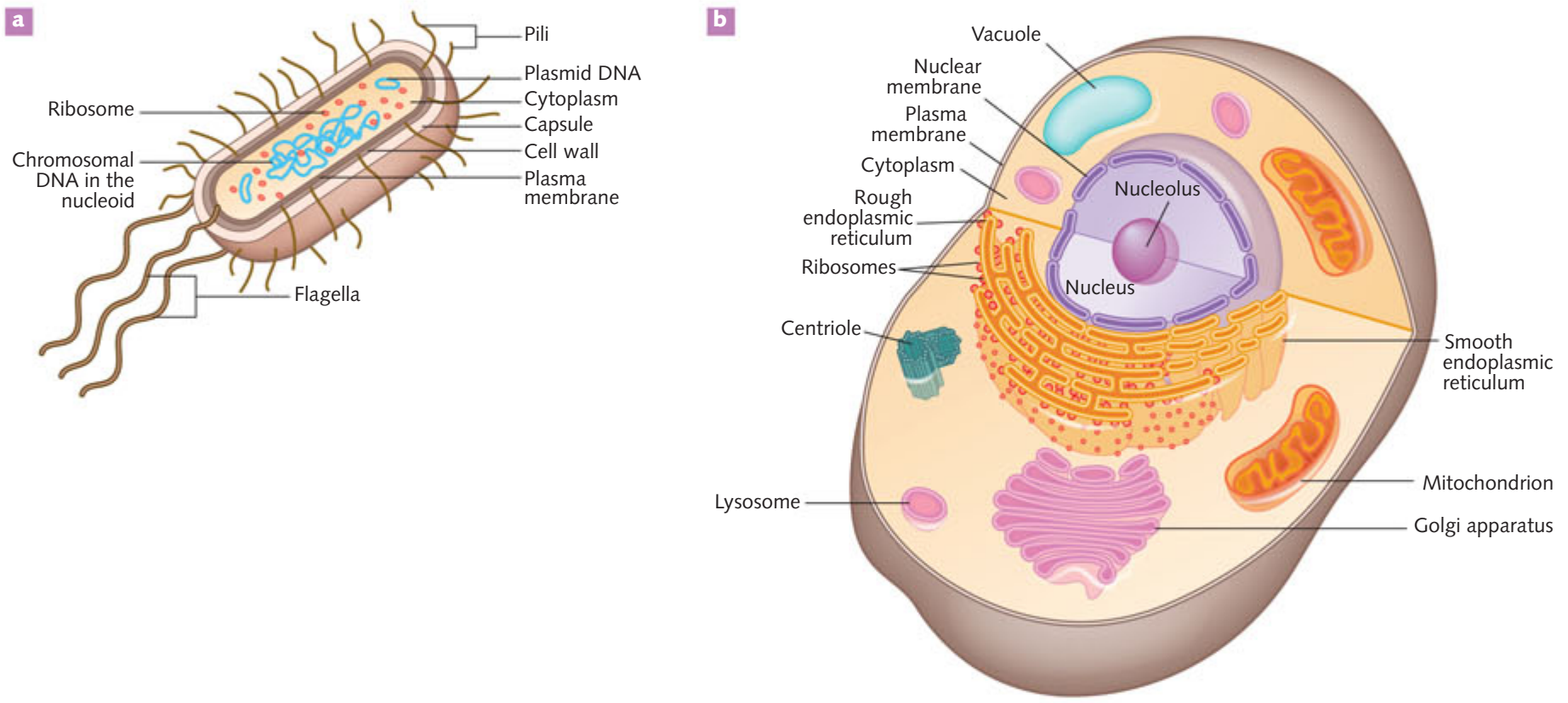


Figure 1.4 The difference between a a prokaryotic cell and b a eukaryotic animal cell

1.2 Size and shape of cells

KEY CONCEPTS

p. 11

- Surface-area-to-volume ratio (SA : V) is a relationship between the size of the outside of an object and the amount of space enclosed within the object.
- Cells with a larger surface-area-to-volume ratio can obtain nutrients and remove wastes more efficiently.
- The shape of a cell can significantly change a cell's surface-area-to-volume ratio.

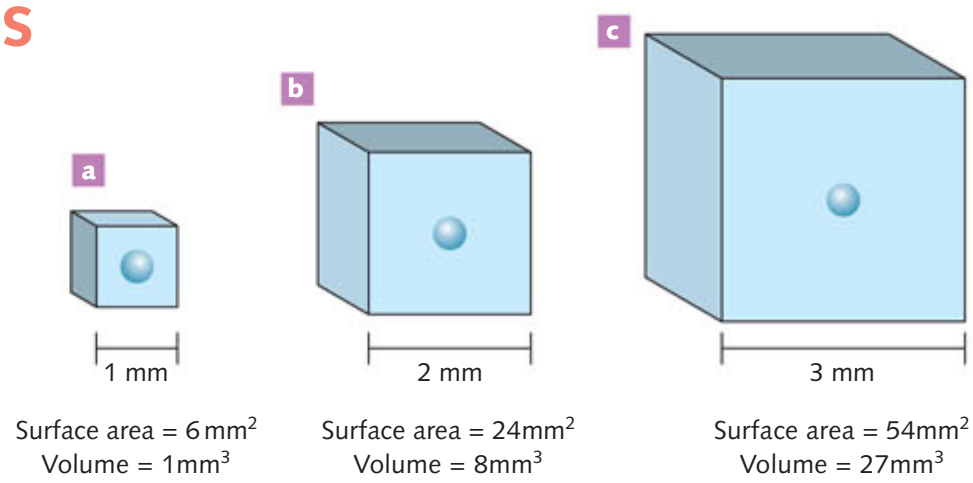


Figure 1.5 Three hypothetical cells. Cell A has a SA : V = 6 : 1, Cell B = 3 : 1 and Cell C = 2 : 1. Cell A is the smallest cell but has the largest SA : V and Cell C is the largest cell with the smallest SA : V. Note that the nucleus remains the same size in all three cells.

9780170452465

1.3 What's inside a cell?

KEY CONCEPTS

p. 17

- Cell organelles carry out specific functions within a cell.
- The cytoplasm makes up the bulk of a cell.
- The nucleus coordinates cell activities.
- Mitochondria are the sites of cellular respiration.
- All cell types contain ribosomes, which build up amino acids into proteins.
- Some substances are moved around the cell in the endoplasmic reticulum.
- The Golgi apparatus packages and stores substances in vesicles in preparation for their release from the cell.
- Lysosomes are formed by the Golgi apparatus and contain digestive enzymes that break complex chemical compounds into simpler ones.
- The cytoskeleton provides shape to the cell.
- Microtubules and microfilaments are structures of the cytoskeleton.
- A cell wall, composed of cellulose, provides extra support and protection to some types of cells.
- Chloroplasts contain chlorophyll, a green pigment that absorbs light energy. They are the site for photosynthesis.
- The vacuole serves as a storage space for sugars, minerals, proteins and water.

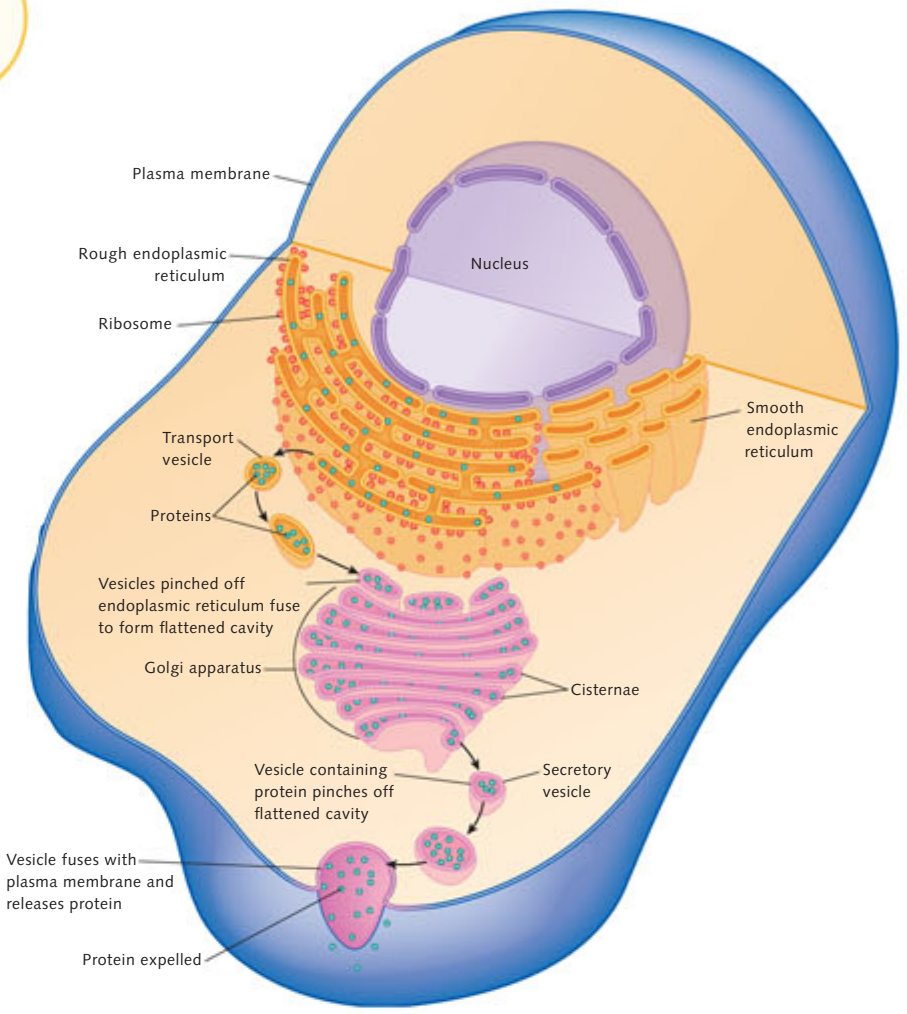


Figure 1.20 How the Golgi apparatus removes and secretes a protein from a cell

1.4 Plasma membrane

KEY CONCEPTS

p. 27

- The plasma membrane forms the boundary between the internal environment of the cell and its external environment.
- The plasma membrane is selectively permeable in that it controls the movement of substances into and out of cells.
- The plasma membrane is composed of a double layer of phospholipid molecules. The head is hydrophilic and the tail is hydrophobic.
- The structure of the plasma membrane can be understood by using a fluid mosaic model.
- Embedded in the plasma membrane are a variety of membrane proteins that enable the membrane to carry out its distinctive activities.
- Membrane proteins allow cells to function appropriately, respond to chemical messages and recognise each other.

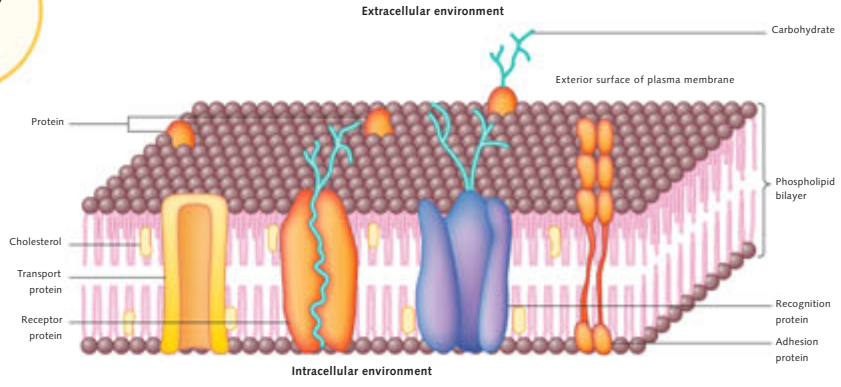


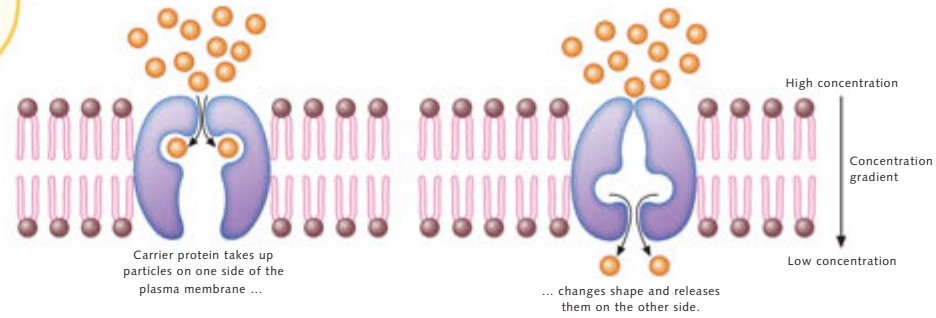
Figure 1.29 Examples of proteins associated with plasma membranes

1.5 Passive movement across membranes

KEY CONCEPTS

p. 32

- Diffusion is the movement of particles down a concentration gradient, from where they are in high concentration to where they are in low concentration, until equilibrium is reached.
- Diffusion is a passive process.
- The greater the concentration gradient of a substance across a membrane, the faster it will diffuse.
- Carrier proteins and channel proteins assist particles to diffuse into a cell. This process is called facilitated diffusion.
- Simple diffusion, facilitated diffusion and osmosis are ways that molecules can cross membranes by passive transport (does not require energy).
- Osmosis is the diffusion of water across a selectively permeable membrane from an area of high water concentration (low solute) to an area of low water concentration (high solute).
- When a large amount of water enters an animal cell it will burst. When water enters a plant cell it becomes turgid because of the presence of a cell wall.



Roberts, M., Reiss, M. & Monger, G. Advanced Biology (2000)

Figure 1.32 Facilitated diffusion using a carrier protein in the plasma membrane of a cell moves particles such as glucose down the concentration gradient.

1.6 Movement across membranes using energy

KEY CONCEPTS

p. 39

- Movement of particles up a concentration gradient, from where they are in low concentration to where they are in high concentration, is active and requires energy.
- Energy from ATP is used to move substances across membranes by active transport and bulk transport.
- Endocytosis and exocytosis are active processes that move large substances or large volumes of molecules into and out of cells.
- The two types of endocytosis are phagocytosis which takes in large particles, and pinocytosis which takes in liquid droplets.

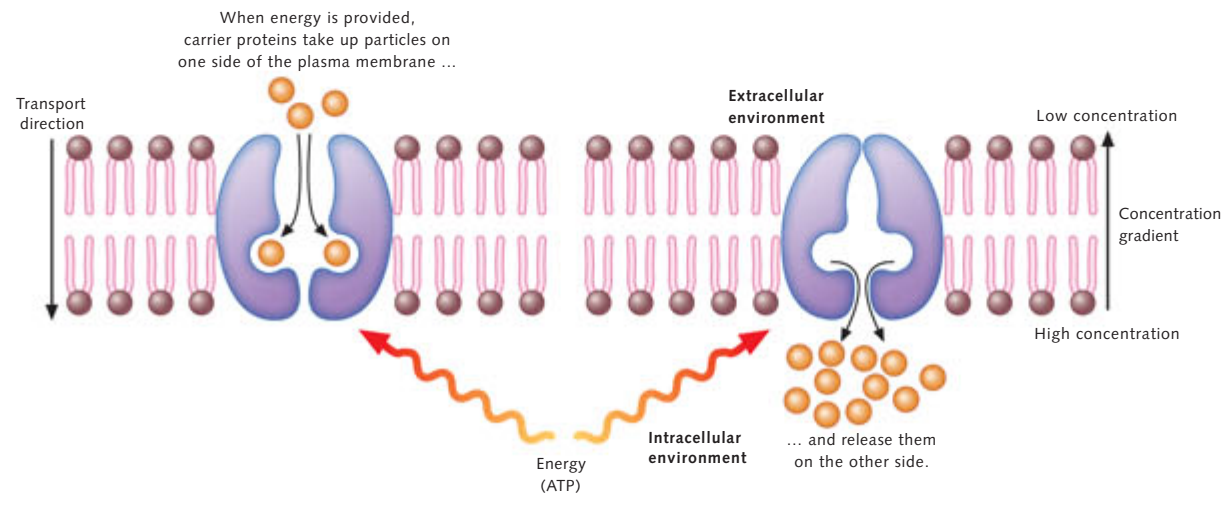


Figure 1.40 Active transport via a carrier protein in the plasma membrane of a cell. Energy is transferred to the carrier protein, enabling it to move the particles against a concentration gradient.

WB
KEY TERMS
PAGE 30

1 Chapter glossary

active transport the process whereby cells use energy in the form of ATP to transport substances across a membrane from low to high concentration

adenosine triphosphate (ATP) a high-energy compound composed of adenine and ribose and three phosphate groups attached; it releases energy for cellular reactions when its last phosphate group is removed and the compound is converted to ADP and inorganic phosphate

adhesion protein a plasma membrane protein that helps link cells together

amino acid a nitrogen-containing compound that is the building block of proteins

carrier protein a protein within membranes that assists other molecules to cross the membrane in facilitated and active transport

cell the basic structural unit of all life forms on Earth

cellular respiration a series of cellular biochemical reactions and processes using glucose and producing carbon dioxide and water; the energy released is used to convert ADP and inorganic phosphate into ATP

cellulose a complex carbohydrate molecule found in cell walls

centriole a structure in animal cells that produces and organises microtubules

channel protein a protein that forms channels within membranes to allow the passage of hydrophobic substances across the membrane

chlorophyll the green pigment found in chloroplasts; it is able to absorb light energy, making it available for photosynthesis

chloroplast a membrane-bound organelle (type of plastid) found in the cytoplasm of plants and algae containing the green pigment chlorophyll; its main function is photosynthesis and storage of carbohydrates

cholesterol part of the structure of the plasma membrane where it alters fluidity of the membrane depending on temperature

chromosome a structure made of a DNA molecule

concentration gradient the difference in concentration of a substance between two different regions

contractile vacoule a specialised vacuole involved in regulating the amount of water inside a cell, which pumps water from the cytoplasm to the outside of the cell

crenation the crinkling of red blood cells when they lose water

cristae infoldings of the inner membrane of the mitochondria, forming partitions

cytoplasm all the cytosolic fluid, dissolved materials and organelles between the plasma membrane and the nuclear membrane

cytoplasmic streaming the mixing and movement of the cytoplasm

cytoskeleton a system of microtubules and microfilaments within a cell that supports and gives shape to it; helps movement and reproduction

cytosol the part of the cytoplasm containing highly organised fluid material with dissolved substances; excluding the organelles

deoxyribonucleic acid (DNA) an information molecule that is the universal basis of an organism's genetic material; it contains instructions, written in a chemical code, for the production of proteins by the cell

diffusion the passive movement of molecules from a high to a low concentration of that substance

endocytosis the movement of solids or liquids into a cell from the environment via vesicle formation

endoplasmic reticulum an organelle in eukaryotic cells consisting of an interconnecting system of thin membrane sheets dividing the cytoplasm into compartments and channels; involved in the synthesis, folding, modification and transport of proteins

enzyme a specific protein catalyst that acts to increase the rate of a chemical reaction within the cell by lowering the amount of energy required for the reaction to proceed

equilibrium the point at which particles are distributed evenly throughout a system; they move at equal rates in all directions

eukaryotic describes a complex type of cell with a nucleus and membrane-bound organelles

exocytosis the movement of solids or liquids from a cell to the environment via vesicle formation

external environment (of a cell) the environment surrounding a cell outside the plasma membrane

extracellular external to the cell

facilitated diffusion a form of diffusion that requires a substance to be attached to a specific carrier molecule to move across a membrane

flaccid floppy; describes the condition of a plant cell that has lost water

fluid mosaic model explains the fluid character of the plasma membrane

glycoprotein protein which has carbohydrates attached

Golgi apparatus a collection of membranes that package and store substances into vesicles in preparation for their release from the cell

grana stack of thylakoid discs within a chloroplast

haemolysis the bursting of red blood cells

hydrophilic tending to interact with and dissolve in water

hydrophobic avoiding association with water

hypertonic a solution with a higher solute concentration compared with another solution

hypotonic a solution with a lower solute concentration compared with another solution

intercellular occurring between cells

internal environment (of a cell) all material contained within the plasma membrane

intracellular occurring within a cell

ion a particle with either a positive or negative charge

isotonic describes fluid with an equal solute concentration to another fluid

lysosome an organelle within the cytoplasm containing digestive enzymes

membrane a thin, pliable sheet or layer acting as a boundary

metabolism the sum of the chemical reactions that occur within a cell

microfilament a solid contractile protein; involved in movement and cell shape

microtubule a hollow, cylindrical tube in cells that acts as scaffolding to determine cell shape and aid movement

mitochondria organelles within the cytoplasm that are the site of aerobic cellular respiration, releasing energy for the cell

mitochondrial matrix gel-like material within the mitochondria

multicellular describes an organism consisting of more than one cell

nanometre (nm) one-thousand-millionth of a metre

nuclear envelope/membrane the membrane surrounding the nucleus

nucleolus a site for assembling protein and RNA that will later form ribosomes; visible in a non-dividing cell

nucleus the organelle containing DNA in a eukaryotic cell; it functions to coordinate cellular activities

organelle a specialised structure or compartment within a cell that has a specific function

osmosis the movement of water across a selectively permeable membrane from a region of low solute concentration to a region of high solute concentration

passive transport the movement of molecules that does not require input of energy

permeable able to pass through

phagocytosis the bulk transport of solids into a cell inside a vesicle; a type of endocytosis

phospholipid a type of lipid which forms part of the plasma membrane

phospholipid bilayer two layers of phospholipids which form the plasma membrane with the hydrophobic end facing inwards and hydrophilic end facing outwards

photosynthesis a chemical reaction using energy from the Sun to convert carbon dioxide and water into glucose and oxygen

phytosterol similar to cholesterol, found in plasma membrane

pinocytosis the bulk transport of liquids into a cell inside a vesicle; a type of endocytosis

plasma membrane the insoluble boundary of all living cells that maintains the contents of the cell and regulates movement of substances into and out of the cell

plasmolysis the cytoplasm pulling away from the cell wall because of water loss

plasmid extrachromosomal circular DNA found in prokaryotes

plastid an organelle in a plant cell containing coloured pigments

prokaryotic describes a simple type of cell that lacks a nucleus and membrane-bound organelles

receptor a cell component that detects changes in the surrounding environment

receptor protein a protein that binds hormones and other signal molecules

recognition protein a protein that acts as a marker on membranes

ribonucleic acid (RNA) the single-stranded nucleic acid that functions in transcribing and translating information from DNA into proteins

ribosome a small structure in all cells that builds amino acids into complex proteins; this organelle is not bound by a membrane

rough endoplasmic reticulum endoplasmic reticulum with ribosomes attached

selectively permeable describes a membrane that allows some substances but not others to pass across it

smooth endoplasmic reticulum endoplasmic reticulum with no ribosomes attached

solute a substance that can be dissolved in another substance

solution a mixture of solute and solvent

solvent a substance in which another substance can be dissolved to produce a solution

spindle fibres microtubules, produced during cell division, that move chromosomes in precise directions

stroma colourless fluid in a chloroplast

surface-area-to-volume ratio (SA : V) the mathematical ratio of the size of the surface area (in two dimensions) compared to the volume of an object (in three dimensions)

synthesise to make

thylakoid membrane system of interconnected membranes in a chloroplast

tonoplast the membrane surrounding the vacuole

transmembrane protein a type of integral protein that spans the entire thickness of the plasma membrane

transport protein a protein that carries molecules across membranes

turgid describes a cell that is tight and rigid from absorbing water

unicellular an organism made up of a single cell

vacuole a membrane-bound fluid-filled space within a cell

vesicle a small, membrane-bound sac in the cytoplasm that transports, stores or digests substances

WB
1.7.2 PRACTICE TEST QUESTIONS PAGE 33

1 Chapter review

Remembering

1 Match each structure with its function.

Organelle/structure		Function	
a	nucleus	i	collecting and packaging centre of the cell
b	endoplasmic reticulum	ii	photosynthesis and storage
c	lysosome	iii	transport of substances around the cell
d	mitochondria	iv	control centre of the cell
e	Golgi apparatus	v	aerobic respiration, which releases energy to the cell
f	chloroplast	vi	breakdown of materials

2 Define solute, solution, solute concentration, concentration gradient and equilibrium.

3 Does glucose enter a cell by facilitated diffusion or active transport? Explain.

4 List two natural conditions that might cause plant cells to become plasmolysed.

5 Explain what would happen, in terms of the movement of water molecules, if an animal cell was placed in a hypertonic solution.

6 Describe, by means of labelled diagrams, the processes of endocytosis and exocytosis.

7 Explain the importance of turgor to plants.

8 a Describe features that are common to all cells.
b Describe features that are unique to:
i prokaryotic cells
ii eukaryotic cells.

Applying

9 Certain cells have densely packed mitochondria and the cristae (infolded projections of a mitochondrion) are very close together. What would you predict about the function of such cells? Explain your reasoning.

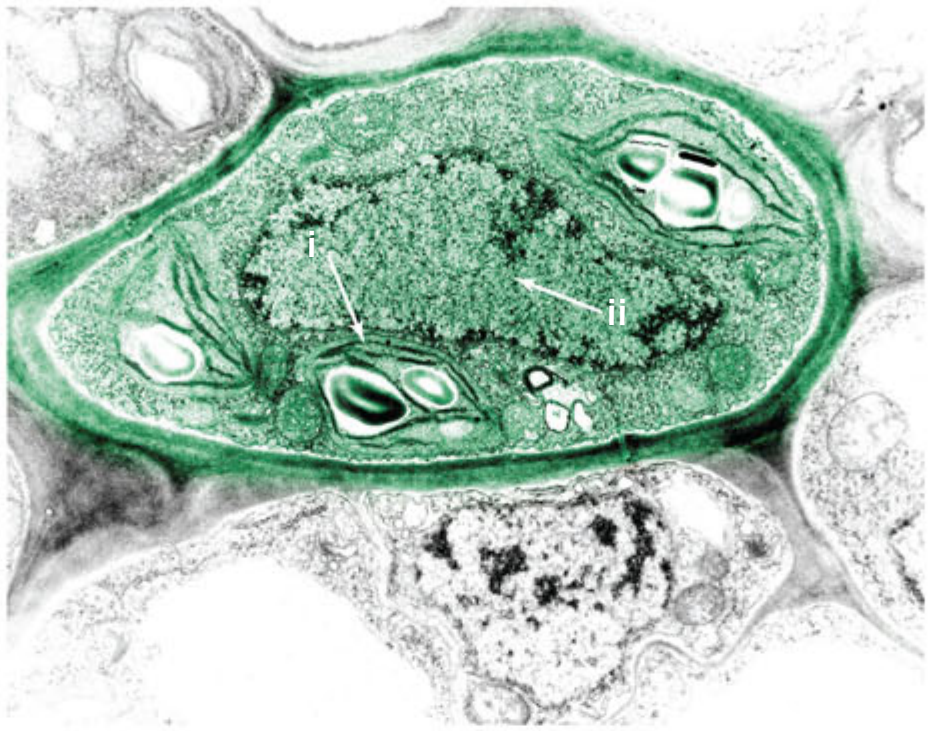
10 Find out how the produce departments of supermarkets keep vegetables looking fresh and feeling firm. Use your understanding of osmosis to explain why this method is successful.

11 When a person's kidneys fail, the person can be connected to a dialysis machine. Arterial blood is pumped through dialysis tubing, which is made of selectively permeable membranes. Surrounding the tubing is a solution similar to blood plasma. Waste materials diffuse from the tubing into the surrounding solution. Cleaner blood then travels back into the person's veins.
a What must be done to the surrounding solution in order for the wastes to continue diffusing out of the dialysis tube?
b Predict what would happen if this was not done to the surrounding solution.

Analysing

12 a State whether the cell shown in Figure 1.46 is from a prokaryote or eukaryote organism. Give reasons for your answer.
b Identify whether the cell shown in this photograph was viewed with an electron microscope or a light microscope. Give your reasons.

c Some organelles may be present in this cell but are not shown in the photograph. Suggest why this might be the case.
d Name the organelles with arrows pointing to them.



Alamy Stock Photo/Science Photo Library

Figure 1.46 Photograph of an unidentified cell

13 If you were asked to classify a particular type of cell, name the structures you would look for. Suggest whether the structures present would allow you to predict the function of the cell.

14 Two cells have the same internal concentration of sugar when they are placed in distilled water. Even though both cells expand over time, one expands faster than the other. Discuss some possible reasons for this observation.

15 Half-fill a drinking cup with water and add 30 mL of raspberry cordial. Do not stir. After half an hour the cordial is evenly distributed in the cup. Explain this example in terms of diffusion. Use the terms 'net movement', 'concentration gradient' and 'equilibrium' in your explanation.

16 A student places living cells into a drop of liquid containing a 5% sugar solution. After 30 minutes, the student notices that the liquid contains less than 5% sugar. Explain what has happened.

17 Three duck eggs with their shells removed all weigh 50 g. They are placed in salt solutions of concentrations 1.0, 1.5 and 2.0 M (molar) concentration, respectively. After 2 hours, the eggs are reweighed. The egg placed in the 1.0 M salt solution weighed 54 g, the egg placed in the 1.5 M salt solution weighed 50 g and the egg in the 2.0 M salt solution weighed 46 g.
   a Construct a line graph showing probable change in egg mass over a 2 hour period.
   b Explain, for each concentration, why the egg gained or lost mass or stayed the same.

18 The concentration of sodium ions, Na^+, in human blood plasma is approximately 150 mmol L^{-1}. In the cytosol of red blood cells the concentration of Na^+ is approximately 30 mmol L^{-1}. Explain how this difference in concentration is maintained when the tendency might be for the Na^+ ions to rush out of the cell.

Evaluating

19 The freshwater bacterium *Gemmata obscuriglobus* has its DNA packaged in a membrane envelope. Recently, Australian scientists showed that the bacterium 'swallows' large particles in a process similar to endocytosis. Explain why scientists are now questioning whether *G. obscuriglobus* is classified correctly as a bacterium.

20 A student examines a human cheek cell under a light microscope. Because she cannot see any mitochondria, she says there are none present in this type of cell. Outline arguments you would use to convince her that she is incorrect.

21 Discuss the impact on the functioning of a cell of having a large number of organelles with folded and stacked membranes.

22 There is a great deal of concern about rising levels of salt in soils in many parts of Australia. Evaluate whether it would be better for a citrus farmer in Mildura to have a lack of available freshwater or to have saline soils. Discuss reasons for your answer.

Reflecting

23 Xenophyophores are giant unicellular organisms found over 10 km below the sea surface. They are the largest individual cells known to exist and can grow up to 10 cm across. Reflect on the issues facing these organisms and describe three adaptations that you would expect them to display.

24 A student made the comment that 'The formation of vesicles by endocytosis should reduce the size of the plasma membrane'. Apply your knowledge of both endocytosis and exocytosis to critically examine this comment.

Creating

25 A cell has been likened to a factory. This type of analogy is useful when considering the structures and functions of cells. A factory is a place where products are made; these are then exported from the factory and distributed for sale. Raw materials and energy are needed for the manufacture of the products.

- a Make a model of an animal or plant cell, with appropriate structures to represent organelles within the cell.
- b Using the following components of a factory, describe a structure or function of a cell that is similar. For example, a factory has outside walls; all cells have a membrane and some types of cells also have cell walls.
  Factory: goods manufactured; business plans; photocopying room; manufacturing area; warehouse; management offices; assembly workers, warehouse packers; doors; hallways; power source
- c Outline one difference in function between a factory and a cell.

2 The cell cycle

By the end of this chapter you will have covered the following material.

Key knowledge

The cell cycle and cell growth, death and differentiation

- binary fission in prokaryotic cells pp. 57–58
- the eukaryotic cell cycle, including the characteristics of each of the sub-phases of mitosis and cytokinesis in plant and animal cells pp. 58–66
- apoptosis as a regulated process of programmed cell death pp. 66–68
- disruption to the regulation of the cell cycle and malfunctions in apoptosis that may result in deviant cell behaviour: cancer and characteristics of cancer cells pp. 68–75
- properties of stem cells that allow for differentiation, specialisation and renewal of cells and tissues, including the concepts of pluripotency and totipotency pp. 75–76

Key science skills

Develop aims and questions, formulate hypotheses and make predictions

- identify, research and construct aims and questions for investigation pp. 72–74
- identify independent, dependent and controlled variables in controlled experiments pp. 72–74
- formulate hypotheses to focus investigation pp. 72–74
- predict possible outcomes pp. 72–74

Plan and conduct investigations

- determine appropriate investigation methodology: case study; classification and identification; controlled experiment; correlational study; fieldwork; literature review; modelling; product, process or system development; simulation pp. 72–74
- design and conduct investigations; select and use methods appropriate to the investigation, including consideration of sampling technique and size, equipment and procedures, taking into account potential sources of error and uncertainty; determine the type and amount of qualitative and/or quantitative data to be generated or collated pp. 72–74
- work independently and collaboratively as appropriate and within identified research constraints, adapting or extending processes as required and recording such modifications pp. 72–74

Comply with safety and ethical guidelines

- demonstrate safe laboratory practices when planning and conducting investigations by using risk assessments that are informed by safety data sheets (SDS), and accounting for risks pp. 72–74
- apply relevant occupational health and safety guidelines while undertaking practical investigations pp. 72–74
- demonstrate ethical conduct when undertaking and reporting investigations pp. 72–74

Generate, collate and record data

» systematically generate and record primary data, and collate secondary data, appropriate to the investigation, including use of databases and reputable online data sources pp. 72–74

» record and summarise both qualitative and quantitative data, including use of a logbook as an authentication of generated or collated data pp. 72–74

» organise and present data in useful and meaningful ways, including schematic diagrams, flow charts, tables, bar charts and line graphs pp. 72–74

» plot graphs involving two variables that show linear and non-linear relationships pp. 72–74

Analyse and evaluate data and investigation methods

» process quantitative data using appropriate mathematical relationships and units, including calculations of ratios, percentages, percentage change and mean pp. 72–74

» identify and analyse experimental data qualitatively, handling where appropriate concepts of: accuracy, precision, repeatability, reproducibility and validity of measurements; errors (random and systematic); and certainty in data, including effects of sample size in obtaining reliable data pp. 72–74

» identify outliers, and contradictory or provisional data pp. 72–74

» repeat experiments to ensure findings are robust pp. 72–74

» evaluate investigation methods and possible sources of personal errors/mistakes or bias, and suggest improvements to increase accuracy and precision, and to reduce the likelihood of errors pp. 72–74

Construct evidence-based arguments and draw conclusions

» distinguish between opinion, anecdote and evidence, and scientific and non-scientific ideas pp. 72–74

» evaluate data to determine the degree to which the evidence supports the aim of the investigation, and make recommendations, as appropriate, for modifying or extending the investigation pp. 72–74

» evaluate data to determine the degree to which the evidence supports or refutes the initial prediction or hypothesis pp. 72–74

» use reasoning to construct scientific arguments, and to draw and justify conclusions consistent with the evidence and relevant to the question under investigation pp. 72–74

» identify, describe and explain the limitations of conclusions, including identification of further evidence required pp. 72–74

» discuss the implications of research findings and proposals pp. 72–74

Analyse, evaluate and communicate scientific ideas

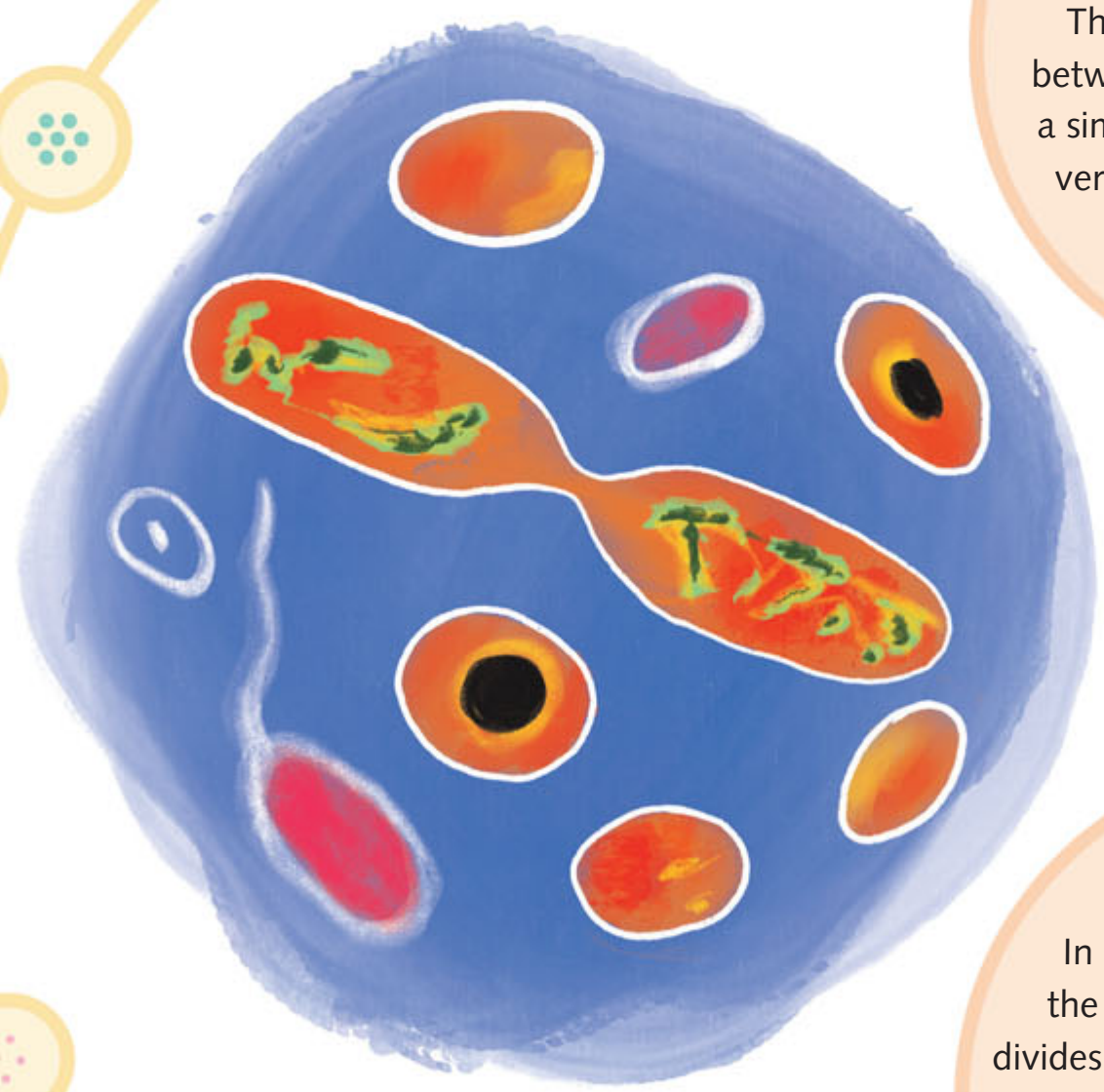
» use appropriate biological terminology, representations and conventions, including standard abbreviations, graphing conventions and units of measurement pp. 72–74

» discuss relevant biological information, ideas, concepts, theories and models and the connections between them pp. 72–74

Online Chapter Map
Chapter 2 map

2 The cell cycle

Cells do not live forever. To survive, cells need to be able to produce new cells. Prokaryotic and eukaryotic cells reproduce differently, mainly because prokaryotic cells do not have a membrane-bound nucleus.



2.1 Binary fission p. 57

Prokaryotic cells reproduce by binary fission where one cell splits into two. The DNA is evenly distributed between the two new cells. This is a simple process and can be done very quickly. Some bacteria can divide every 20 minutes. Think diseases!

2.2 Eukaryotic cell cycle p. 58

In eukaryotic cells, the DNA in the nucleus is duplicated, then it divides in half in a series of steps called mitosis. Regular checks ensure division is successful. Next, cytokinesis splits the plasma membrane and cytoplasm to produce two new cells identical to the parent cell.

2.3 Apoptosis

p. 66

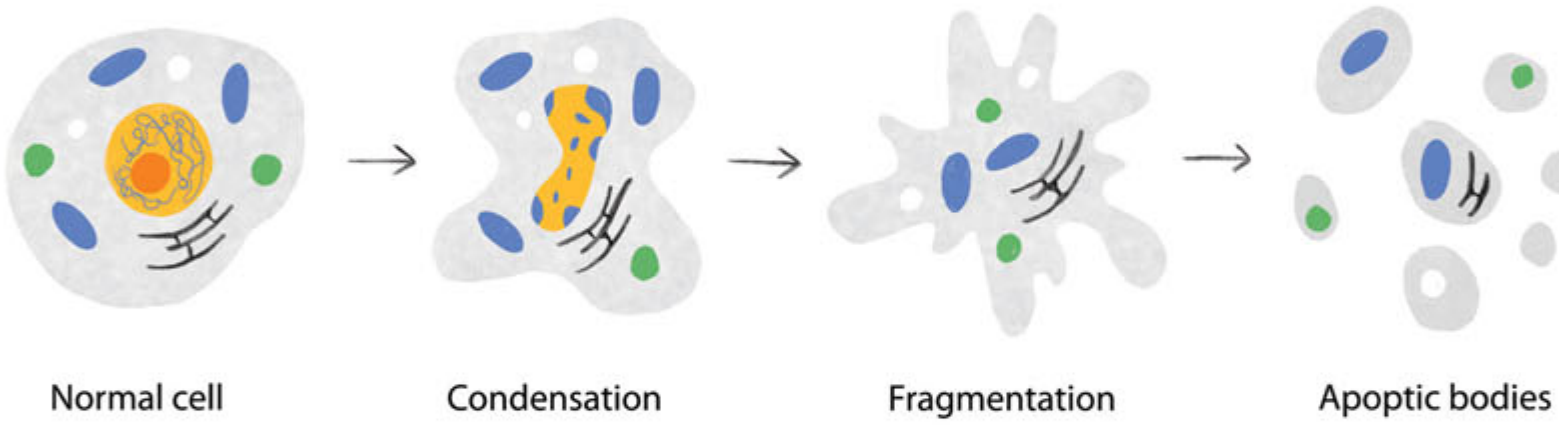
Cells die due to damage, infection, reaching the end of their lifespan, or because they are programmed to die. An unborn baby has webbing between its fingers and toes. Through cell death, the webbing is removed. This process of programmed cell death is called apoptosis.

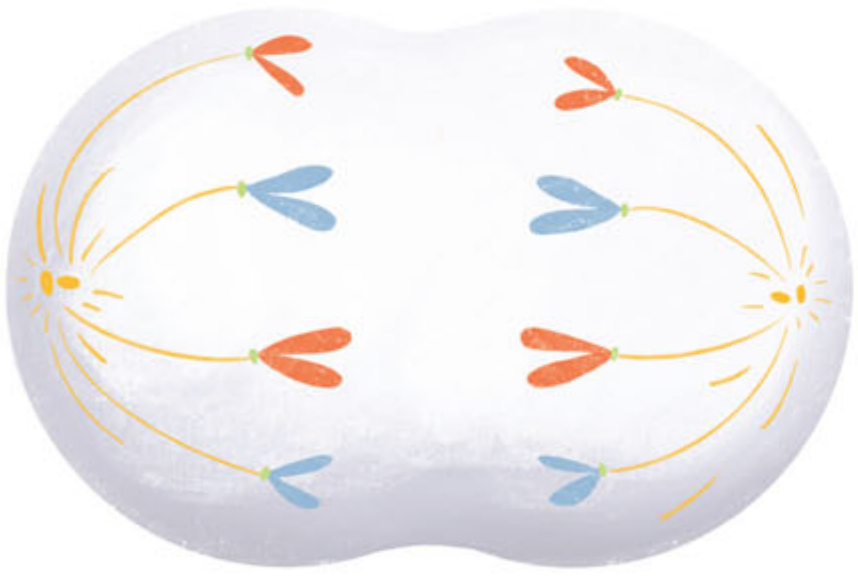
2.4 Disruption to the regulation of the cell cycle

p. 69

The cell cycle is complex and requires checking. The *p53* gene detects cell damage and either halts the cycle to repair the damage or triggers apoptosis. If the genes are faulty, cancerous tumours may result.

Apoptosis





2.5 Stem cells

p. 75

Stem cells can develop into a range of cells. A fertilised egg is a totipotent cell and forms an embryo; pluripotent cells give rise to most tissues of a developing embryo and multipotent stem cells are programmed with specific functions; e.g. blood stem cells.

Cells join to make up tissues, tissues make up organs and organs make up systems. Systems form functioning organisms such as plants and animals.

To access resources below, visit www.nelsonnet.com.au

Online Chapter Map:
- Chapter 2 map (p. 54)

Online Key Terms:
- Chapter 2 flashcards (p. 56)

Weblinks:
- Mitosis and the cell cycle (p. 59)
- What is apoptosis? (p. 67)

Online Worksheets:
- Mitosis and the cell cycle (p. 59)
- What is apoptosis? (p. 67)

Online Key Concepts:
- Chapter 2: Summary of key concepts (p. 80)

Know your key terms

Online Key Terms
Chapter 2 flashcards

adult stem cell
anaphase
apoptosis
binary fission
blastocyst
bleb
cancer
carcinogen
cell cycle
cell plate
centromere
chemical mutagen
chromatid
chromatin
cleavage
cleavage furrow
cyclin
cycline-dependent kinase (CDK)
cytokinesis
daughter cell
differentiation
embryo
embryonic stem cell
foetus
G_0 phase
G_1 phase
G_2 phase
genetic predisposition
interphase
M phase
macrophage
metaphase
mitosis
multipotent stem cell
mutagen
mutation
necrosis
oncogene
p53 gene
parent cell
phagocyte
placenta
pluripotent stem cell
pole
prophase
proto-oncogene
quiescent cell
S phase
spindle
stem cell
telophase
teratogen
terminally differentiated cell
totipotent stem cell
tumour
tumour suppressor gene

Remember

This chapter will build on the following concepts that you will have already met. Take the time to refresh these concepts before you start this chapter.

WB
REMEMBER
PAGE 35

1. All living things are made up of one or more cells.
2. There are two types of cells: prokaryotic and eukaryotic.
3. Centrioles are rod-like structures found only in animal cells.
4. Chromosomes are made up of DNA, which is organised into genes.
5. Genes code for protein formation.

Cells do not live forever. They wear out, get damaged and die. In order for unicellular or multicellular organisms and species to continue to survive there has to be a process to replace damaged cells. In unicellular prokaryotic organisms, such as bacteria, this process is called **binary fission**. This occurs when one bacterial cell divides into two, producing two new bacterial cells. In complex multicellular organisms the process is more ordered to ensure that each new cell contains all the organelles and material it needs to survive. This process is called **mitosis**, and is used for cell repair, replacement and growth.

As you learnt in Chapter 1, cell size is determined by the relationship between surface area and volume. Therefore, for an organism to grow, such as a baby into a toddler (Figure 2.1), its cells do not increase in size; rather, they increase in number.

a

Getty Im

b

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Figure 2.1 a A baby grows into **b** a toddler through the process of mitosis.

2.1 Binary fission

Prokaryotic cells reproduce by binary fission; essentially, one cell splits into two cells. Prokaryotic cells such as bacteria have their DNA in one large coiled chromosome in an area of the cell called a nucleoid as well as some small plasmids (rings of extra-chromosomal DNA) throughout the cytoplasm. During binary fission it is essential that the DNA in the **parent cell** is divided evenly between the two new **daughter cell**. During replication the chromosome will uncoil and replicate. Other structures that exist within the cell, such as ribosomes and plasmids, also replicate. The cell itself will begin to elongate and grow larger. The cell is now ready to divide into two.

The chromosomes move away from each other towards each end of the parent cell. The cytoplasm is distributed to each end as well. The cell lays down proteins, such as peptidoglycan, across the middle of the cell to start the production of a new cell wall and the cell begins to pinch in two. At the end of this process, two new daughter cells of identical genetic composition are formed.

Because of the relative simplicity of prokaryote division, completion of the cell cycle is rapid. Bacterial cells can reproduce every 20 minutes in ideal conditions (Figure 2.2).

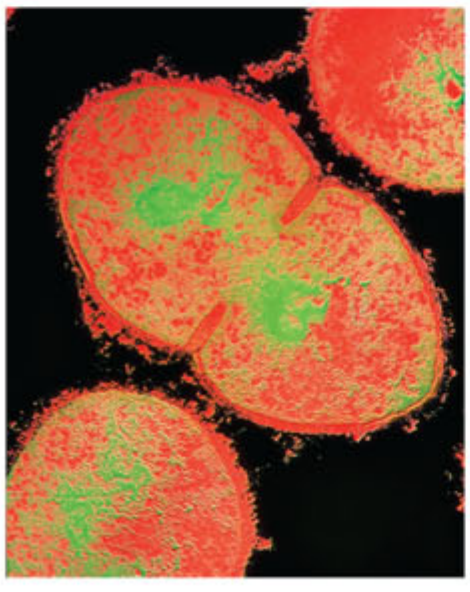
WB 2.1.1 BINARY FISSION PAGE 36

WB 2.1.2 EFFECT OF TEMPERATURE ON BINARY FISSION – PART A PAGE 36

WB 2.1.3 EFFECT OF TEMPERATURE ON BINARY FISSION – PART B PAGE 37

WB 2.1.4 EFFECT OF TEMPERATURE ON BINARY FISSION – PART C PAGE 39

a



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b

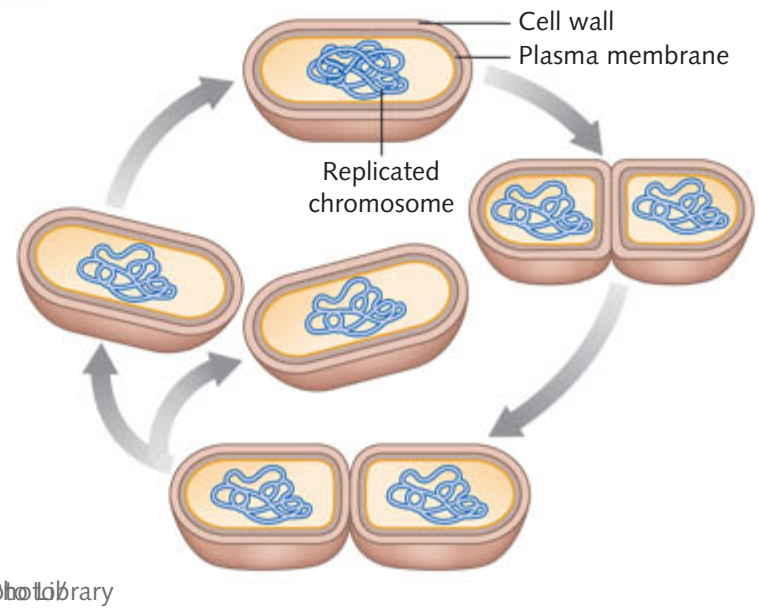

Figure 2.2a Transmission electron micrograph of a *Listeria* bacterium dividing in two by binary fission (magnification ×39 800). Non-dividing cells are smaller and circular. **b** Bacterial cell cycle

KEY CONCEPTS

- Prokaryotic cells divide by binary fission.
- One parent cell gives rise to two identical daughter cells.
- The DNA, ribosomes and cytoplasm in the parent cell are evenly divided between the two daughter cells.
- Bacterial cells can divide every 20 minutes.

Concept questions 2.1

1 List three reasons why cells in an adult human need to be continuously replaced.

2 Write a hypothesis about the effect of increasing temperature on binary fission in bacterial cells.

3 Define nucleoid, plasmid, parent cell, daughter cell, binary fission.

4 Binary fission results in exponential growth in numbers of cells down the generations. The mathematical expression to describe this is 2^n.

If n = the number of generations (divisions) and the first prokaryotic cell is equivalent to 2^0, how many prokaryotic cells dividing by binary fission would be present if all survived after 26 generations?

5 Outline the steps of a prokaryotic cell cycle.

HOT Challenge

6 Prokaryotic cells can reproduce every 20 minutes in ideal conditions. Kingdom Eubacteria includes organisms that reproduce by binary fission. Many of these organisms are bacteria and some are pathogenic. Consider this information and postulate why the process of reproduction in these prokaryotes might be a problem.

2.2 Eukaryotic cell cycle

Eukaryotic cells have a more complex structure than prokaryotic cells and their division is also more complex. The series of phases that a dividing eukaryotic cell passes through from one cell division to another is known as the **cell cycle** (Figure 2.3). It is called a cycle because the events repeat each time the cell divides. Even though we describe this cycle as taking place in phases, in reality it is usually a continuous process. The phases of the cell cycle are:

- **G_1 phase**: the cell produces new proteins and organelles, grows and carries out its normal tasks for the body. This phase ends when the cell's DNA begins to replicate. A checkpoint ensures the cell is ready for DNA replication and to proceed to the S phase.
- **S phase**: exact duplicates of DNA molecules are formed, resulting in chromosomes with two chromatids.
- **G_2 phase**: preparation for cell division. This phase is a gap phase where the cell has its final opportunity to grow before undergoing nuclear and cytoplasmic division.
- **M phase**: the cell divides into two daughter cells (M stands for mitosis). Mitosis is the division of the nucleus and is only a small part of the cell cycle. This phase also includes cytokinesis, whereby the cytoplasm is divided across the daughter cells.

In addition to these four phases, another phase exists. The **G_0 phase** indicates the non-proliferating state, in which cells are undergoing an extended G_1 phase but are not preparing to replicate DNA and divide. These **quiescent cells** have withdrawn from the active cell cycle. **Terminally differentiated cells** (that is, the most specialised cells), such as nerve cells, are described as being in G_0 phase. Cells in G_0 can re-enter the cell cycle under certain circumstances.

The cell cycle is controlled by a specific set of genes and gene products and has multiple checkpoints that allow the cell cycle to be stalled while mistakes are fixed, reducing the chance of error in the formation of daughter cells.

The length of the cell cycle varies in different cells. Phases in the cell cycle can be identified by measuring the changes in cell volume or in the amount of nuclear DNA, which vary depending on whether the cell is in a phase of growth or DNA synthesis (Figure 2.4). But not all cells divide. Specialised cells tend not to divide (they are usually in G_0 phase), but other cells in areas of high growth or wear, such as skin cells and lining cells of the mouth and gut, tend to divide frequently to replace worn tissues. Dead

cells in these organs 'slough off' as a result of mechanical disturbance or replacement from new cells growing below. New cells not only replace old cells but can also divide to create new organs or tissues. Cells of a growing plant root tip may divide every 20–24 hours.

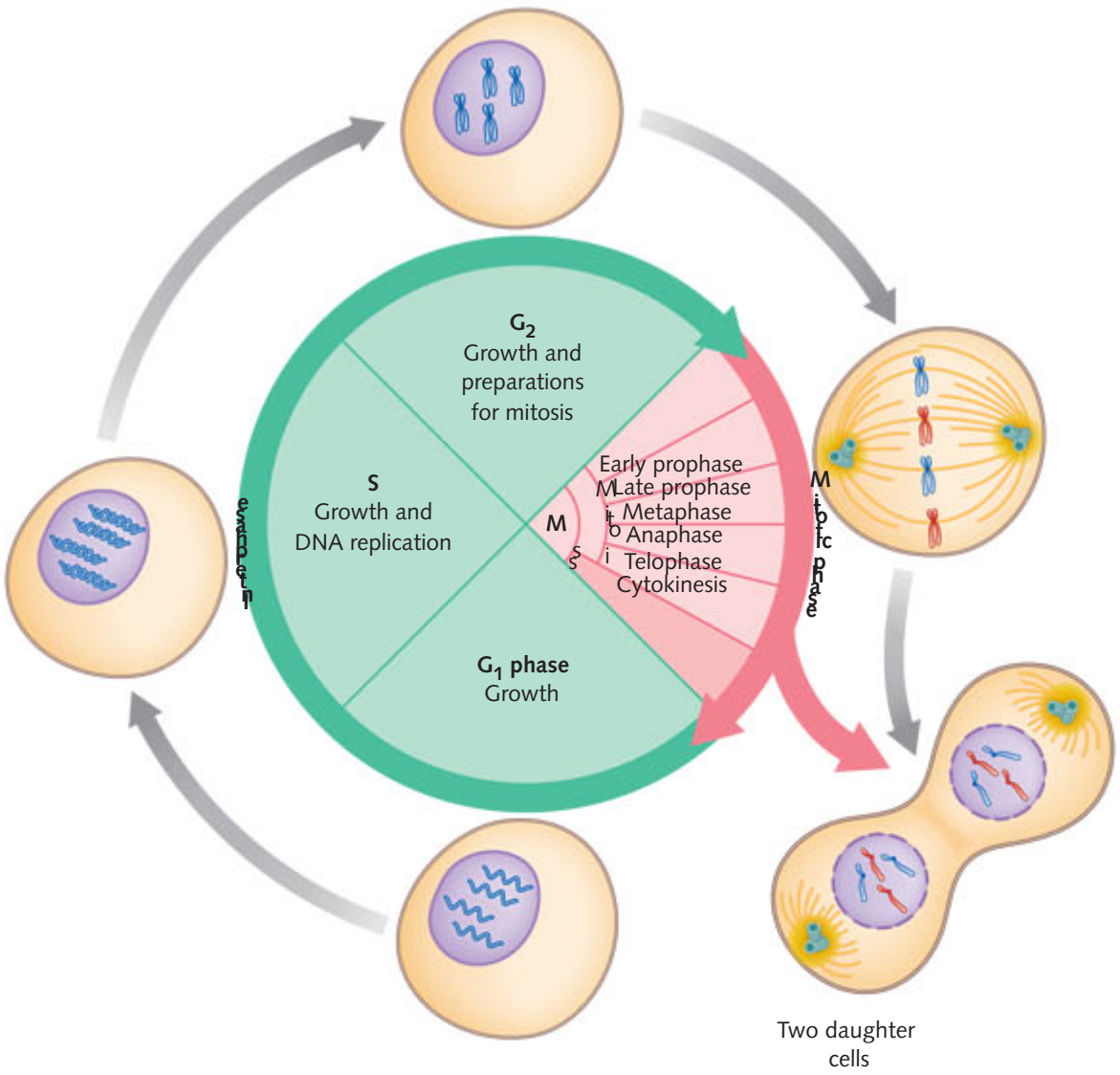

Figure 2.3 The cell cycle

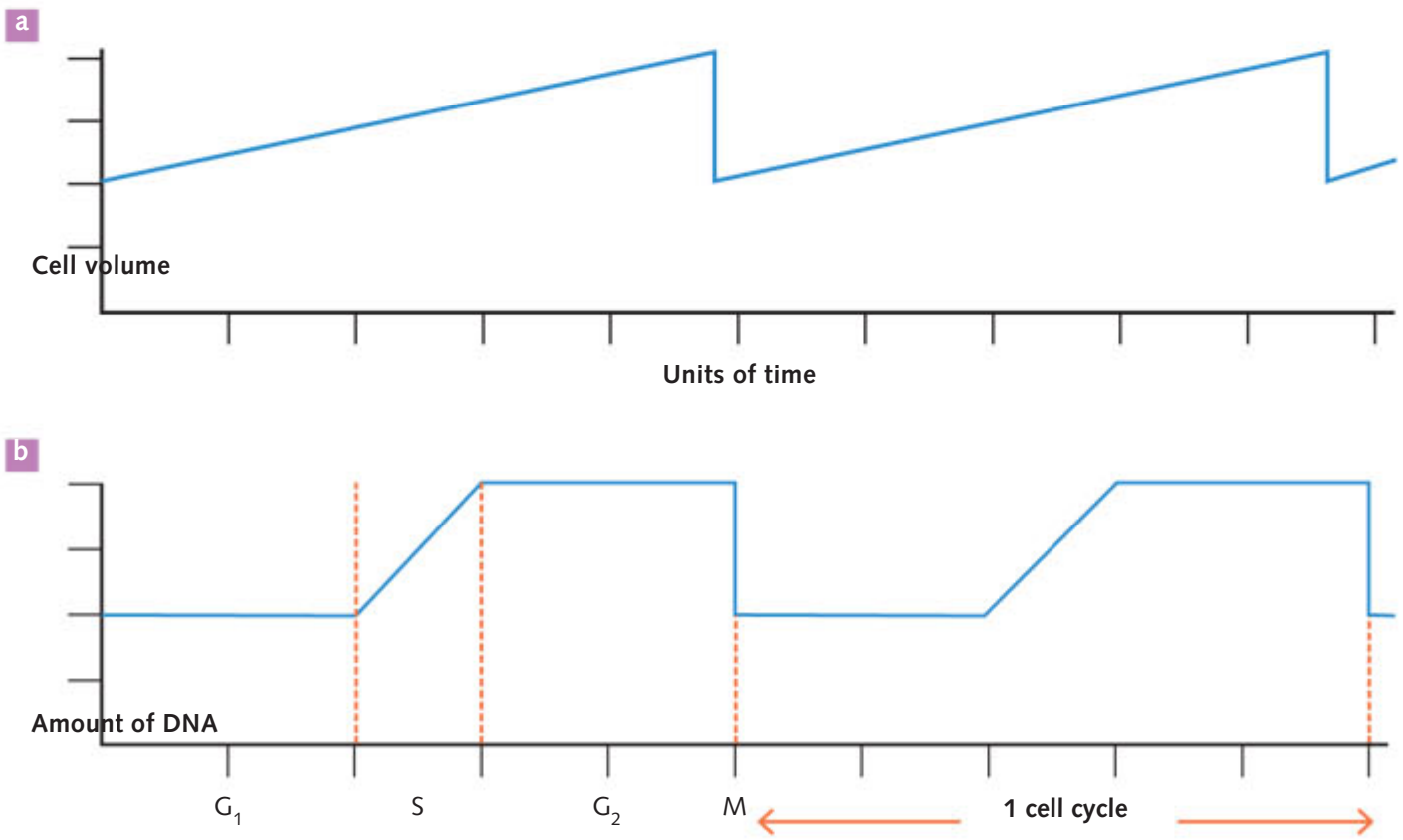

Figure 2.4a The cell volume and **b** amount of nuclear DNA change during a cell cycle, reflecting the different phases of the cycle.

Weblink
Mitosis and
the cell cycle

Worksheet
Mitosis and
the cell cycle

2.2.1
THE CELL CYCLE
PAGE 41

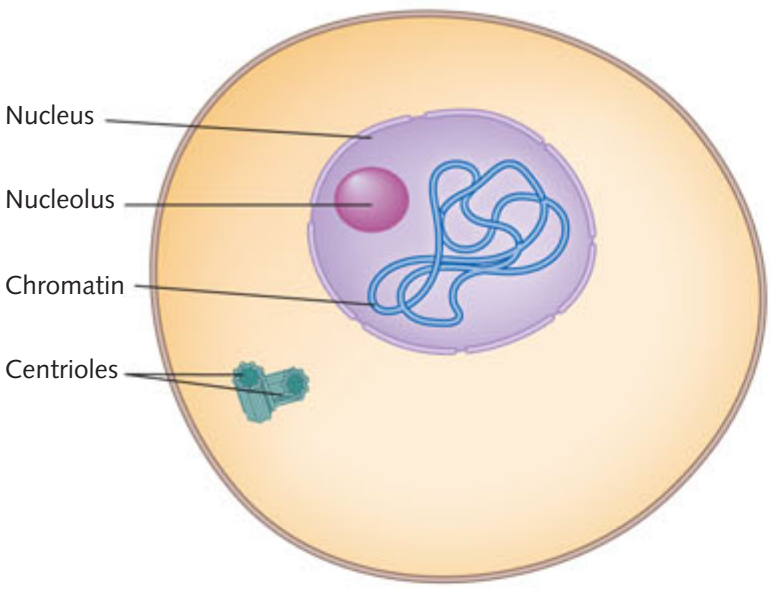

Figure 2.5 Interphase in a eukaryotic animal cell

Interphase

The stage between nuclear divisions is called **interphase** and is a period of active growth (G_1 phase), synthesis of DNA (S phase) and preparation for the next division (G_2 phase). This is illustrated in Figure 2.5.

During interphase the chromosomes are not visible and cannot be clearly distinguished under a light microscope or an electron microscope. This is because the DNA strands are loose and the chromosomes are long and unwound. Immediately before mitosis begins, centrioles are visible in many animal cells. Centrioles will later help to form a structure within the cell that allows the separation of the chromosomes into the daughter cells. As the cell leaves interphase and begins mitosis, the threads of **chromatin** (a loose mass of DNA and associated proteins) become shorter and thicker, forming chromosomes that are visible under a light microscope.

WB
2.2.2 THE PHASES OF MITOSIS IN EUKARYOTIC CELLS PAGE 42

Phases of mitosis in eukaryotic cells

Mitosis is the division of the nucleus of a cell. For convenience, biologists describe mitosis in four stages: prophase, metaphase, anaphase and telophase. However, the process is continuous; it does not occur in a series of stepped stages.

Prophase

During **prophase**, the chromatin threads condense and become visible as pairs of **chromatids**, held together at a **centromere**. Centrioles move to opposite ends (or poles) of the cell and microtubules begin to radiate from them. Some of these microtubules join to form a framework of fibres called a **spindle** while others keep the shape of the cell intact by anchoring the centrioles. The nucleolus disappears from view. The nuclear membrane breaks down. Figure 2.6 illustrates the changes that the cell undergoes during early and late prophase.

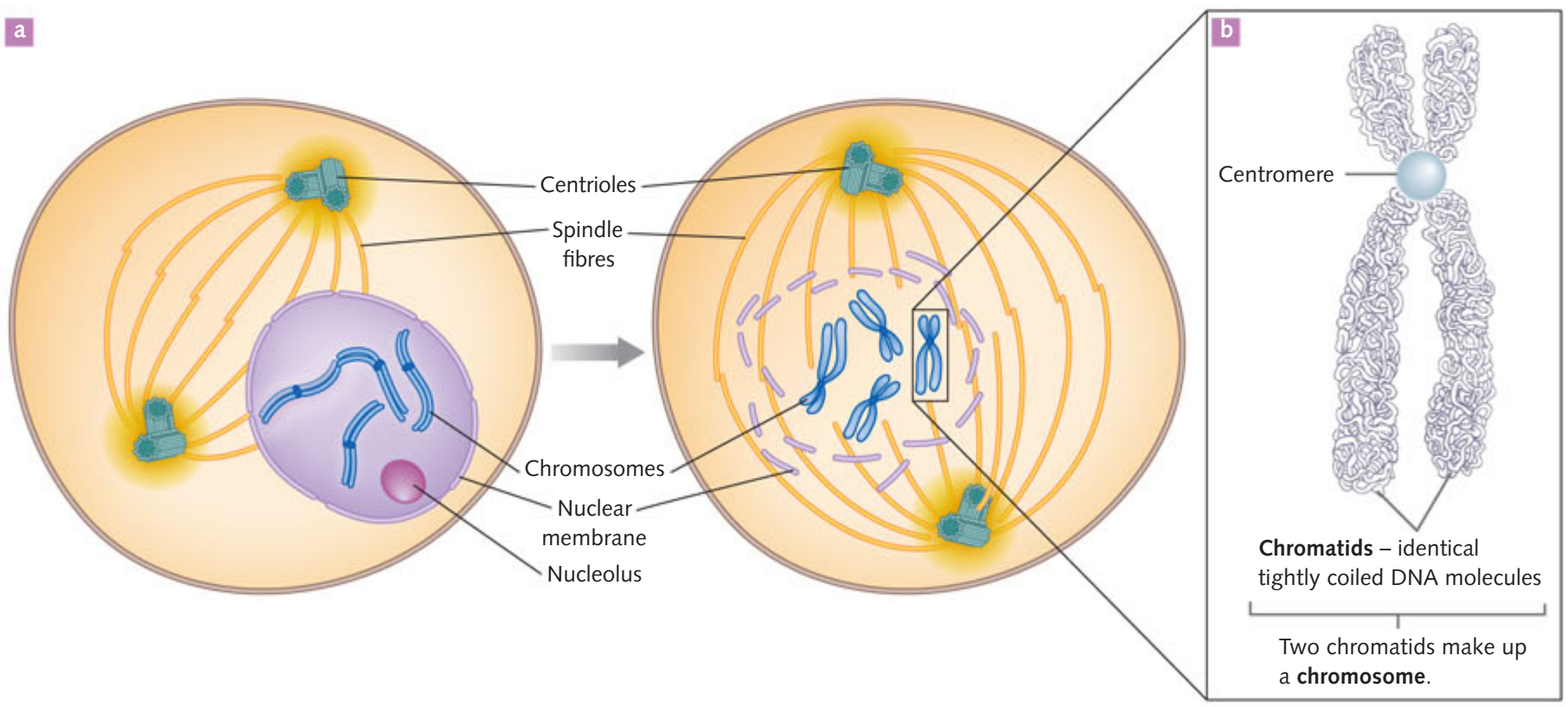

Figure 2.6a Early and late prophase in a eukaryotic animal cell **b** During prophase, chromosomes become visible as pairs of chromatids.

A word about chromosomes

During mitosis, chromosomes change shape and what is happening can get a bit confusing. Chromosomes can either consist of a single chromatid (Figure 2.7a) or two chromatids when they have duplicated (Figure 2.7b). Each arm of the chromosome is called a chromatid. Chromosomes that consist of one chromatid are one complete chromosome as well. The two chromatids in a chromosome that has been duplicated are held together by a centromere at some point along their length.

The position of the centromere can vary in different chromosomes, and descriptive names are given according to their position (Figure 2.8).

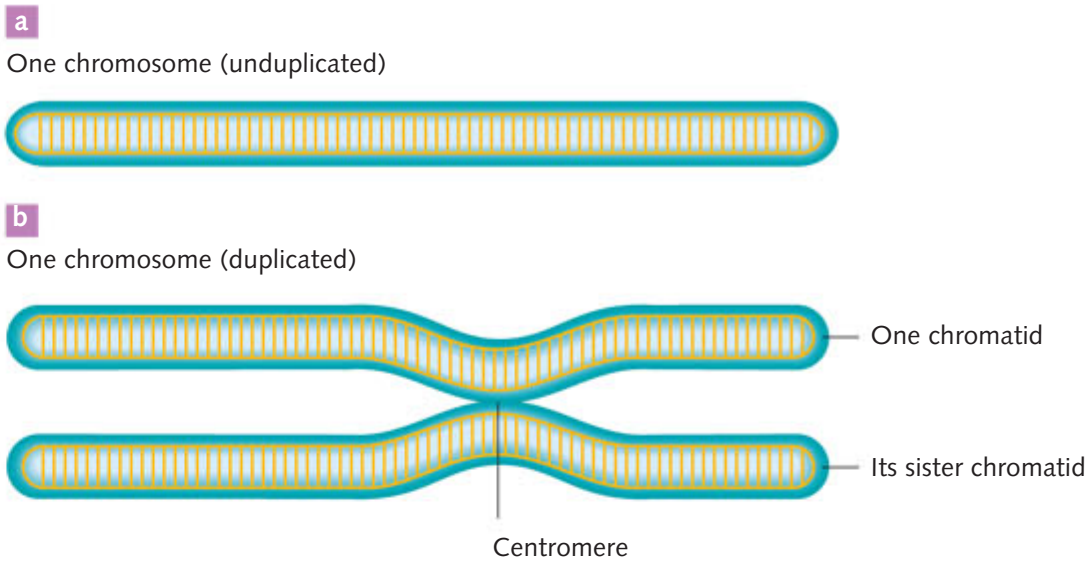

Figure 2.7a An unduplicated chromosome and **b** a duplicated chromosome, showing the position of the centromere

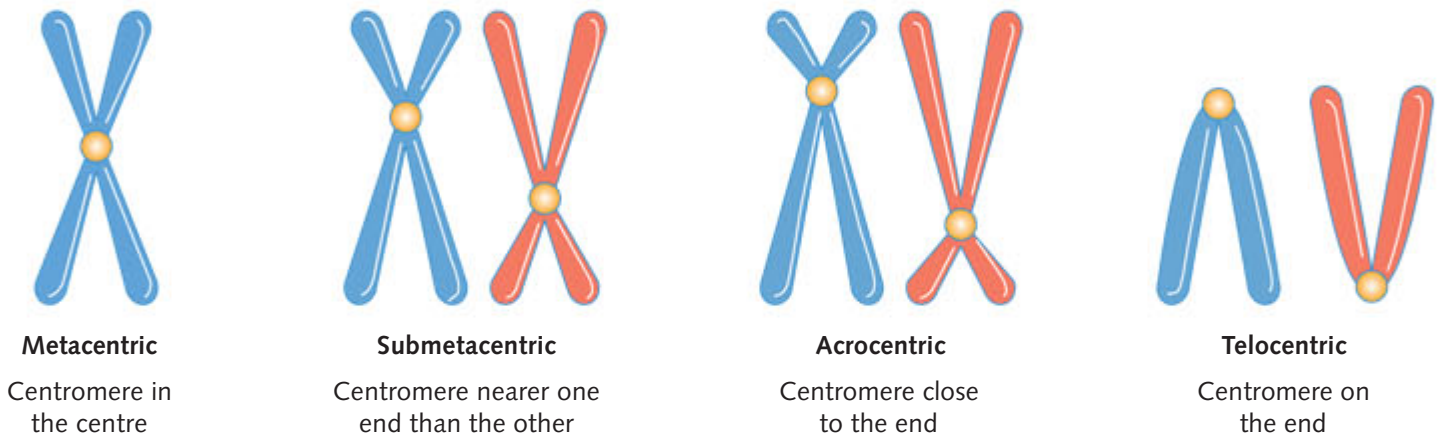

Figure 2.8 Chromosomes with centromeres in different positions

Metaphase

During **metaphase**, the chromosomes, each made up of two chromatids, move to the centre of the cell and line up along the equator (sometimes called the metaphase plate), as shown in Figure 2.9. The centromere of each chromosome is attached to a spindle fibre.

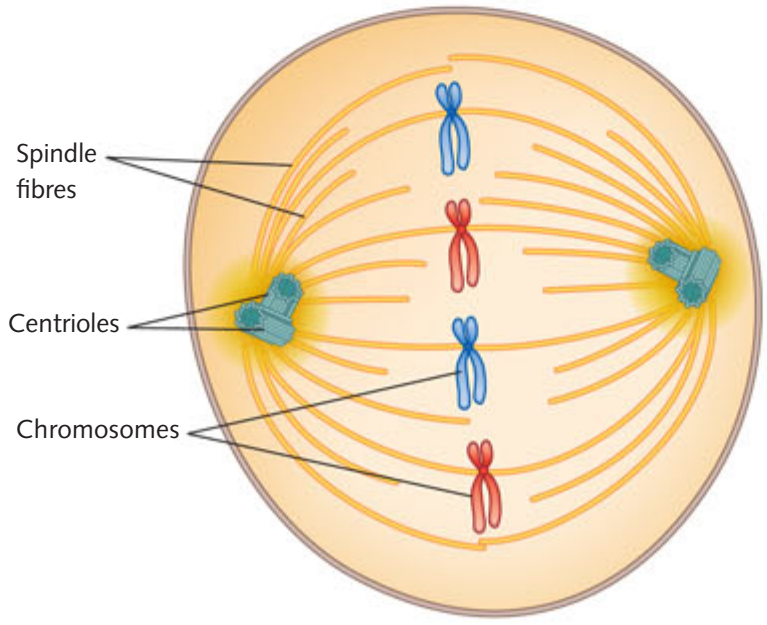

Figure 2.9 Metaphase in a eukaryotic animal cell

Anaphase

During **anaphase**, the spindle fibres attached to the centromere contract to either end of the cell (**poles**) and pull the chromatids apart. Chromatids separate at the centromere (at structures called kinetochores, of which there are two, one for each chromatid) and move to opposite poles of the cell. As the chromatids have become independent of each other they are now called chromosomes. Figure 2.10 shows this process.

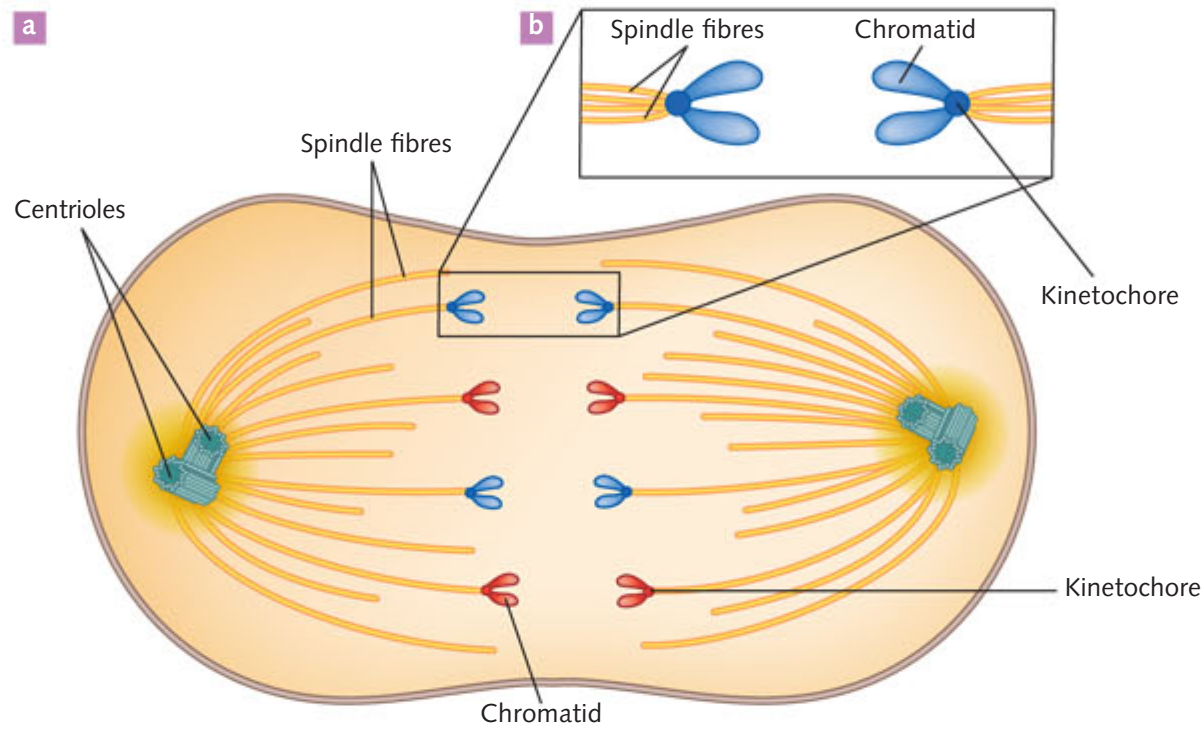

Figure 2.10a Anaphase in a eukaryotic animal cell b Spindle fibres attached to two sister chromatids pulling them to opposite poles of the cell

Telophase

During **telophase**, the two sets of separate chromosomes form tight clusters at each pole of the cell, as shown in Figure 2.11. The chromosomes de-condense as the chromatin unwinds and becomes less visible. A new nuclear envelope forms, nucleoli reform and the spindle disassembles. Figure 2.12a summarises mitosis for an animal cell, and Figure 2.12b shows mitosis in onion root tip cells.

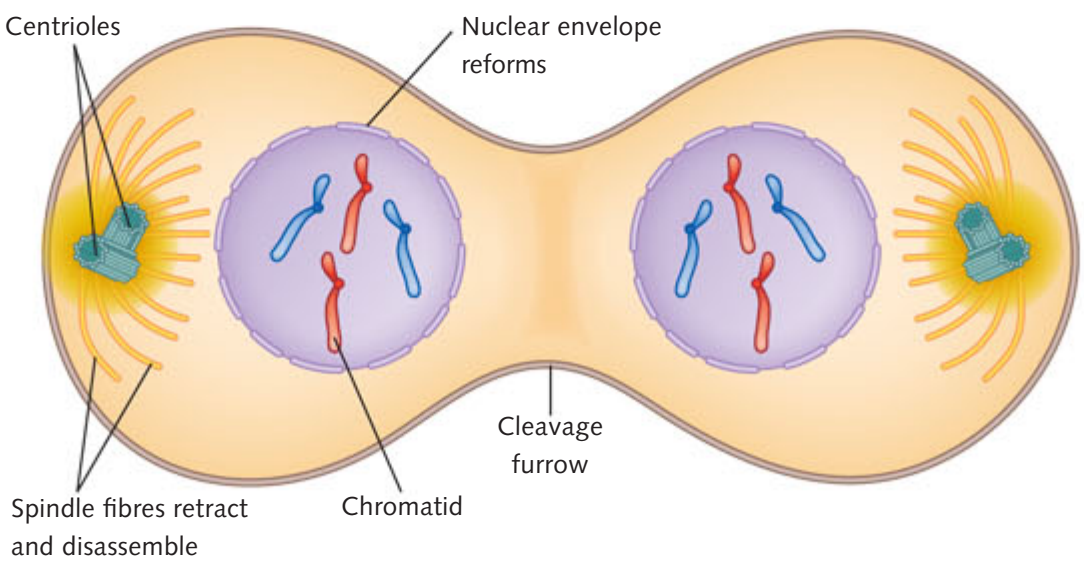

Figure 2.11 Telophase in a eukaryotic animal cell

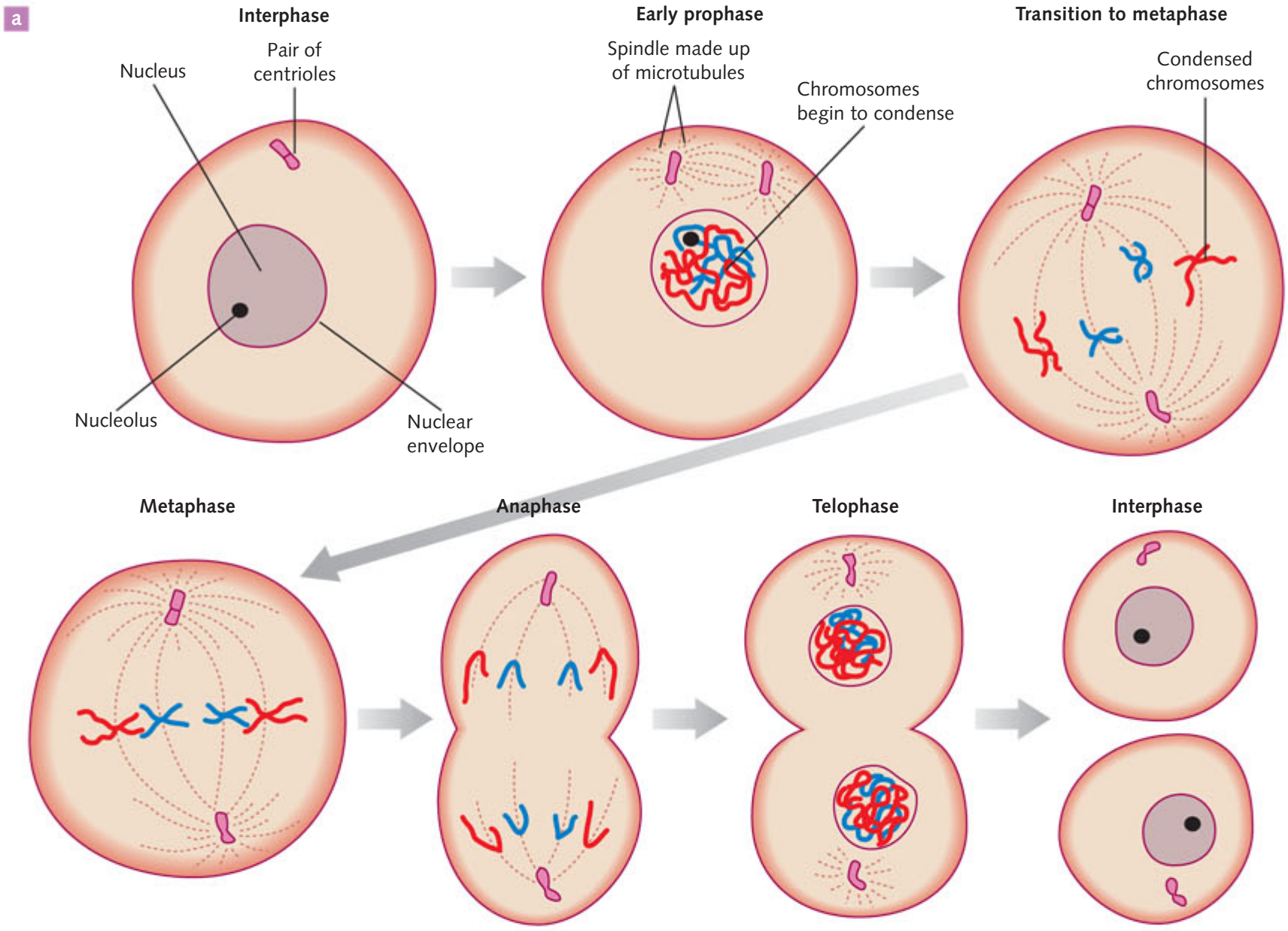

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Figure 2.12 Putting it all together **a** The stages of mitosis in animal cells **b** Mitosis in the root tip cells of onion

Cytokinesis in eukaryotic cells

Following mitosis, cytoplasmic division (called **cytokinesis**) occurs. In animal cells the cytoplasm divides by a process known as **cleavage**. The plasma membrane around the middle of the cell draws together to form a **cleavage furrow**; Figure 2.13a shows this for an animal cell. The cleavage furrow continues to develop until it eventually meets, and the cell is then cleaved, or split, with two new daughter cells resulting (Figure 2.13b).

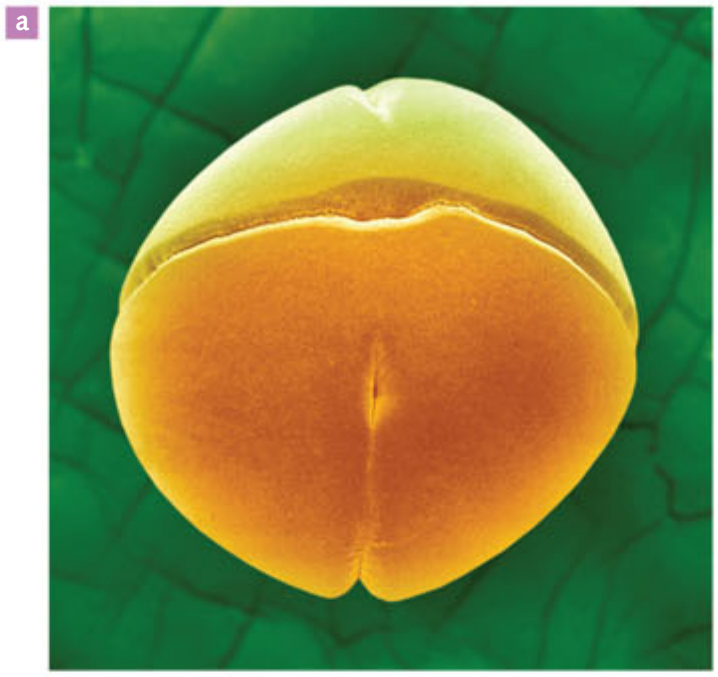

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Figure 2.13a Micrograph of an animal cell during cytokinesis **b** Cytokinesis in an animal cell results in the formation of a cleavage furrow, where the cell eventually divides to produce two new daughter cells.

Plant cells have a cell wall around their plasma membrane so the process of cleavage is slightly different. In plant cells, a new cell wall must form around each daughter cell and so cytokinesis of plant cells involves the formation of a structure called a **cell plate**. Figure 2.14 shows how parts of the cell wall fuse with parts of the spindle, forming the cell plate. Cellulose is deposited at this site, forming a wall that divides the parent cell into two daughter cells, each one with a plasma membrane.

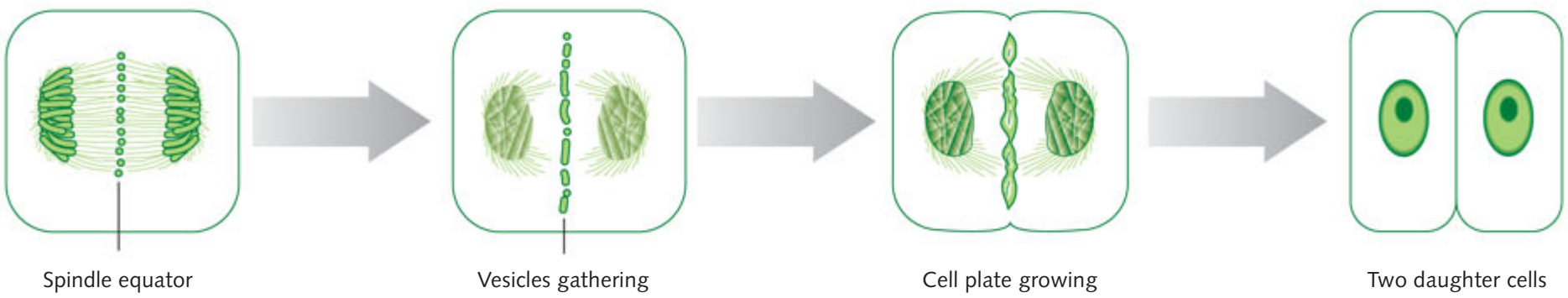

Figure 2.14 Cytokinesis in a plant cell results from the formation of a cell plate, on which cellulose is deposited to form a cell wall around the two new daughter cells.

Mitosis and cytoplasmic division thus result in the formation of two daughter cells, which now enter interphase. Because each chromosome has been duplicated and the duplicates have separated into daughter cells, each daughter cell has exactly the same number and type of chromosomes as the parent cell. The genetic information is therefore passed on completely and without change, from parent cell to daughter cells. The two new daughter cells can now differentiate into specialised types of cells. For example, in animals they could become blood cells or skin cells, and in plants they could become leaf cells or root cells.

ACTIVITY 2.1

Identifying stages of the cell cycle

The cell cycle describes the sequence of events from one cell division to another. Mitosis is one of the phases of the cell cycle and is itself divided into a number of stages.

What to do

Part A

1. In the middle of an A3 piece of paper or other surface, draw a graphic depicting the cell cycle. You may wish to use a graphic similar to Figure 2.3. Alternatively, you could create an infographic or digital presentation.
2. Create four chromosomes from items such as beads, string, pipe cleaners or any other material you decide on. Start at the G_1 phase of the cell cycle. Model the events that happen at each phase, including all phases of the M (mitosis) phase, with your model chromosomes.
3. As you work through each of the phases, record an image and detailed description on the outside of your cell cycle graphic.

Part B

Obtain some prepared slides of dividing cells. (These are often from the root tip of an onion.) Using a light microscope, locate cells in each of the phases of mitosis. On your model page, make a labelled drawing of each cell, showing different phases. Alternatively, you could take an image of the cell and add it to your digital presentation.

What did you discover?

1. Interphase is the stage between nuclear divisions.
   a. List the phases that comprise interphase.
   b. Suggest why interphase takes up the longest time in the cell cycle.
2. Describe three differences between your model cell drawings and cells from the prepared slide.
3. Propose an explanation of why centrioles and spindles were not observed in the prepared slides.
4. Discuss how useful model making was in your understanding of the cell cycle.

Cell cycle checkpoints

WB 2.2.3 CELL CYCLE CHECKPOINTS PAGE 47

The amount of information and complexity contained in DNA is vast and, every time DNA replicates, there is a chance that mistakes or **mutations** will arise. Mutations can be detrimental to a cell and even to the whole organism. Ensuring that mutations are repaired before the cell continues through the cell cycle to cell division depends on cell cycle checkpoints. Cellular signals control progression through the checkpoints, depending on whether key cellular processes such as DNA replication have been completed correctly.

A group of molecules called **cyclins** and **cycline-dependent kinases (CDKs)** act as gatekeepers for each of the checkpoints of the cell cycle. Cyclins and some CDKs promote cell cycle progression, while other CDKs inhibit and stop the cell cycle.

G_1 checkpoint

Prior to DNA replication in the S (synthesis) phase, the G_1 checkpoint checks DNA for any damage, makes sure nutrients are sufficient, and that cell size and growth patterns are normal. If these conditions are not met, CDK inhibitors will stop progression of the cell cycle while DNA damage is repaired or nutrients are imported. If any detected damage cannot be repaired, **apoptosis** (programmed cell death, p. 66) will be initiated to destroy the cell.

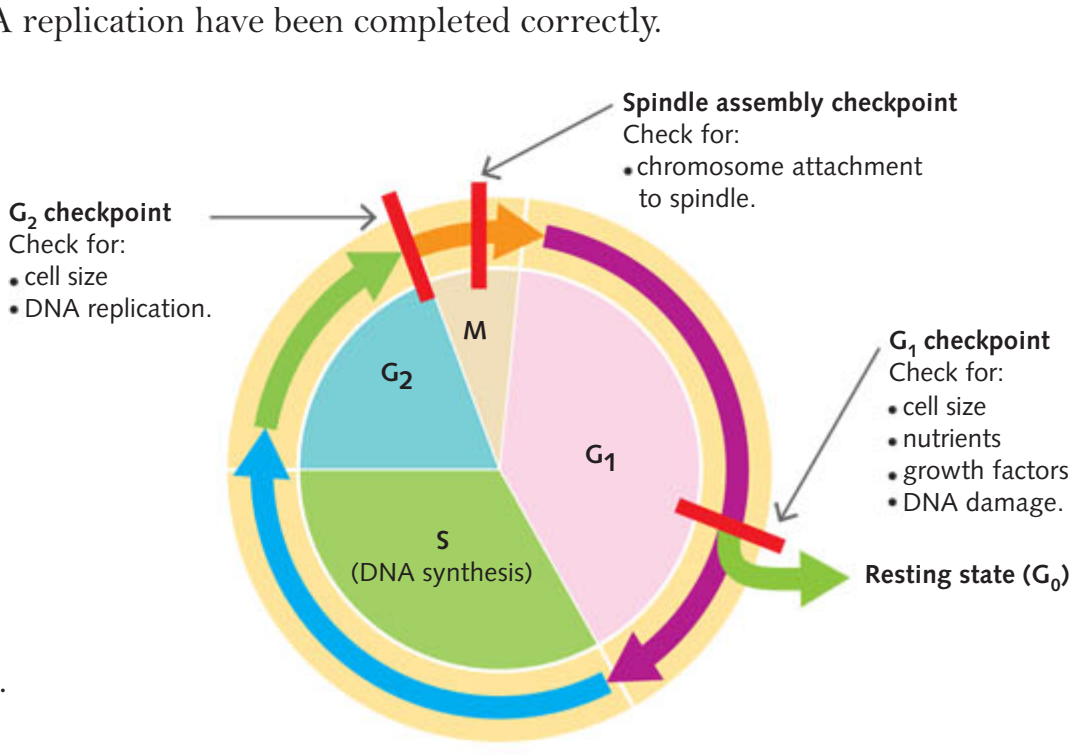

Figure 2.15 Cell cycle checkpoints

G_2 checkpoint

The next checkpoint happens at the end of the G_2 phase. The cell cycle can pause for a period of time at this point in the cycle. DNA is again screened for any structural damage and checks are made to determine whether replication of DNA has proceeded without any errors. If there are replication errors or DNA is damaged, the cell cycle will stop to allow DNA repair mechanisms to do their work, or apoptosis will be induced if the damage is beyond repair. Cell size is also checked at this point.

Mitosis checkpoint

During mitosis, in particular the metaphase/anaphase transition, checks are made on the spindle for defects in chromosome attachment. Chromosomes must be aligned correctly, and chromatids separated properly. If anaphase is initiated before both centromeres of a replicated chromosome become attached to the spindle, daughter cells are produced that have a missing or extra chromosome.

KEY CONCEPTS

- The cell cycle is the series of phases that a dividing eukaryotic cell passes through from one cell division to another. It is divided into G_1 phase, S phase, G_2 phase and M phase.
- Eukaryotic cell division involves a number of phases resulting in nuclear division (mitosis) and cytoplasmic division (cytokinesis).
- Mitosis is the division of the nucleus. It is divided into phases called prophase, metaphase, anaphase and telophase.
- Cells spend most of their time in interphase, which is a period of active growth (G_1 phase), synthesis of DNA (S phase) and preparation for the next division (G_2 phase).
- Daughter cells formed by mitosis have the same genetic material as their parent cell.
- A number of checkpoints throughout the cell cycle determine whether conditions are adequate to continue with the cell cycle.

Concept questions 2.2

1 Explain why cell division is part of the cell cycle.
2 Name the four phases of the cell cycle.
3 Distinguish between mitosis and cytokinesis.
4 Draw an annotated graphic that summarises the cell cycle, including the phases of mitosis.
5 Suggest why it is important for DNA to replicate before cell division.
6 **a** Name the checkpoints in the cell cycle.
b List three reasons why it is important to regulate the cell cycle.
c Explain why cyclins and CDKs are termed 'gatekeepers'.

HOT Challenge

7 A cell fails to proceed from G_2 to M phase. Explain why this could happen and list the possible resolutions that could occur.

WB 2.3.1 WHEN APOPTOSIS FAILS: HeLa CELLS PAGE 48

2.3 Apoptosis

Cells do not live forever; they age, and then they die at a given point in their life. For example, some skin cells, known as keratinocytes, live for approximately 3 weeks. The dead cells form a surface layer that is continually shed. Keratinocytes self-destruct in an orderly and programmed manner called apoptosis, also known as programmed cell death. In contrast, if a cell dies because there is damage to its plasma membrane, this is defined as **necrosis**.

Apoptosis occurs in invertebrates, vertebrates and plants, and the proteins and fundamental processes involved are remarkably similar across diverse organisms. When coral cells are treated with a human protein that causes apoptosis, TNFa, apoptosis is up-regulated and the coral shows signs of bleaching. Bleaching occurs in corals when the coral is under stress and evicts the symbiotic algae that give it colour; it is usually associated with apoptosis of the coral cells. The ability of the human protein to activate the apoptotic program in coral cells indicates that this apoptotic pathway evolved very early and remained essentially the same throughout evolution.

Because of the fairly uniform and highly coordinated way in which apoptosis proceeds once it has begun, apoptosis is often called programmed cell death. The demise of these cells is genetically programmed. Signals for apoptosis to start can come from within the cell or from other cells. When the time comes, death is orchestrated by the regulated expression of dozens of genes. Apoptotic cells are destroyed through a series of active, orderly events that start with enzymes shredding a dying cell's DNA into thousands of fragments. The nucleus is gradually dismantled and the membrane begins to form **blebs**. Blebs are balloon-like outgrowths of the plasma membrane. They occur when the plasma membrane detaches from the underlying cytoskeleton. The membrane inflates rapidly and stops abruptly. Eventually, apoptotic bodies, containing the contents of the dead cell encased by plasma membrane, are formed and are cleared by scavenging cells called **phagocytes**, particularly **macrophages**, as seen in Figure 2.16.

All cells in multicellular organisms are capable of undergoing apoptosis. Under certain conditions, such as when cells have been infected or when a cell has reached the end of its natural life span after a certain amount of normal wear and tear, the apoptotic program can be activated.

Weblink
What is apoptosis?

Worksheet
What is apoptosis?

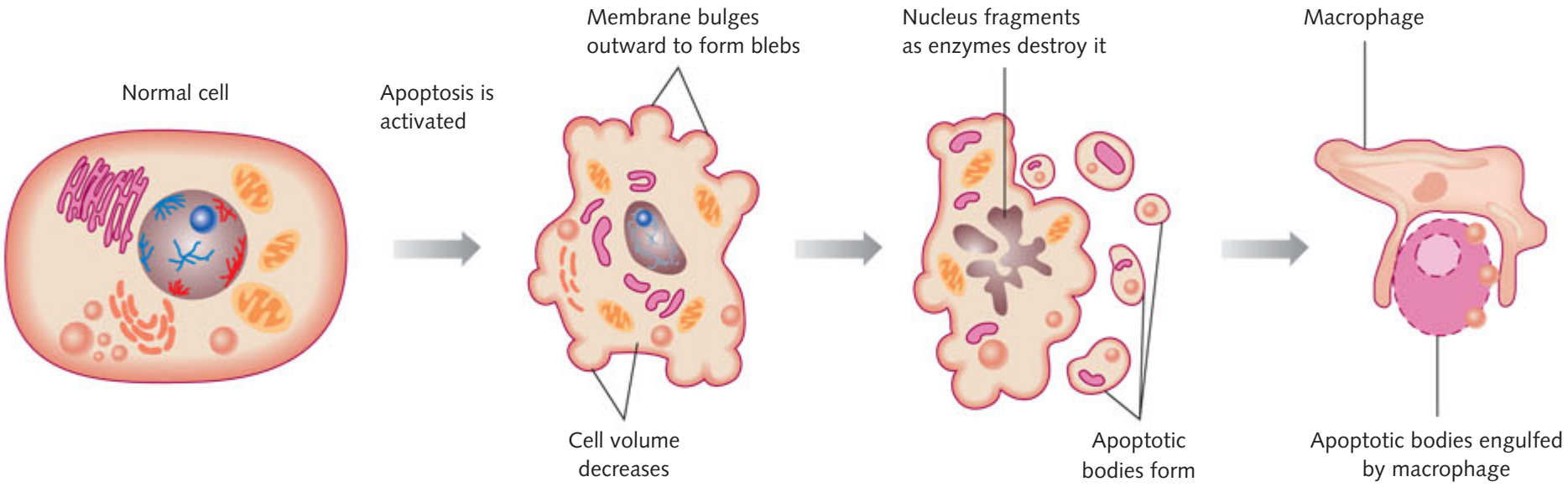

Figure 2.16 An overview of how apoptosis works

Far from being detrimental to an organism, controlled cell death is a vital and formative process that is essential for shaping organs and tissues during development and removing cells that are old or no longer needed. For example, apoptosis enables a tadpole to lose its tail as it becomes a frog and a human **embryo** to lose the webbing between its fingers and toes. In fact, almost all multicellular organisms have cells that are born to die.

Figure 2.17 During mouse embryonic development, programmed cell death (apoptosis) leads to loss of cells in the webbing, or interdigital tissue, between fingers to help form a paw.

Failure in apoptosis can result in many problems, ranging from developmental defects to **cancer**. An important stage in the formation of cancer occurs when apoptosis is avoided and cells do not die as they should. Some **tumour** cells have changes to their apoptosis genes that make them unable to activate the apoptosis program or become unresponsive to pro-apoptotic stimuli. Cancer is normally controlled by keeping a tight rein

on cell division, particularly by preventing division when damage has occurred to DNA. When this damage cannot be repaired, apoptosis is initiated and the cell is disposed of. It is much safer to remove an individual cell, replacing it later, than to allow the cell to persist if it carries changes in its DNA that may result in cancer.

Conventional cancer treatments usually target sick and healthy cells alike, so one treatment goal is to find drugs that trigger apoptosis only in cancer cells. Some proteins seem to act as a brake; that is, when they are not produced, apoptosis begins. Pharmaceutical companies are searching for ways to inhibit these proteins in the hope of finding drugs that will disable them only in cancer cells.

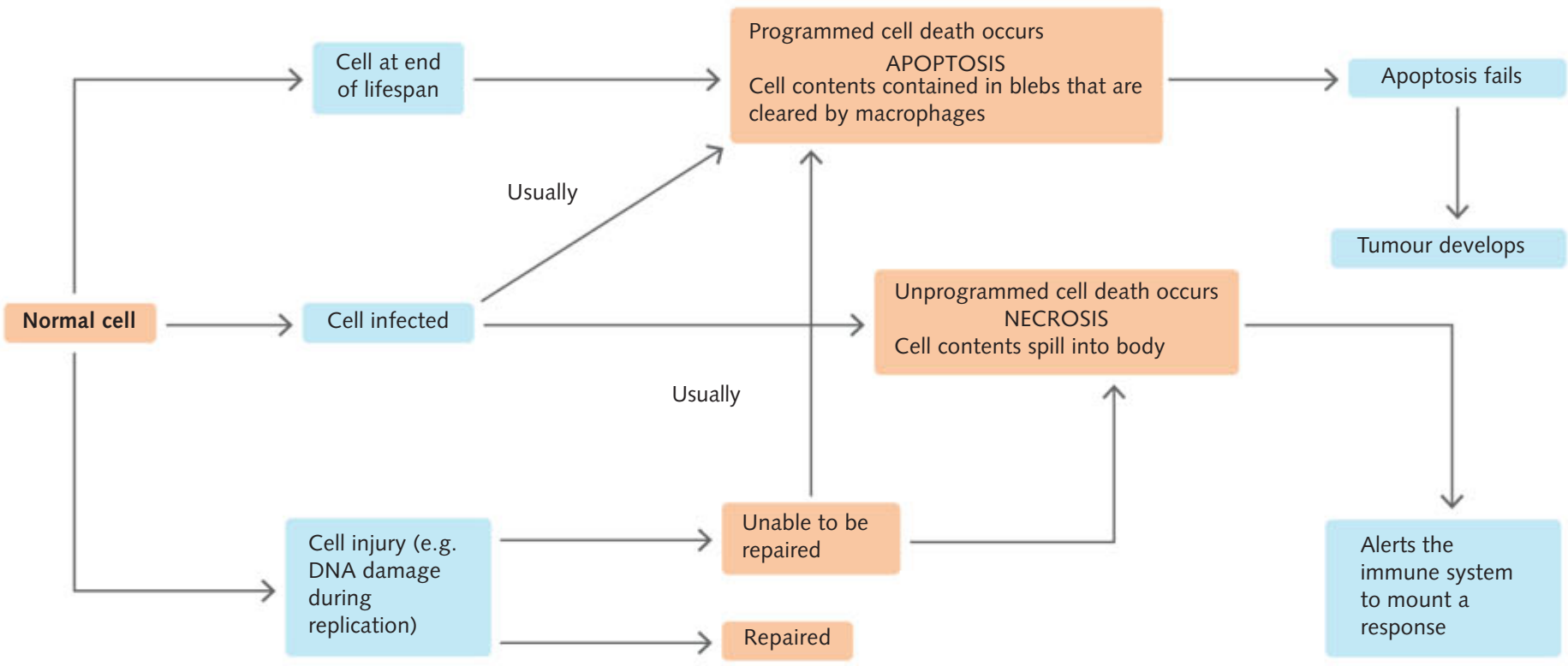

Figure 2.18 Summary of potential cell fates

KEY CONCEPTS

- Apoptosis is a carefully regulated, active process of programmed cell death that is essential for normal development of multicellular organisms.
- Apoptosis is important for development, removing unwanted cells and protecting an organism from ill health.
- Apoptosis can be triggered by signals from within the cell and external to the cell.
- Apoptosis is controlled by genes that code for enzymes (proteins).
- During apoptosis the cell is dismantled, forming blebs and apoptotic bodies, which are engulfed by phagocytes.
- Failure in apoptosis could result in cells forming a cancerous tumour.

Concept questions 2.3

1 Name two types of cells that would be destroyed by apoptosis.
2 What are blebs and how are they important in the apoptosis process?
3 Outline the sequence of events in apoptosis.
4 Explain why apoptosis is important for maintaining life.
5 Explain what types of events might trigger apoptosis. Include examples in your explanation.

HOT Challenge

6 Checkpoint inhibitors are used in cancer treatment. Tumours form when mutations lead to uncontrolled cell divisions and comprehensive apoptosis does not occur to remove the faulty cells. The G_2 DNA damage checkpoint is a site of particular interest to researchers. Using your understanding of the G_2 checkpoint, why would this be a reasonable focus for investigational research?

2.4 Disruption to the regulation of the cell cycle

WB 2.4.1 PROTO-ONCOGENES AND TUMOUR SUPPRESSOR GENES PAGE 49

Two types of genes play a major role in regulating the cell cycle, and their importance has been realised by their abnormal activities in cancer. One group of genes, called **proto-oncogenes** (meaning genes that can promote cancer), code for proteins that can stimulate cell division, prevent cell **differentiation** or regulate programmed cell death. Proteins produced by these genes act like accelerators, stimulating the cell to grow and divide. These processes are essential for normal growth and development and the maintenance of healthy organs and tissues. Any change in these genes that enhances their production or function can promote uncontrolled cell growth and cancer.

In contrast, genes called **tumour suppressor genes** inhibit cell division. Tumour suppressor genes are normal genes that slow down cell division, repair DNA mistakes, or tell cells when to die. Proteins produced by these genes act like brakes to slow down or stop cell division. They normally keep the cell from dividing too quickly, just as a brake keeps a car from going too fast. Most of these genes have been discovered because they are mutated or silenced in cancer.

The balance between the activities of proto-oncogenes and tumour suppressor genes keeps normal cells dividing at a rate that is appropriate for their position and role in the body.

A very important means of controlling the cell cycle is via the ***p53* gene**. This gene activates when DNA damage is detected, or cell injury occurs. When the levels of p53 protein increase in response to DNA damage, one of two possible pathways is triggered, depending on the stage of the cell cycle. During the early stage of the cell cycle, such as just after the M phase, progress is halted to allow damaged DNA to be repaired. During the later stages of the cell cycle, at G_2 phase, apoptosis is initiated to prevent the damaged cell from replicating (Figure 2.20).

p53 is sometimes called the 'guardian of the genome'. In many types of cancer, the *p53* gene is mutated and the loss of p53 protein results in rapid, unchecked cell proliferation and evasion of apoptosis. A mutation in this gene causes Li-Fraumeni syndrome, in which multiple cancers develop at a relatively young age.

There are other genes that normally act to suppress uncontrolled cell growth, such as the *BRCA1* and *BRCA2* genes (named BRCA because they were discovered in breast cancer). Proteins produced by these genes protect the cell's DNA by repairing damage to it. If a person has inherited a harmful mutation in either the *BRCA1* or the *BRCA2* gene such that its protein product is not made or does not function correctly, DNA damage may not be repaired properly and the person is at a heightened risk of developing breast cancer. They may also be at increased risk of other types of cancer.

If mutated, another gene called *RB1* results in retinoblastoma, a cancer of the retina in the eye. *RB1* normally inhibits progression of the cell cycle. Like the *BRCA* genes, it is a tumour suppressor gene. Normally, by the time an embryo has developed, immature cells in the retina have stopped growing and dividing. The immature retinoblasts become differentiated, resulting in distinct photoreceptor and nerve cells within the retina. In children with the mutated gene, the cell cycle continues and differentiation does not occur. Retinal tumours develop. While genes such as *BRCA1*, *BRCA2* and *RB1* are named according to particular cancers in which they have been implicated, these genes, like *p53*, are important in controlling the cell cycle in most cell types and are found to be mutated in many different cancers.

a

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b

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Figure 2.19a Proto-oncogenes act like the accelerator on a car. **b** Tumour suppressor genes act like the brakes on a car.

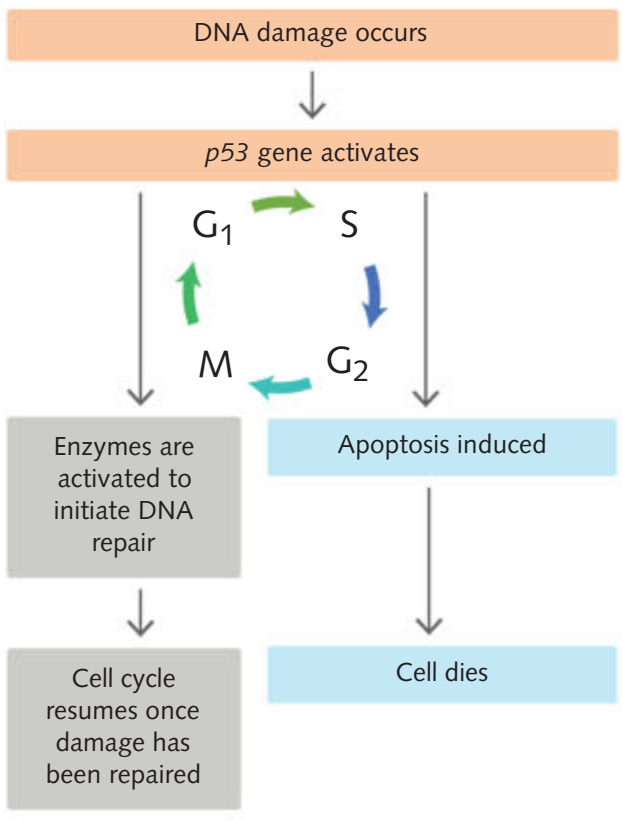

Figure 2.20 ***p53* gene activates either DNA repair or apoptosis**

Genetic predisposition to cancer

Mutations in proto-oncogenes and tumour suppressor genes such as *BRCA1* or *BRCA2* increase the likelihood of cancer because they impair the mechanisms that suppress cancer. They result in a **genetic predisposition** (genetic susceptibility resulting in an increased risk) to cancer. However, while some people with a genetic predisposition will get cancer, others will never get it. This is because the risk of the disease developing is altered by many factors in addition to the gene variations. They can include viral infection, lifestyle habits and environmental factors such as exposure to certain chemicals. For example, smoking is a known cancer-causing environmental factor. It is more likely that a smoker with a genetic predisposition will get cancer than a smoker without a genetic predisposition for cancer.

Apoptosis and anti-cancer drugs

Many mutations that lead to the development of cancerous tumours indicate a malfunction of apoptosis within the cell cycle. Chemotherapy often focuses on reinstating apoptosis within the tumour cells; however, cancerous cells are often resistant to the effects of these treatments.

Chemotherapy in early-stage cancer is usually designed to kill cancer cells. The success of this treatment is demonstrated by whether the patient suffers relapse or not. If a second line of chemotherapy is required, it typically employs drugs that activate the programmed cell death pathway within the cell. The drugs regulate a sequence of apoptosis-related genes in malignant cells to end the cell cycle and promote apoptosis.

Resistance to the effects of the chemotherapy is common, however, and this leads to ineffective treatments. Drug resistance can occur if there are changes to the target. For example, some drugs target the DNA in the nucleus of the cell, but changes to the DNA may mean they accumulate in the cell's cytoplasm instead. The end result can be mutations in both **oncogenes** and tumour suppressor genes, and this allows uncontrolled cell growth to take place. Treatments for some cancers must now ensure that resistance to the drugs used is minimised.

Researchers have identified a number of genes that require mobilisation to ensure the success of chemotherapy. As well as inducing pro-apoptosis effects in cancer cells, the activity of anti-apoptotic proteins needs to be reduced. It is these anti-apoptotic proteins that lead to cancer resistance. Current research in the battle against cancers includes developing an in-depth understanding of the way cells evade apoptosis so that cancer resistance to chemotherapy can be circumvented. At present, the most effective approach appears to be to use a number of drugs simultaneously.

KEY CONCEPTS

- The balance between the activities of proto-oncogenes and tumour suppressor genes keeps normal cells dividing at a rate that is appropriate for their position and role in the body.
- The *p53* gene initiates either DNA repair or apoptosis of cells.
- Failure of the *p53* gene results in rapid, unchecked cell proliferation and evasion of apoptosis.
- Mutations in proto-oncogenes and tumour suppressor genes lead to a genetic predisposition to cancer.
- Many chemotherapy treatments focus on reinstating apoptosis within the tumour cells.

Concept questions 2.4a

1. What type of event could lead proto-oncogenes to promote tumours?
2. Tumour suppressor genes are the 'brakes' on uncontrolled cell division. How do they do this?
3. Describe what would happen if the *p53* surveillance system did not work properly.
4. Define genetic predisposition.
5. Explain in your own words the meaning of the following sentence about chemotherapy drugs used in cancer treatment.

   'As well as inducing pro-apoptosis effects in cancer cells, there also needs to be a reduction in the effects of the upregulation of anti-apoptotic proteins.'

HOT Challenge

6 Insurance companies may seek to have a copy of your genome so that they can look for genes that may predispose you to certain conditions. On the basis of the information they obtain, they may refuse to insure you against the effects of those conditions if they occur later in life. Is this fair or not fair? Explain your reasoning.

Action of mutagens on the cell cycle

WB 2.4.2 ACTION OF MUTAGENS ON THE CELL CYCLE PAGE 51

In the 1970s it was shown that many cancer-causing agents, such as certain chemicals and radiation, caused cancer by making changes in DNA. Research showed that the cancer-causing agents were powerful **mutagens** – agents that can induce or increase the frequency of mutation in DNA. This gave scientists an important clue as to what might make cells become cancerous.

When mutated, proto-oncogenes can become oncogenes – genes that stimulate excessive cell division. The gene can become permanently turned on or activated when it is not supposed to be. The production of oncogenic proteins can lead to unregulated cell division, a slower rate of cell differentiation and inhibition of cell death. When this happens, the cell grows out of control and this can lead to cancer.

Chemical mutagens

The many types of **chemical mutagens** have one thing in common: their ability to interfere with DNA, by interrupting its structure, sequence or replication. Mutagens can introduce mutations in DNA that can change the function of proteins in the cell and impair normal cellular processes. This is especially dangerous when the mutations affect tumour suppressor genes or proto-oncogenes. If the mutation causes the tumour suppressor to become inactive, the result is impaired regulation of cell cycle checkpoints and loss of inhibition of cell growth, allowing the cell to keep dividing in an uncontrolled manner. If a mutation affects a proto-oncogene, boosting its activity, a similar effect on cell growth may occur.

Tobacco smoke contains a number of cancer-causing chemicals called **carcinogens**. Some of these chemicals cause changes in genes that control spindle formation. The resulting irregular division and instability of chromosomes commonly result in uncontrolled cell cycles. The chemical carcinogens in cigarettes are a major identified cause of cancer in humans. It is estimated that smoking is responsible for many cancer deaths, including those from lung cancer and cancers of the mouth, pharynx, larynx, oesophagus and other sites.

Environmental factors have been shown to cause defects in a developing **foetus**. During pregnancy, if a woman smokes, or consumes alcohol or other drugs, the developing foetus may be adversely affected. Many chemicals and drugs have been shown to be toxic and teratogenic to a developing foetus. A teratogenic agent (or **teratogen**) is one that causes physical defects in the developing foetus. The wide range of potential teratogens includes some hormones, some antibiotics, oral anticoagulants, anticonvulsants, anti-tumour drugs, thyroid drugs, thalidomide, LSD and marijuana. The actions and effects of teratogens vary significantly.

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Figure 2.21 Many children of women who took the drug thalidomide during pregnancy in the 1950s were born with malformed limbs.

Developed by Southern Biological

INVESTIGATION 2.1

Investigating the effect of UV on *Saccharomyces cerevisiae*

Background

We classify the broad spectrum of electromagnetic radiation from the Sun into segments according to the effects we experience. For example, the warm sensation of sunshine on our skin is caused by invisible infrared radiation with wavelengths ranging from 700 nm to 1000 000 nm (1 mm). Visible light is comprised of wavelengths between 400 nm (violet) and 700 nm (red). Radiation with wavelengths shorter than 400 nm but longer than 10 nm is classified as ultraviolet (UV) radiation. Radiation with wavelengths shorter than 10 nm is classified as X-rays. Some exposure to UV radiation is necessary for humans to produce vitamin D, but a careful balance is required because X-rays and UV radiation are destructive to many biological molecules, including DNA. Fortunately, Earth's atmosphere acts as a protective screen and filters out almost all the Sun's radiation with wavelengths shorter than 290 nm. Nevertheless, the narrow UV band from 290–400 nm that can penetrate the atmosphere and reach the surface of Earth is capable of causing photochemical damage to DNA that can lead to skin cancer, so it is important to avoid over-exposure. As a defence against too much UV exposure, most organisms that are subject to the Sun's rays have evolved to incorporate some level of DNA repair in their cell mechanisms. This confers a limited amount of inherent UV resistance.

Aim

To determine how UV radiation can be destructive for many biological molecules

Time requirement

55 minutes
Schedule the investigation at a time of year when you can be sure of bright sunny conditions.

Materials

- UV-sensitive yeast, Live Slope starter plate
- Wild yeast, Live Slope starter plate
- 8 sterile swabs
- 8 YED agar plates
- 4 plastic pipettes
- 2 sterile culture tubes
- Bunsen burner
- Adhesive tape
- Permanent marker
- Sterile inoculation loop
- Ethanol or bleach
- Sterile water
- Disposable gloves
- Aluminium foil

What are the risks in this investigation?	How can you manage these risks to stay safe?
While lab strains are usually harmless, fungi may cause disease, so assume them to be pathogenic.	Wear lab coats, safety glasses and gloves; wash hands thoroughly at end. Decontaminate benches before and after activity. Flood spills with bleach.
Microorganisms will grow on the agar plates.	Do not open plates once they are securely taped. Dispose of plates appropriately after autoclaving.
Disposable gloves may pose allergy risk.	Use a type of glove that removes allergy risk and is suited to chemicals being used.

Method

Part A: Inoculation of exposure plates

Note: To use aseptic technique, wipe your bench down with ethanol (or bleach) and keep your work near the Bunsen burner to take advantage of the updraught the flame will create to waft potential contaminants away from your materials.

1 Collect eight sterile agar plates and label them as shown in Figure 2.22, using a permanent marker.
2 Using a plastic pipette, place 1 mL of sterile water into a sterile culture tube.

3 Using a sterile inoculation loop, carefully scrape a single colony of the UV-sensitive yeast from the starter plate.
4 Select a large colony (>4 mm in diameter) or, if the colonies are small, scrape up two, even three, colonies onto the loop.
5 Place the loop in the water in the sterile tube and spin/swirl it to transfer the yeast into the water.
6 Visually check that the cell mass has transferred from the loop to the water.
7 Using a plastic pipette, immediately pump the liquid to distribute and suspend the yeast cells in the water. Avoid introducing air bubbles or splashing the liquid up the sides of the tube. When finished, hold the tube up to the light to check that there are no visible lumps or particles in the water.

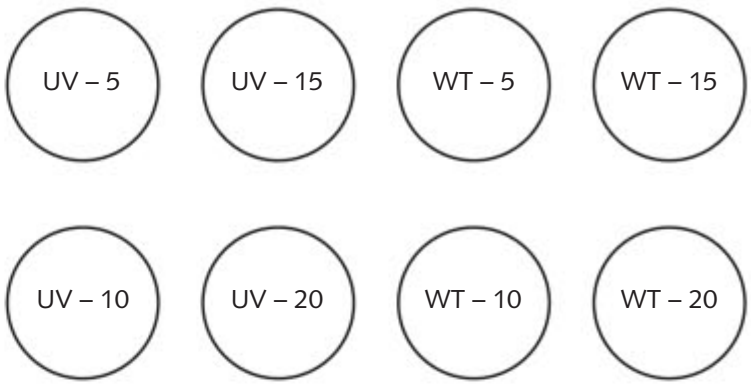

Figure 2.22 Labelled agar plates

8 Dip a sterile swab into the yeast suspension and, as you withdraw it, press it against the sides of the tube to squeeze out excess water. It should come out moist but not dripping.
9 Using aseptic technique, 'paint' the surface of the 'UV – 5' YED plate in three directions to inoculate for a lawn culture.
10 Cover the plate to shield it from light and allow it to rest the right way up (with agar at the bottom) for a period of at least 15 minutes and up to 1 hour. This allows the moisture from the swab to be absorbed by the agar.
11 Repeat steps 8–10 for the remaining three UV-sensitive yeast plates.
12 Using the wild-type yeast, repeat steps 2–10 for four plates.

Part B: Exposure to sunlight

13 State your hypothesis.
14 After the post-inoculation resting period, expose the inoculated plates from each strain to direct sunlight for 5, 10, 15 and 20 minutes respectively, according to the times written on the plates.
15 Immediately after exposure, incubate the plates in darkness for 48 hours at 30°C or four days at room temperature. For best results, follow these guidelines:
   a Keep the plate shielded from light until the last moment.
   b Use adhesive tape to attach the lid of the Petri dish to the base, but do not allow the tape to extend on to the surface of the lid where it will absorb UV light and shield the yeast from exposure.
   c Orientate the plate so the lid is pointing directly at the Sun. Aim to minimise the size of the shadow. If the Sun's rays strike the lid at a glancing angle, most of the UV light will be reflected and the effectiveness of the exposure will be reduced.

Results

1 Copy the table below into your logbook and fill in with the results of your investigation. Use the key below to indicate the level of coverage of the yeast on each agar plate.
   +++ High coverage
   ++ Medium coverage
   + Low coverage
   – No coverage

Table 2.1 UV exposure results

Exposure time (minutes)	UV-sensitive yeast coverage	Wild-type yeast coverage
0		
5		
10		
15		
20		

2 Graph your results in your logbook.
3 Compare the results of your UV-sensitive yeast sample with the wild-type yeast sample. What differences do you observe? What conclusions can you draw from this data?

Discussion

1 What is your hypothesis?
2 What is your independent variable?
3 What is the range of your independent variable?
4 What is your dependent variable?
5 What are your controlled variables and how did you control them?
6 Were there any extraneous variables that you needed to consider?
7 Compare your results with others in your class. Were the results consistent?
8 Did your investigation support or refute your hypothesis, or were your results inconclusive?

Conclusion

Write a conclusion of no more than 60 words for this investigation.

Taking it further

To protect our skin from harmful UV rays we apply different sunscreens with different sun protection factor (SPF) values. Do these values have any merit? Are commercially produced sunscreens any better than alternatives such as coconut oil, clothing material and sunglass lenses? Design an investigation to find out.

Physical mutagens

Physical factors including ultraviolet light, X-rays and nuclear radiation can cause mutations in DNA. Ultraviolet radiation has been shown to be a major contributing factor to human skin cancers. When UV light is absorbed, DNA can be damaged. This is not a problem as long as the DNA is efficiently repaired. However, with excessive exposure to sunlight the repair pathway in skin cells may be overwhelmed, allowing DNA damage to persist. Mutations in the tumour suppressor gene *p53* are thought to play a critical role in the development of pre-cancerous lesions and have been implicated in all types of skin cancer.

Biological mutagens

Biological factors, including some viruses, can cause mutations in DNA or impair cell cycle regulation, which can eventually result in cancer. Many viruses have evolved ways to keep their host cells alive despite the many cellular changes caused by viral infection. Some viruses have oncogenes that promote survival and replication of the infected cell. Viral DNA may also be inserted into proto-oncogenes in the host cell's chromosome, causing the gene to mutate into an oncogene; or viral DNA could be inserted into a tumour suppressor gene, disrupting its function. Any of these events could cause uncontrolled cell growth. Viruses associated with cancer include human papillomavirus, hepatitis B and Epstein-Barr virus.

Fortunately for us, our immune system is normally effective at removing any suspicious cells, such as those infected with a virus or transformed by cancer. These cells are attacked and destroyed by our immune cells. Usually, it is only when our immune system fails to adequately remove these cells that we are at risk of developing cancer.

During the 1990s, studies provided evidence of a relationship between infection with HPV (human papillomavirus) and cervical cancer. It was shown that where there was cervical cancer, there was also always HPV DNA. Professor Ian Frazer from the University of Queensland (Figure 2.23) and his team created a world-first vaccine against HPV and, hence, HPV-caused cervical cancer, in 1991. He was honoured as Australian of the Year in 2006. His research has the potential to eradicate virally induced cervical cancer.

Getty Images/Stringer/Jonathan Wood

Figure 2.23 **Professor Ian Frazer led a team that developed the world's first vaccine against a virus associated with cervical cancer.**

KEY CONCEPTS

» Cell cycle regulation can be disrupted by the action of chemical, physical or biological mutagens. Mutagens that can lead to cancer are called carcinogens.

» Mutagens can cause mutations in DNA that may affect proto-oncogenes or tumour suppressor genes, leading to uncontrolled cell division and potentially cancer.

Concept questions 2.4b

1 Distinguish between the following pairs of words:
   a mutagen and carcinogen
   b biological mutagen and chemical mutagen
   c proto-oncogene and oncogene
2 How is a chemical mutagen different from a carcinogen?
3 How do physical mutagens act on the cell cycle?
4 List one biological mutagen and explain how it can lead to cancer.
5 Why was cervical cancer thought to be caused by a biological mutagen?

HOT Challenge

6 One of the treatments for cancers is radiotherapy, which utilises radioactive isotopes (radioisotopes) to kill tumour cells. Radioisotopes, themselves, can behave as physical mutagens. Why do you think oncologists use something to treat cancer that may itself cause cancer?

2.5 Stem cells

WB 2.5.1 BIOETHICAL ISSUES: EMBRYONIC STEM CELLS PAGE 51

Mitosis ensures that each daughter cell receives the same genetic material as the parent cell. Therefore, every cell in an organism has the same genetic information. However, most of the cells of our body, such as blood, liver, brain and nerve cells, are specialised to perform particular functions. The process by which cells become specialised is called differentiation and this process is linked to cell division. Differentiated cells have become specialised by following a particular developmental pathway as they divide from their parental cells, and for them there is no turning back.

On the other hand, **stem cells** are undifferentiated cells that have the potential to replicate and to develop into many different kinds of cell.

Potency of stem cells

Several types of stem cells exist, and these will be described in the context of the ways in which humans develop. A fertilised egg has the potential to develop into a complete embryo. At this point, the fertilised egg is a **totipotent stem cell**, which means that it has total potential – the potential to create any type of cell necessary for embryonic development, including the embryo itself, and all the membranes associated with embryonic development.

In the first few hours after fertilisation, the fertilised egg undergoes several cell divisions that produce identical totipotent cells (Figure 2.24). Because these cells are still totipotent, any one of them has the potential to develop into an entire human being. In fact, identical twins are formed when two totipotent cells separate and develop into two genetically identical embryos.

The totipotent cells undergo several rounds of cell division. Approximately 5 days after fertilisation, they begin to specialise and form a **blastocyst**. The blastocyst is a ball of cells consisting of a hollow outer layer of cells, within which is a cluster of cells called the inner cell mass (Figure 2.25).

The outer layer of cells will eventually form the **placenta**, the organ that supplies nutrients to, and removes wastes from, the foetus and other tissues that are needed for the support and development of the foetus. The inner cell mass will form all the tissues of the human body; therefore, these

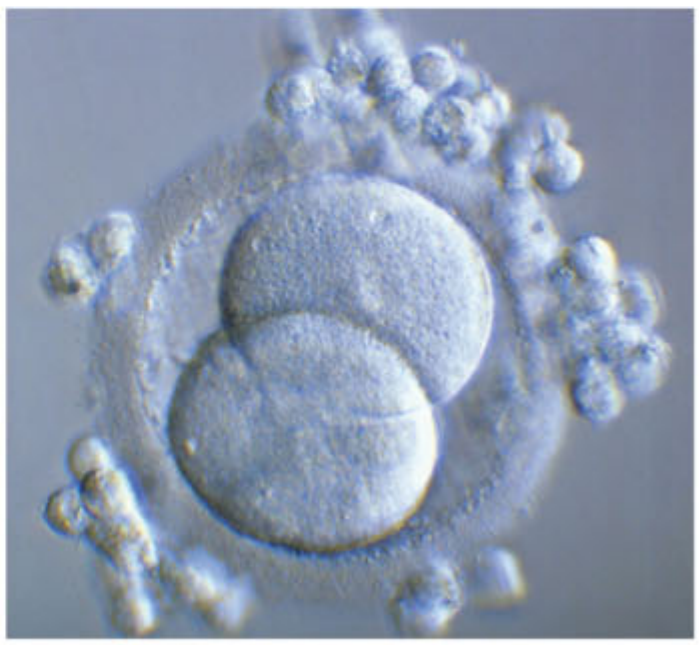

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Figure 2.24 A human embryo at the two-cell stage. In this photograph the embryo is still surrounded by the gelatinous covering that was around the egg.

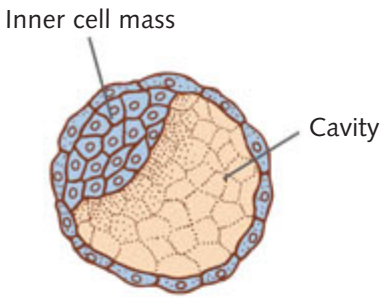


Figure 2.25 Blastocyst formation

are the cells that develop into the foetus. The cells of the inner cell mass are **pluripotent stem cells**. This means that they are able to give rise to all cell types in a foetus.

Each pluripotent cell then undergoes further specialisation into another type of stem cell, a **multipotent stem cell**. Multipotent stem cells give rise to cells that have a particular function (Figure 2.26). For example, multipotent blood stem cells give rise to red blood cells, white blood cells and platelets. In each person's bone marrow, blood stem cells constantly replenish the supply of red blood cells, multiple types of white blood cell and platelets. Multipotent skin stem cells give rise to the different types of skin cells.

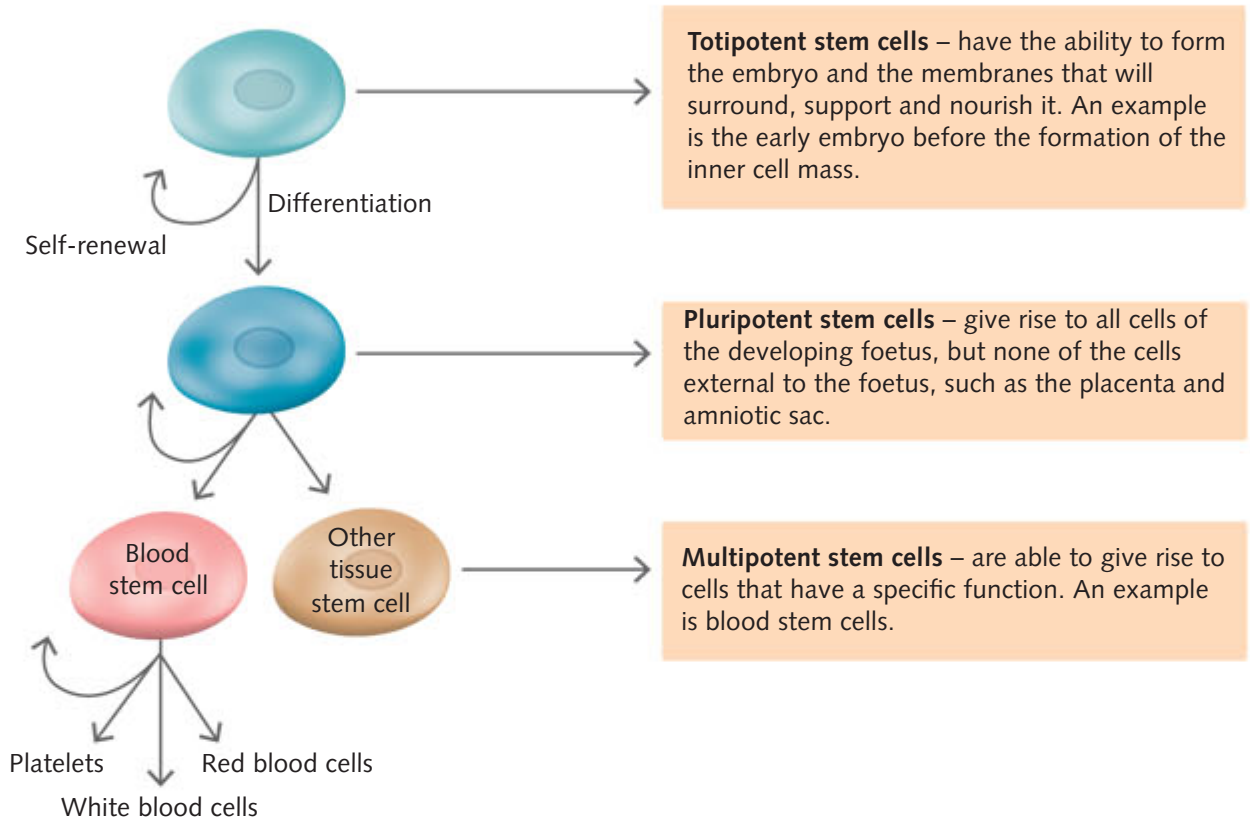


Figure 2.26 The process of cell differentiation

KEY CONCEPTS

- As they divide, unspecialised cells develop special characteristics through the process of differentiation to suit particular functions.
- Stem cells can differentiate into various tissues.
- Totipotent stem cells have the potential to form any type of cell necessary for embryonic development.
- Pluripotent stem cells have the ability to form many but not all types of cells necessary for foetal development.
- Multipotent stem cells give rise to cells that have a particular set of functions.

Concept questions 2.5

1. Do all cells start off as stem cells after cell division?
2. Describe the three different types of stem cells.
3. Explain the importance of stem cells to the body.
4. All stem cells, regardless of their source, have three general properties:
   - They are capable of dividing and renewing themselves for long periods
   - They are unspecialised
   - They can give rise to specialised cell types.

   Bone marrow contains large numbers of stem cells. What type of stem cells would be found in bone marrow and why is this a useful type of stem cell to have in the body?
5. Define differentiation and provide one example.

HOT Challenge

6. Map out the three different types of stem cells involved in the development of the blastocyst from the point of fertilisation of the egg.

BRANCHING OUT

Sources of stem cells for research and therapy

Stem cells have the potential to be used as a form of therapy to replace damaged or degenerated tissues – for example, in Parkinson's disease, diabetes and spinal injuries.

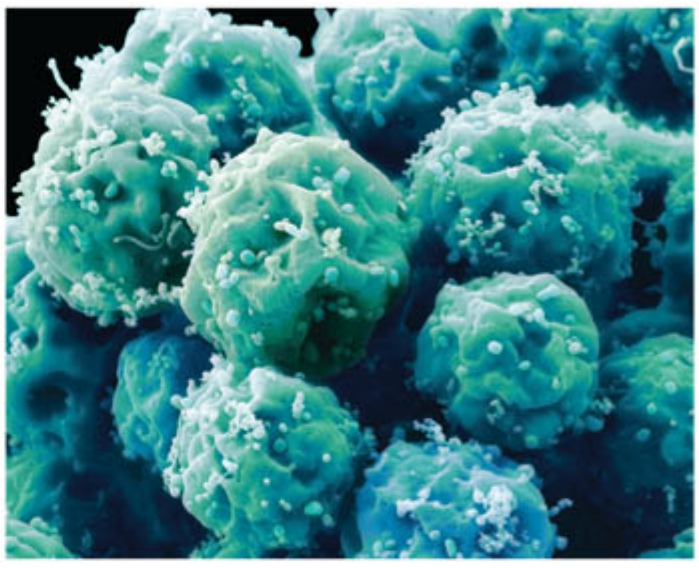
There are three sources of stem cells.

1 Umbilical cord blood and placental stem cells: Stem cells are present in the blood in the umbilical cord and the placenta. Once the baby is born, these cells can be extracted from the discarded tissue and used for the benefit of children and adults who suffer from devastating bone marrow and blood diseases. They can also be stored in case the baby requires replacement tissues or organs later in life. These stem cells are obtained after the baby is born and are multipotent. There is no harm to the mother or the child.

In Australia there is a national network of umbilical cord blood banks called AusCord. Parents can choose to donate their baby's cord blood to one of AusCord's public cord blood banks. The donated blood is then available to any suitable recipient. If parents wish to ensure that the cord blood is available for their own baby later in life, they can pay to have the cord blood stored at a private blood bank.

2 Embryonic stem cells: **Embryonic stem cells** (Figure 2.27) are cultured from frozen embryos (Figure 2.28) that are obtained from in vitro fertilisation clinics. Unused embryos from in vitro fertilisation may be donated to research because the couple no longer desires additional children and does not wish to continue storage. However, there are significant ethical issues related to the use of embryonic stem cells because obtaining them requires destruction of an embryo, and governments have strict regulations in place for controlling this type of technology. A potential advantage of using embryonic stem cells is that they are pluripotent. They can become any of the cell types of the body and are therefore more versatile than **adult stem cells**. A disadvantage is that they come from embryos that are not derived from the patient's own cells, and the patient's immune system may therefore reject them.

3 Adult stem cells: Multipotent adult stem cells can form cells of many kinds of tissue. An important potential



GettyImages/S

Figure 2.27 A scanning electron micrograph of human embryonic stem cells

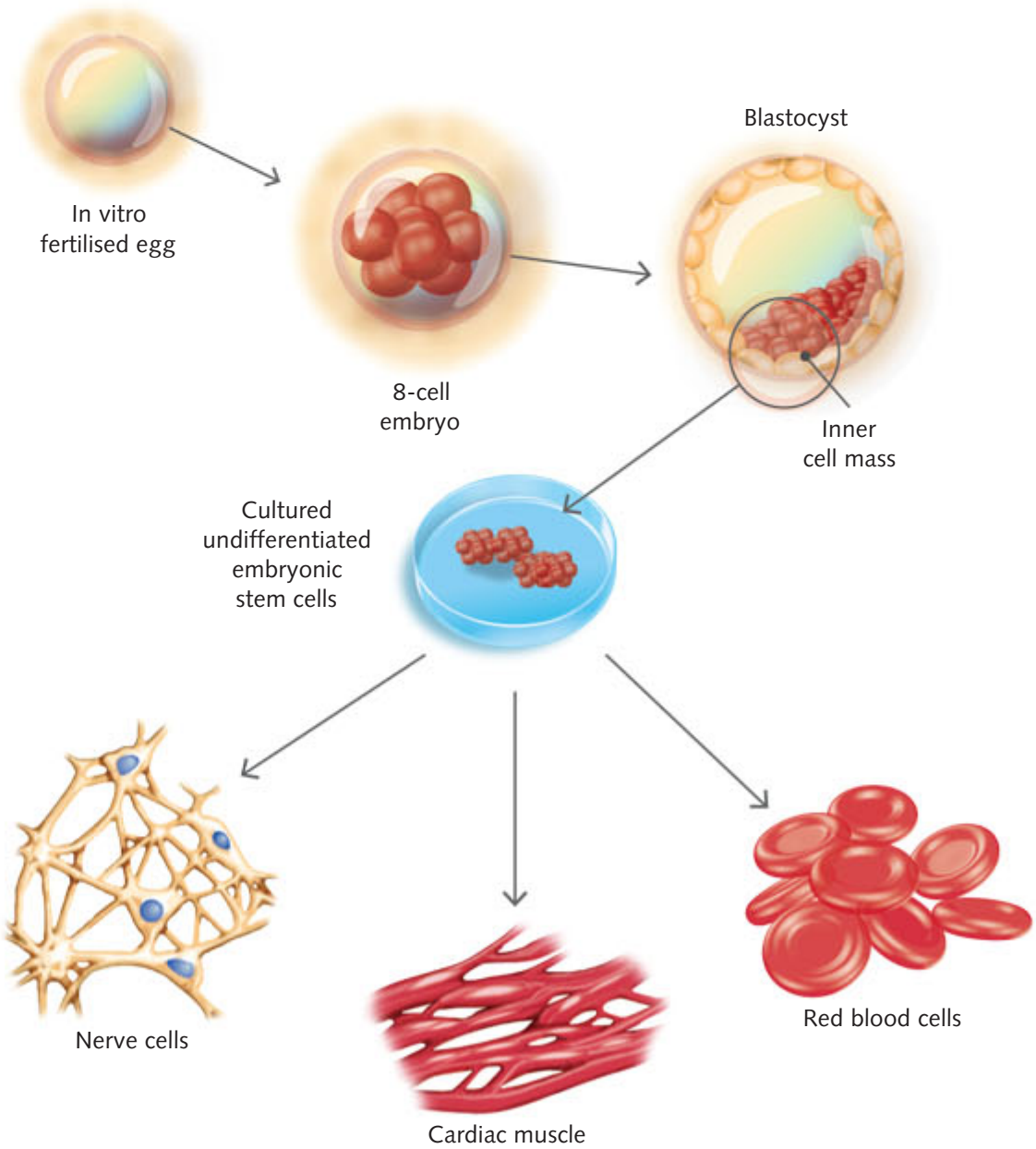


Figure 2.28 Culturing embryonic stem cells may allow scientists to grow replacement tissues and organs for patients.

advantage of using adult stem cells to treat disease is that a patient's own cells could be used for treatment. Risks are lower because a patient's immune system would not reject its own cells. A disadvantage of most adult stem cells is that they are pre-specialised – for example, blood stem cells make only blood cells, and brain stem cells make only brain cells. It appears that most organs of the body have stem cells so that they can replace dead or damaged cells. For example, bone marrow contains multipotent stem cells that give rise to all the cells of the blood. Bone marrow is, therefore, a good source of adult stem cells (Figure 2.29).

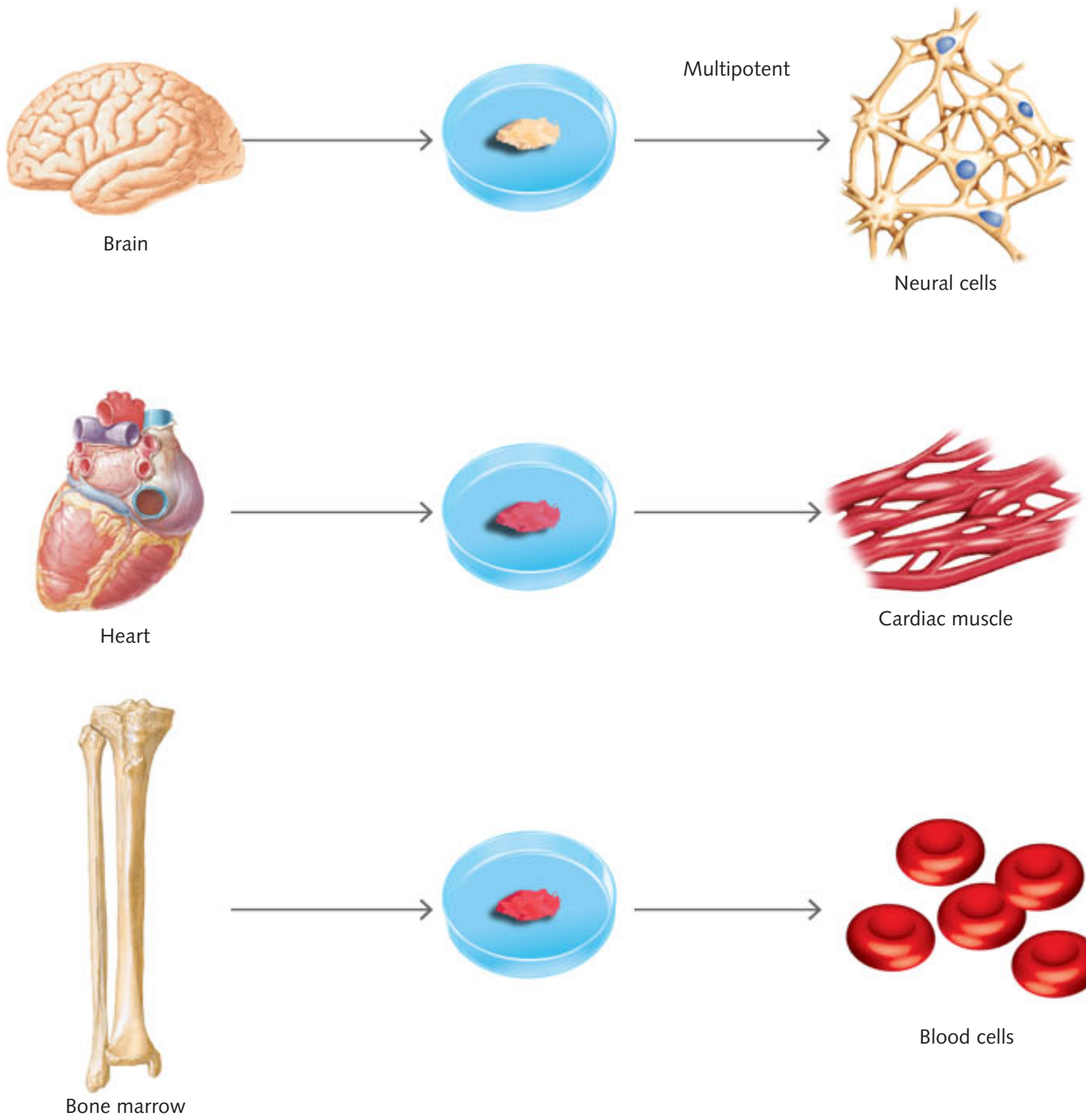


Figure 2.29 **Examples of adult stem cells. Adult stem cells are now thought to be multipotent.**

Researchers are continuing to work to understand the ways in which adult cells can be manipulated to induce pluripotency in stem cells, which could then be stimulated to differentiate into the desired tissue. There is a risk that such manipulation may result in cells that do not differentiate properly and have the ability to divide and give rise to cancers, so this research has some way to go before it reaches the clinic.

Stem cell research

Stem cells have three characteristics that distinguish them from other cells: they have not yet undergone differentiation – that is, they are not specialised for any particular role; they are capable of repeated division by mitosis for long periods of time; and, given the right conditions, they can differentiate into specialised cells.

Because of their ability to differentiate into cells of many different types, stem cells are the subject of intense scientific research. It is hoped that ways will be found to use stem cells in cell-based therapies to treat disease (Figure 2.30). If stem cells could be made to differentiate into particular cell types, they could provide replacement tissues for treating conditions such as stroke, spinal cord injury, burns, heart disease, diabetes, arthritis, Alzheimer's disease and Parkinson's disease. In addition to being used in cell-based therapies, stem cells are currently used for such things as testing new drugs or testing toxins, and for understanding the causes of birth defects. Stem cells are also used in the generation of organoids: small, three-dimensional tissue cultures that are miniature versions of organs. They are generated to enable the study of all the various cells within organs of the body such as the brain. The organoids are developed by culturing human pluripotent stem cells over several months.

Another potential use for stem cells is in identifying agents that are toxic to a developing embryo. These teratogens are identified when foetuses exposed to them before birth are born with defects. By testing new drugs and other substances on human stem cells, it should be possible to identify those with the potential to disrupt normal embryonic development before any tragic birth abnormalities occur.

Research into stem cells is aimed particularly at identifying, first, how stem cells are able to remain undifferentiated and self-renewing for several years and, second, the signals that stimulate stem cells to begin differentiation.

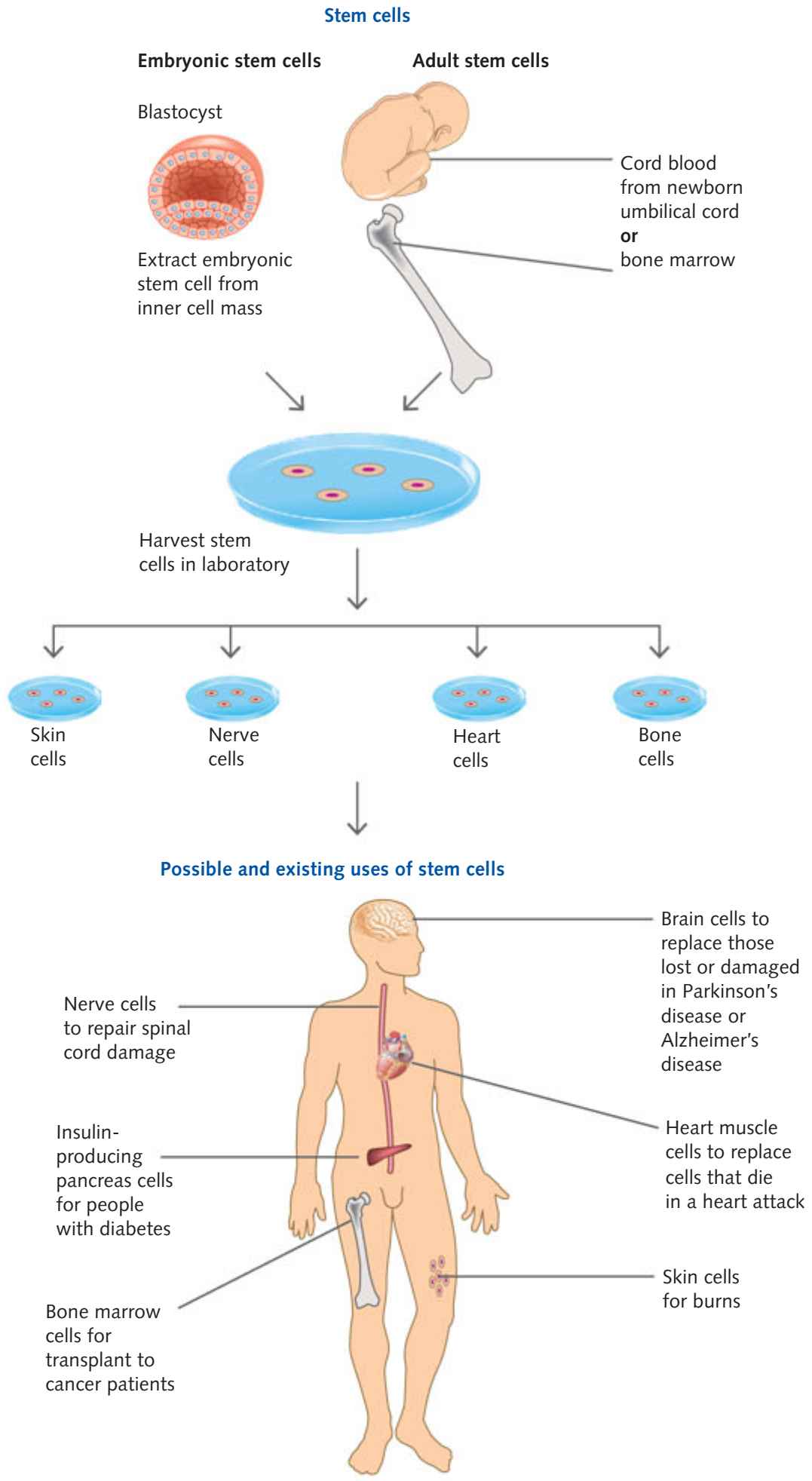


Figure 2.30 The process of culturing stem cells, and their possible uses

Questions

1 What features of stem cells make them ideal for research in treating human conditions and diseases?
2 Summarise the differences between embryonic stem cells and adult stem cells.
3 Describe the benefit of using adult stem cells in treating adults.
4 What impact does the source of stem cells have on their potential uses?

Online Key Concepts
Chapter 2 summary
of key concepts

2 Summary of key concepts

2.1 Binary fission

KEY CONCEPTS

p. 57

- Prokaryotic cells divide by binary fission.
- One parent cell gives rise to two identical daughter cells.
- The DNA, ribosomes and cytoplasm in the parent cell are evenly divided between the two daughter cells.
- Bacterial cells can divide every 20 minutes.

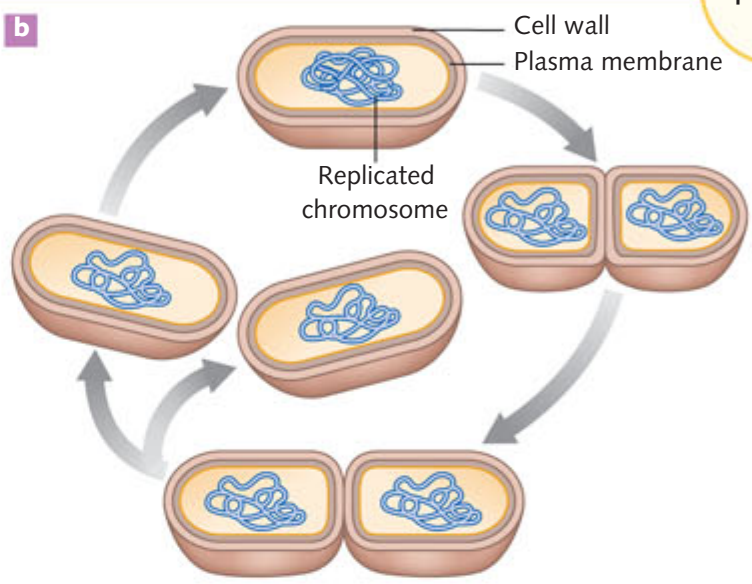


Figure 2.2b Bacterial cell cycle

2.2 Eukaryotic cell cycle

KEY CONCEPTS

p. 58

- The cell cycle is the series of phases that a dividing eukaryotic cell passes through from one cell division to another. It is divided into G_1 phase, S phase, G_2 phase and M phase.
- Eukaryotic cell division involves a number of phases resulting in nuclear division (mitosis) and cytoplasmic division (cytokinesis).
- Mitosis is the division of the nucleus. It is divided into phases called prophase, metaphase, anaphase and telophase.
- Cells spend most of their time in interphase, which is a period of active growth (G_1 phase), synthesis of DNA (S phase) and preparation for the next division (G_2 phase).
- Daughter cells formed by mitosis have the same genetic material as their parent cell.
- A number of checkpoints throughout the cell cycle determine whether conditions are adequate to continue with the cell cycle.

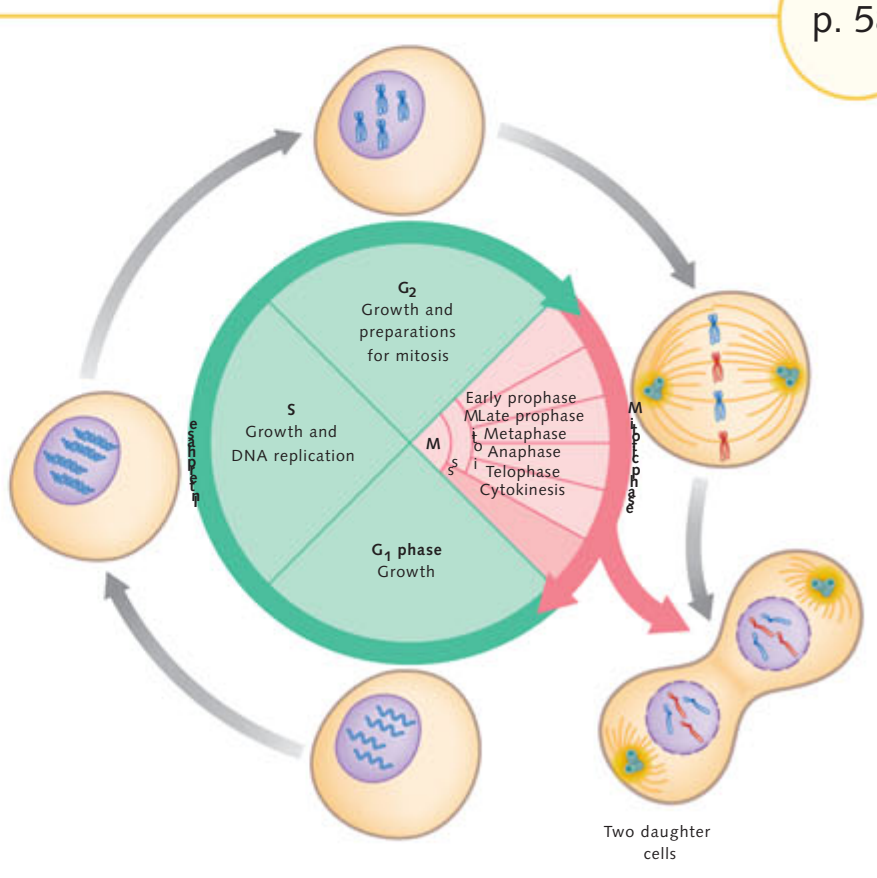


Figure 2.3 The cell cycle

2.3 Apoptosis

KEY CONCEPTS

p. 66

- Apoptosis is a carefully regulated, active process of programmed cell death that is essential for normal development of multicellular organisms.
- Apoptosis is important for development, removing unwanted cells and protecting an organism from ill health.
- Apoptosis can be triggered by signals from within the cell and external to the cell.
- Apoptosis is controlled by genes that code for enzymes (proteins).
- During apoptosis the cell is dismantled, forming blebs and apoptotic bodies, which are engulfed by phagocytes.
- Failure in apoptosis could result in cells forming a cancerous tumour.

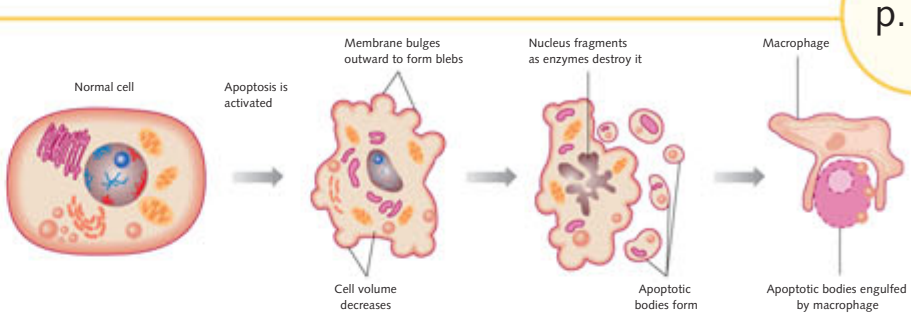


Figure 2.16 An overview of how apoptosis works

2.4 Disruption to the regulation of the cell cycle

KEY CONCEPTS

p. 69

- The balance between the activities of proto-oncogenes and the tumour suppressor genes keeps normal cells dividing at a rate that is appropriate for their position and role in the body.
- The *p53* gene initiates either DNA repair or apoptosis of cells.
- Failure of the *p53* gene results in rapid, unchecked cell proliferation and evasion of apoptosis.
- Mutations in proto-oncogenes and tumour suppressor genes lead to a genetic predisposition to cancer.
- Many chemotherapy treatments focus on reinstating apoptosis within the tumour cells.
- Cell cycle regulation can be disrupted by the action of chemical, physical or biological mutagens. Mutagens that can lead to cancer are called carcinogens.
- Mutagens can cause mutations in DNA that may affect proto-oncogenes or tumour suppressor genes, leading to uncontrolled cell division and potentially cancer.

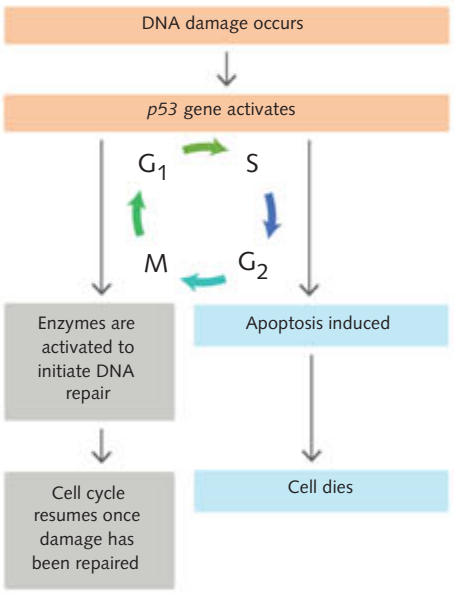


Figure 2.20 *p53* gene activates either DNA repair or apoptosis

2.5 Stem cells

KEY CONCEPTS

p. 75

- As they divide, unspecialised cells develop special characteristics through the process of differentiation to suit particular functions.
- Stem cells can differentiate into various tissues.
- Totipotent stem cells have the potential to form any type of cell necessary for embryonic development.
- Pluripotent stem cells have the ability to form many but not all types of cells necessary for foetal development.
- Multipotent stem cells give rise to cells that have a particular set of functions.

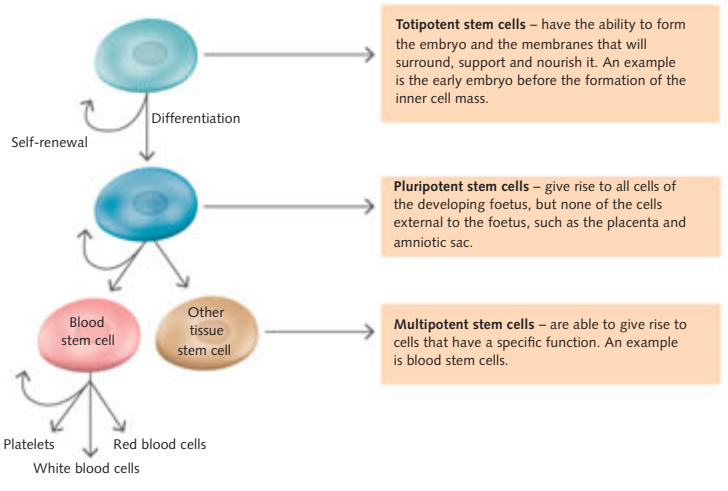


Figure 2.26 The process of cell differentiation

WB
2.6.1
KEY TERMS
PAGE 53

2 Chapter glossary

adult stem cell a stem cell harvested from tissues such as bone marrow, that are not part of an embryo

anaphase the division stage of mitosis where the chromatids separate at the centromere and move to either pole of the cell

apoptosis a programmed series of events that lead to cell death

binary fission the division of a cell into two without mitosis; the process by which a prokaryotic cell divides to form two cells

blastocyst a hollow ball of cells formed during early embryonic development

bleb a balloon-like outgrowth of the plasma membrane

cancer a disease that arises when the signals that control apoptosis and cell division are disrupted, so cells survive and divide uncontrollably

carcinogen a cancer-causing agent

cell cycle the sequence of events from one cell division to the next

cell plate the structure produced by dividing plant cells where the new cell wall is to be formed

centromere the waist-like constriction in a chromosome that links the daughter chromatids; required for the movement of chromosomes during cell division

chemical mutagen a compound that can increase the rate of mutation

chromatid one strand of a chromosome; can exist as one chromatid, or when replicated as two chromatids joined at the centromere

chromatin a tangled network of DNA in the nucleus of a cell that is not dividing

cleavage division of the cytoplasm in an animal cell

cleavage furrow a shallow, ring-like depression that forms at the cell surface of an animal cell undergoing cytokinesis as contractile microfilaments pull the plasma membrane inward; it defines where the cytoplasm will be divided across the two daughter cells

cyclin a type of molecule that regulates the cell cycle

cycline-dependent kinase (CDK) a type of molecule that regulates the cell cycle

cytokinesis division of the cytoplasm

daughter cell a cell resulting from the mitotic division of a parent cell

differentiation the process by which unspecialised cells develop special characteristics to suit particular functions

embryo the early stage of development of an organism; in humans, from fertilisation to the end of the eighth week of pregnancy

embryonic stem cell a stem cell that is cultured from an embryo

foetus the developing individual after the second month of pregnancy

G_0 phase the non-proliferating state where cells undergo an extended G_1 phase

G_1 phase an intermediate phase in the cell cycle from the end of cytokinesis to the beginning of DNA synthesis

G_2 phase an intermediate phase in the cell cycle from the end of DNA synthesis to the beginning of mitosis; involves a time of cell growth

genetic predisposition an increased risk of developing a particular disease, based on a person's genetic makeup

interphase the stage of the cell cycle between nuclear divisions

M phase the phase of the cell cycle when the nucleus undergoes a series of steps to divide, leading to two daughter cells

macrophage a phagocytic white blood cell

metaphase the stage in mitosis when all the chromosomes are fully condensed and attached by a spindle fibre at their centromere

mitosis a type of nuclear division that maintains the parental number of chromosomes for daughter cells; it is the basis of bodily growth and asexual reproduction in many eukaryotic species

multipotent stem cell a stem cell that is able to give rise to a limited number of other cell types; for example, blood stem cells will give rise to red blood cells, white blood cells and platelets

mutagen an agent that can induce or increase the frequency of mutation in DNA

mutation a change or mistake in the copying of a DNA sequence in chromosomes

necrosis unprogrammed cell or tissue death

oncogene a gene that can promote cancer

***p53* gene** a gene that monitors DNA and is activated when DNA damage is detected or there is cell injury

parent cell a cell before it divides by mitosis to produce two daughter cells

phagocyte a scavenging cell that engulfs and absorbs cell particles and bacteria

placenta the organ that supplies nutrients to, and removes wastes from, the foetus

pluripotent stem cell a stem cell that is able to give rise to many, but not all, of the cell types necessary for foetal development

pole one end of a cell

prophase the first phase of mitosis where the DNA condenses to form the chromosomes

proto-oncogene a gene that can promote cancer

quiescent cell an inactive cell

S phase the phase of the cell cycle where DNA is replicated

spindle the framework of microtubules that radiates out from the poles of a cell during cell division

stem cell a cell that has the ability to produce a different type of body cell

telophase the final stage of mitosis where the nuclear material has been evenly and equally separated to opposite ends of the parent cell and the two daughter cells begin to take shape

teratogen an agent that causes developmental abnormalities in a developing foetus

terminally differentiated cell a cell that has lost the ability to replicate

totipotent stem cell a stem cell able to create any of the types of cells necessary for embryonic development

tumour a lump in any part of the body caused by the abnormal growth of cells or tissue

tumour suppressor gene a gene that inhibits cell division

WB
2.6.2
PRACTICE TEST
QUESTIONS
PAGE 54

2 Chapter review

Remembering

1 Describe the relationship between parent cells and daughter cells.
2 Describe the events of each of the four phases of the cell cycle. Include the events of mitosis in the M phase of the cell cycle.
3 Name the cell cycle checkpoint where:
   a the cell cycle is halted if the cell's DNA is damaged
   b the cell commits to proceed through to mitosis and cell division.
4 Describe the differences between the three types of stem cells: totipotent, pluripotent and multipotent.
5 Explain how stem cells are different from cells in tissues and organs.

Understanding

6 Distinguish between a chromatid and a chromosome.
7 Compare binary fission to mitosis.
8 Outline the role of the *p53* gene and what can happen if the gene is mutated.
9 Explain the role of tumour suppressor genes and oncogenes in cancer development.

Applying

10 The amount of nuclear DNA in any given cell can be measured accurately during the cell cycle. Predict at what stages throughout the cell cycle you would expect to see changes in the amount of nuclear DNA.
11 Draw a Venn diagram to illustrate the relationship between cell division, nuclear division and cytokinesis.
12 Predict what would happen if cytokinesis did not occur during a cell cycle.
13 Describe three locations in the body of a healthy adult where mitosis is likely to occur. Explain why you have chosen these places.
14 Explain why mutations that arise in proto-oncogenes and/or tumour suppressor genes may lead to the development of cancer.
15 Discuss how a person's genetic make-up can affect their chances of developing cancer.
16 Propose reasons why:
   a the use of sunscreen in childhood is critically important for preventing the development of skin cancers later in life
   b the incidence of cancer of the cervix has declined in Australia.
17 The categorisation of stem cells is based on the potency, or ability, of that cell to produce a range of other cells. Consider the three types of stem cells and describe how the name fits the range of cells it is able to produce.
18 Give two examples of the use of stem cells in human medicine.
19 There are many points of regulation in the cell cycle that must be impaired for full cancer development. Explain how cancer is a failure of cell cycle regulation.

Evaluating

20 An umbilical cord blood bank was established in Australia in 1995. Parents can voluntarily have a sample of their baby's cord blood stored for later use. Discuss the advantages of such a bank.

21 A group of cells being studied was never observed to undergo division. Predict whether this means the cells were dead. Justify your answer.

22 Interphase is sometimes referred to as the 'resting phase'. Evaluate this statement, giving reasons why this description is or is not accurate.

23 Paclitaxel is a drug that stops microtubules such as spindle fibres from disassembling.

a Predict what effect microtubules not disassembling would have on mitosis.

b Describe the checkpoint of the cell cycle that would normally detect this fault.

Creating

24 Create a concept map showing how cancer develops, using your understanding of how proto-oncogenes, oncogenes and tumour suppressor genes contribute to the process.

25 In 2007, scientists reported the development of a technology that induced fully mature specialised cells (such as human skin cells) to mimic characteristics of embryonic stem cells. These altered cells could provide a source of stem cells for replacement and regeneration after damage caused by disease or injury, or even to reduce the effects of normal ageing. While these altered cells have great potential, a lot is still unknown about the cells and their usefulness. Research stem cell technology to answer the following questions.

- How can these technologies be tested to see if they are safe for humans?
- How can the study of their potential be continued?
- Who or what should they be tested on?
- What kinds of guidelines should scientists follow in this type of research?

Present your findings in an appropriate format agreed with your teacher.

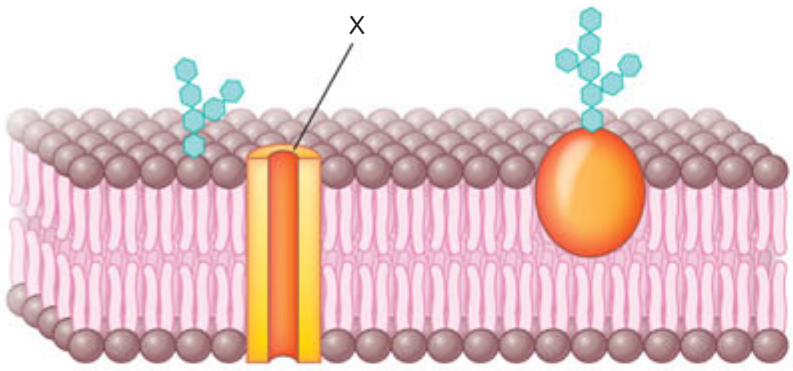
Unit 1, Area of Study 1 review

Multiple choice

Question 1

©VCAA 2014 SECTION A Q6 (ADAPTED) EASY

The diagram below shows the structure of the plasma membrane.



Structure X represents a molecule of:

A phospholipid.
B glycoprotein.
C carbohydrate.
D protein.

Question 2

©VCAA 2014 SECTION A Q9 (ADAPTED) EASY

In apoptosis:

A a cell rapidly divides and releases cytokines.
B a signal is received by the target cell from within or outside the cell.
C DNA is replicated.
D an inflammatory response is initiated by enzymes.

Question 3

©VCAA 2009 E1 SECTION A Q4 (ADAPTED) HARD

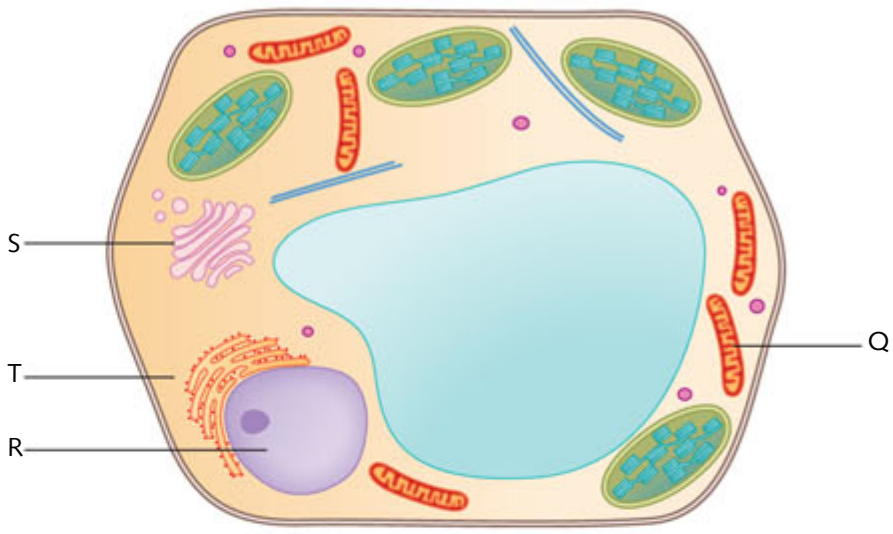
Eukaryotic cells have membrane-bound organelles that result in the formation of compartment-like structures. This is useful for a cell because it:

A keeps the nucleus isolated from the cytosol.
B allows select entry and exit of particular molecules.
C enables a variety of intracellular environments to exist in the cell.
D provides a structural network that acts to support the cell.

Question 4

©VCAA 2011 E1 SECTION A Q10 (ADAPTED) HARD

Consider the following cell.



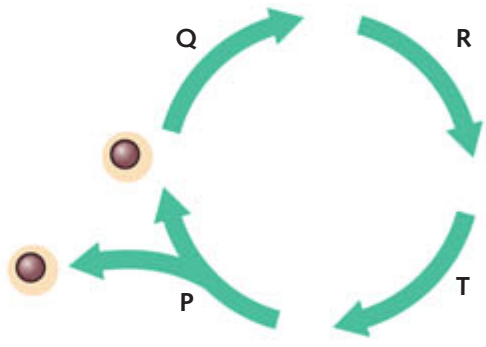
The synthesis of:

A DNA occurs in structure R.
B glucose occurs at structure Q.
C protein occurs at structure S.
D RNA occurs at T.

Question 5

©VCAA 2013 SECTION A Q21 (ADAPTED) MEDIUM

The following diagram represents the cell cycle in cells of a eukaryotic organism. Each letter represents a particular section of the cell cycle.

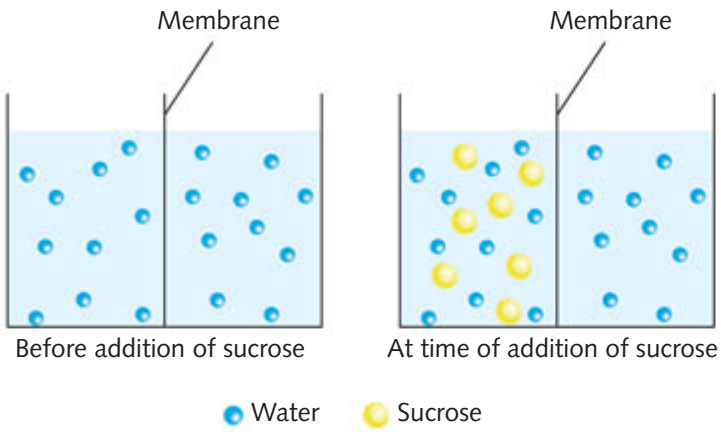


During this cycle:

A cytokinesis occurs during P.
B mitosis occurs during T.
C DNA replicates during Q.
D cell growth occurs during R.

Question 6 ©VCAA 2004 E1 SECTION A Q9 (ADAPTED) MEDIUM

A student set up an experiment with a semipermeable membrane. The membrane was not permeable to sucrose. At the beginning of the experiment the same amount of water was added to both sides of the membrane. The student then added sucrose to the left-hand side of the membrane as shown in the following diagram.

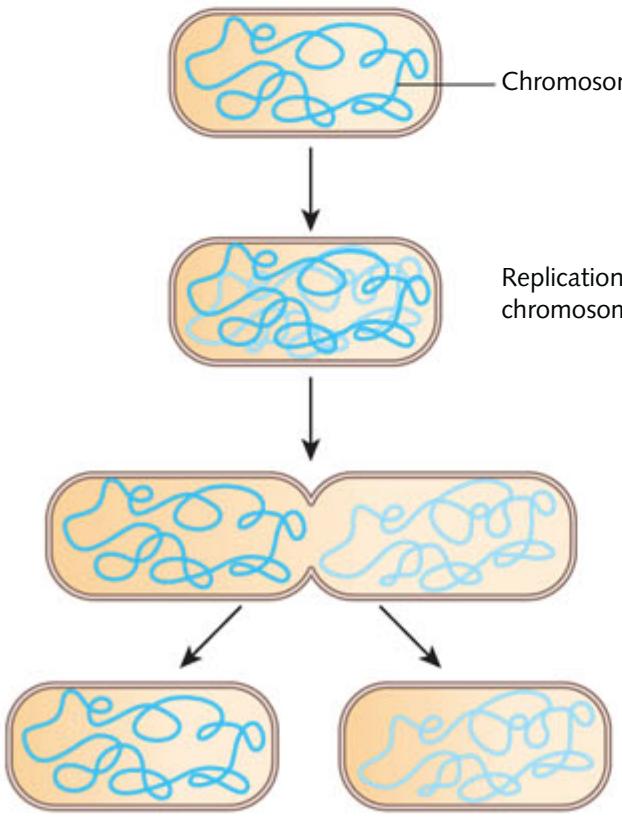


You would expect:

A the sucrose concentration to increase on the right-hand side of the membrane.
B the water level to stay unchanged on both sides of the membrane.
C the water level to drop on the left-hand side of the membrane.
D the water level to drop on the right-hand side of the membrane.

Question 7 ©VCAA 2010 E2 SECTION A Q1 (ADAPTED) MEDIUM

The diagram below is a representation of binary fission.



This occurs:

A in the formation of gametes.
B during apoptosis.
C in eukaryotic cells.
D in prokaryotic cells.

Question 8 ©VCAA 2011 E2 SECTION A Q5 (ADAPTED) MEDIUM

Multipotent stem cells:

A are used in human reproductive cloning.
B can differentiate into any cell type.
C are found in adults and embryos.
D only differentiate into blood cells.

Question 9 During the growth stage of a cell, its surface-area-to-volume ratio:

A stays the same.
B increases.
C decreases.
D doubles.

Question 10 The overall movement of phosphate ions from the soil into a root hair cell is carried out by the process of:

A osmosis.
B active transport.
C diffusion.
D facilitated diffusion.

Question 11 ©VCAA NHT 2018 SECTION A Q2 (ADAPTED)

Molecules can move across a plasma membrane in various ways. Which of the following molecules are most likely to cross a plasma membrane by passing through a transport protein?

A Carbon dioxide
B Molecules of an enzyme
C Hydrophilic molecules
D Water

Question 12 The type of cell division called mitosis will:

A produce gametes.
B produce haploid cells.
C involve two nuclear divisions.
D supply cells for the replacement of damaged tissue.

Question 13 ©VCAA 2017 SECTION A Q19 (ADAPTED) MEDIUM

In cancer, the number of cancer cells within tissues can increase rapidly. The increase in cancer cells can be explained by:

A increased rate of apoptosis in the cancer cells.
B inhibition of tumour suppressor genes.
C increased shredding of the cells' DNA.
D increased rate of apoptosis in surrounding normal cells.

Question 14 ©VCAA 2006 E1 SECTION A Q4 (ADAPTED) HARD

Molecules found in a plant plasma membrane include:

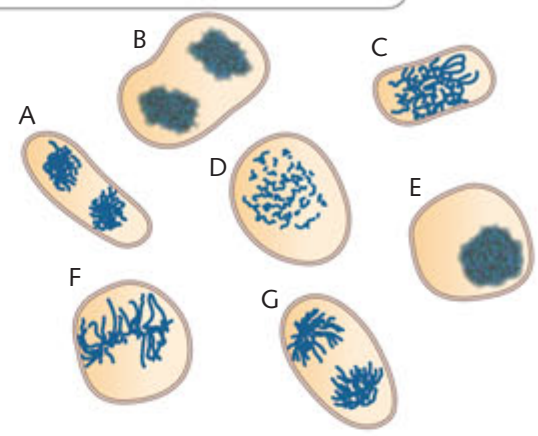
A chitin.
B cellulose.
C proteins.
D nucleotides.

Question 15 Which of the following features could be used to classify a cell as a eukaryote?

A The presence of a cell wall
B The presence of linear chromosomes
C Ribosomes
D A flagellum

Short answer

1 ©VCAA 2008 E2 SECTION B Q1 (ADAPTED)



a Starting with the cell closest to the beginnings of mitosis, arrange the letters A, B, C, D, E, F, G in the order in which they would occur during the cell cycle.
b Name the mitosis phase shown in diagram F.
c What event must occur before the start of mitosis?
d Name one type of cell that may undergo mitosis.
e During the cell cycle, a number of checkpoints determine if conditions have been met for the cell cycle to continue.
   i What specific checks are made during mitosis?
   ii Explain the purpose of these checks.

(3 + 1 + 1 + 1 + 1 + 1 + 1 marks)

2 The table lists the organelles present in three different cells as observed using an electron microscope.

Organelle	Cell A	Cell B	Cell C
Nucleus	Yes	Yes	No
Mitochondria	Yes	Yes	No
Chloroplast	No	Yes	No
Ribosomes	Yes	Yes	Yes

a Cell A contained mitochondria at four times the number observed in any other cell. What can you conclude about the function of Cell A based on this observation?

(1 mark)

b Which cell is a prokaryote? Give the reason for your answer.

(2 marks)

c What other organelle or structure would be found in cell B and not in the other cells?

(1 mark)

d In which cell or cells could you find the following structure?

(1 mark)

e Name the structures labelled X in the diagram above.

(1 mark)

Functioning systems

3

By the end of this chapter you will have covered the following material.

Key knowledge

Functioning systems

» specialisation and organisation of plant cells into tissues for specific functions in vascular plants, including intake, movement and loss of water, pp. 93–99

» specialisation and organisation of animal cells into tissues, organs and systems with specific functions: digestive, endocrine and excretory, pp. 100–120

Key science skills

Develop aims and questions, formulate hypotheses and make predictions

» identify independent, dependent and controlled variables in controlled experiments, pp. 103–104, 117–118

» formulate hypotheses to focus investigation, pp. 103–104, 117–118

» predict possible outcomes, pp. 103–104, 117–118

Plan and conduct investigations

» design and conduct investigations; select and use methods appropriate to the investigation, including consideration of sampling technique and size, equipment and procedures, taking into account potential sources of error and uncertainty; determine the type and amount of qualitative and/or quantitative data to be generated or collated, pp. 103–104, 117–118

» work independently and collaboratively as appropriate and within identified research constraints, adapting or extending processes as required and recording such modifications, pp. 97–98, 103–104, 117–118

Comply with safety and ethical guidelines

» demonstrate safe laboratory practices when planning and conducting investigations by using risk assessments that are informed by safety data sheets (SDS), and accounting for risks, pp. 97–98, 103–104, 117–118

» apply relevant occupational health and safety guidelines while undertaking practical investigations, 97–98, 103–104, 117–118

» demonstrate ethical conduct when undertaking and reporting investigations, pp. 103–104, 117–118

Generate, collate and record data

» systematically generate and record primary data, and collate secondary data, appropriate to the investigation, including use of databases and reputable online data sources, pp. 97–98

» record and summarise both qualitative and quantitative data, including use of a logbook as an authentication of generated or collated data, pp. 97–98, 103–104, 117–118

Analyse and evaluate data and investigation methods

» identify and analyse experimental data qualitatively, handling where appropriate concepts of: accuracy, precision, repeatability, reproducibility and validity of measurements; errors (random and systematic); and certainty in data, including effects of sample size in obtaining reliable data, pp. 103–104, 117–118

» identify outliers, and contradictory or provisional data, pp. 103–104, 117–118

Construct evidence-based arguments and draw conclusions

» evaluate data to determine the degree to which the evidence supports the aim of the investigation, and make recommendations, as appropriate, for modifying or extending the investigation, pp. 103–104, 117–118

» evaluate data to determine the degree to which the evidence supports or refutes the initial prediction or hypothesis, pp. 103–104, 117–118

» use reasoning to construct scientific arguments, and to draw and justify conclusions consistent with the evidence and relevant to the question under investigation, pp. 97–98

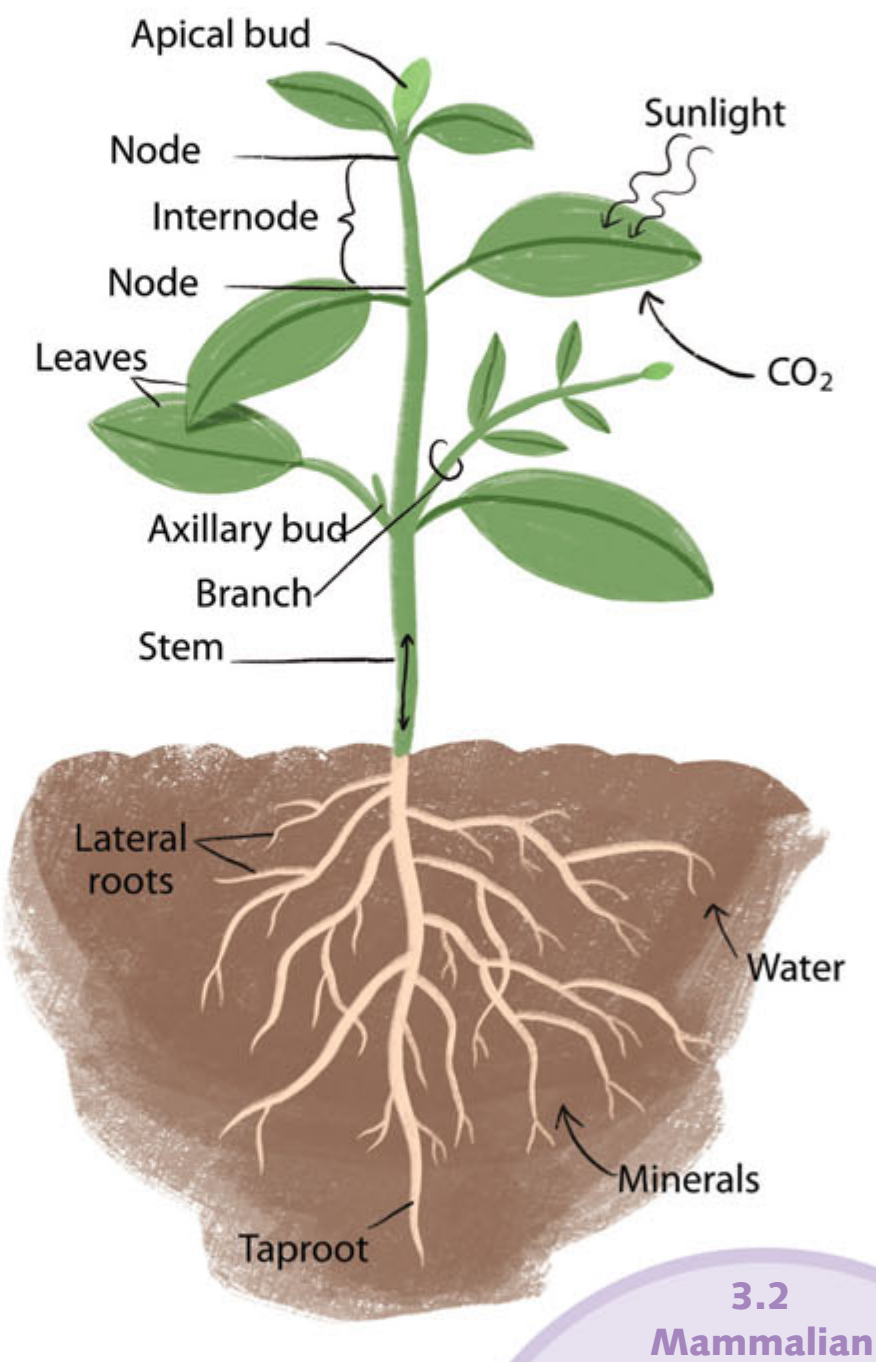
Analyse, evaluate and communicate scientific ideas

» discuss relevant biological information, ideas, concepts, theories and models and the connections between them, pp. 103–104, 117–118

Online Chapter Map
Chapter 3 map

3 Functioning systems

All living organisms are made up of cells. Simple organisms are unicellular, and groups of similar cells form tissues. Grouped tissues make organs and organs make systems; for example, the root and shoot systems in plants. Various systems make up whole organisms.

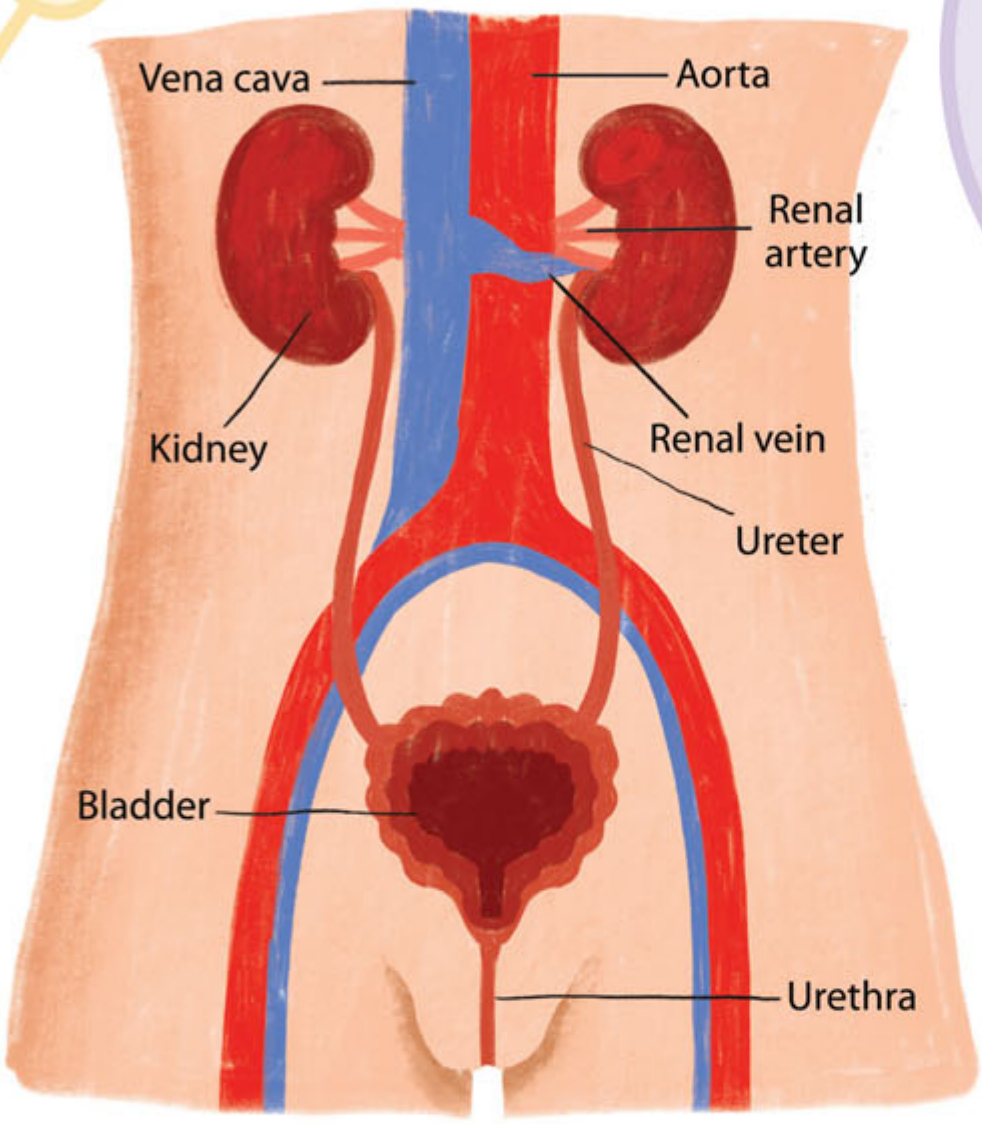


3.1 Vascular plants p. 93

Plants have two main systems: root and shoot. Xylem carries water from the root system to the rest of the plant; phloem carries sugars produced in photosynthesis throughout the plant for use by cells in cellular respiration, for structure and for storage.

3.2 Mammalian systems: digestive system p. 100

Digestion begins with mechanical digestion to break food down into smaller pieces. Enzymes then act to decrease the size of molecules to be absorbed from the intestines into the bloodstream to be used by cells.



3.3 Mammalian systems: endocrine system

p. 110

The endocrine system receives messages from the body and responds by sending out hormones. Hormones are made in ductless glands and travel in the bloodstream until they bind to the target tissue or organ that interprets the message and carries out the response.

3.4 Mammalian systems: excretory system

p. 113

When cells metabolise they produce waste. When waste builds up in our blood, the body stops functioning properly. The kidney's nephrons remove this waste from the blood without getting rid of the good stuff.

Your body is a well-oiled machine made up of cells, tissues, organs and systems. These systems are interlinked and work together to keep your body running at its maximum potential.

To access resources below, visit www.nelsonnet.com.au

Online Chapter Map:
- Chapter 3 map (p. 90)

Online Key Terms:
- Chapter 3 flashcards (p. 92)

Weblinks:
- Transport in the xylem of plants (p. 93)
- How your digestive system works (p. 100)

Online Worksheets:
- Transport in the xylem in plants (p. 93)
- How your digestive system works (p. 100)

Video:
- Chemical digestion (p. 105)

Online Key Concepts:
- Chapter 3 summary of key concepts (p. 122)

Know your key terms

Online Key Terms
Chapter 3 flashcards

absorption
adhesion
ammonia
amylase
anus
basal metabolic rate
bile
Bowman's capsule
chemical digestion
chyme
cohesion
colon
cuticle
deamination
digestion
digestive system
distal tubule
ductless gland
egestion
endocrine gland
endocrine system
epidermis
excretion
exocrine gland
external environment
faeces
filtrate
gall bladder
gastric juice
gastrointestinal tract
glomerulus
heterotroph
hormone
ingestion
internal environment
kidney
lacteal
large intestine
lignin
loop of Henle
lymph
lymphatic system
mechanical digestion
microvilli
nephron
oesophagus
organ
pancreatic juice
parenchyma
peristalsis
pH
phloem
polypeptide
protease
proximal tubule
pyloric sphincter
rectum
renal artery
renal pelvis
root hair cells
root pressure
small intestine
sphincter
stomata
system
terrestrial
thyroxine
tissue
tracheid
translocation
transpiration
transpiration stream
transpirational pull
urea
vascular bundle
vascular plant
vascular tissue
villi
xylem
xylem vessel element

Remember

This chapter will build on the following concepts that you will have already met. Take the time to refresh these concepts before you start this chapter.

WB
REMEMBER
PAGE 56

1. Cells make up tissues, tissues make up organs, and organs make up systems.
2. Xylem consists of the water-conducting tubes in a plant; phloem conducts organic nutrients throughout the plant.
3. An autotroph produces its own organic molecules using inorganic molecules, whereas a heterotroph ingests organic molecules from the environment.
4. The digestive system physically and chemically breaks down food into smaller pieces and then into smaller molecules so they can be absorbed into the bloodstream.
5. The circulatory system carries nutrients and oxygen to cells and removes wastes.
6. Four processes involved in the exchange of substances across cell surfaces are: simple diffusion, facilitated diffusion, osmosis and active uptake.

The tallest flowering tree species in the world is *Eucalyptus regnans*, known as mountain ash in Victoria and swamp gum in Tasmania. One specimen near Hobart is 101 m tall (Figure 3.1). Aptly named 'Centurion', this swamp gum is estimated to be around 400 years old. One of the greatest physiological challenges for tall trees is how to draw water and minerals from the roots to the canopy. This requires many litres of water to be lifted through vertical distances of 50–100 m up the trunk against the force of gravity.

Getty Ima

Figure 3.1 **'Centurion' in Tasmania is an example of *Eucalyptus regnans*, the tallest flowering plant species in the world.**

3.1 Vascular plants

Multicellular plants have specialised cells that make up tissues with specific functions to assist in their survival. The individual cells are organised into **tissues** (such as clusters of photosynthetic cells), which are grouped together to form **organs** (such as the leaf), which together form specific **systems**. In plants there are two systems: the shoot system and the root system.

1. The shoot system is comprised of all parts of the plant found above ground. It is responsible for the transportation of resources, exchange of oxygen and carbon dioxide, photosynthesis in the leaves and sexual reproduction.
2. The root system is below ground and is responsible for absorbing water and minerals from the soil, as well as anchoring the plant in the soil.

In a **vascular plant**, a plant that has regions of specialised transporting tissue, the cells of each of the tissues are differentiated to perform an important function that supports the life of the plant. These functions include obtaining energy, producing organic compounds, distributing materials, removing wastes and exchanging gases. The specialised cells that distribute organic compounds, water and minerals around the plant are in the **vascular tissue**. Vascular tissue is composed of two different types of tissues: **xylem** and **phloem**. Phloem is composed of thin-walled living cells that transport sugars, in the form of sucrose, and other plant products from one part of a plant to another either upwards or downwards. Xylem consists of dead thick-walled tubes and is responsible for the transport of water and minerals upwards from the roots to the leaves.

Weblink
Transport in the xylem of plants

Online Worksheet
Transport in the xylem of plants

Water transport: xylem

Obtaining water can be a challenge for many organisms. Unlike animals, which can move to find water, plants require a local water supply. Apart from algae and aquatic plants, plants obtain their water through the roots. Life in a **terrestrial** environment necessitates a root system to obtain water and a specialised transport system in the vascular tissue to move the water from the roots to the leaves.

Water is absorbed initially by the roots and moves against the downward force of gravity up through the stem to the leaves. This involves a one-way system called the xylem. It is made up of two types of cells: **tracheids**, which are elongated cells that are narrower than xylem vessels but also dead, hollow and lignified; and **xylem vessel elements** (Figure 3.2). As the cells that will form the xylem vessel tissue mature, they die and the end walls of the cells break down, leaving behind hollow cells that form long tubes. The cell walls become thickened with a strong substance called **lignin** in different patterns. Lignin is one of the most abundant organic polymers on Earth. These elongated, hollow, tubular cells of xylem

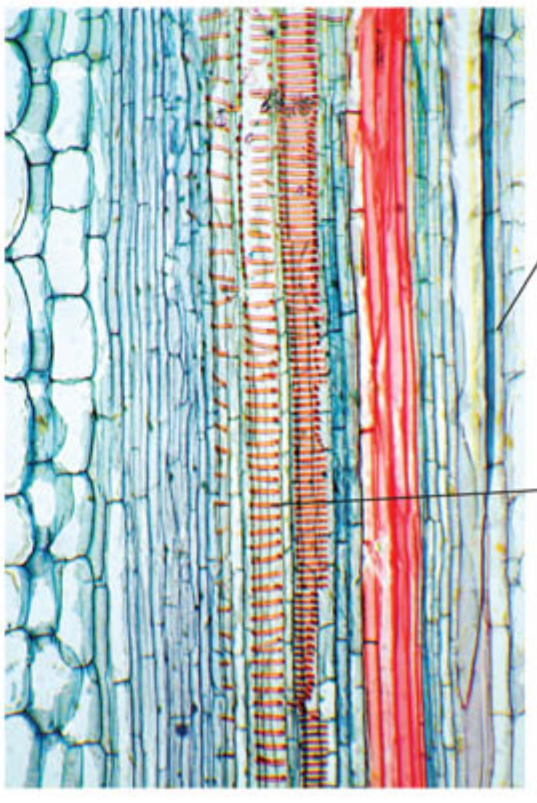


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Figure 3.2 **Micrograph image of a longitudinal section (LS) of a stem, showing xylem and phloem tissue**

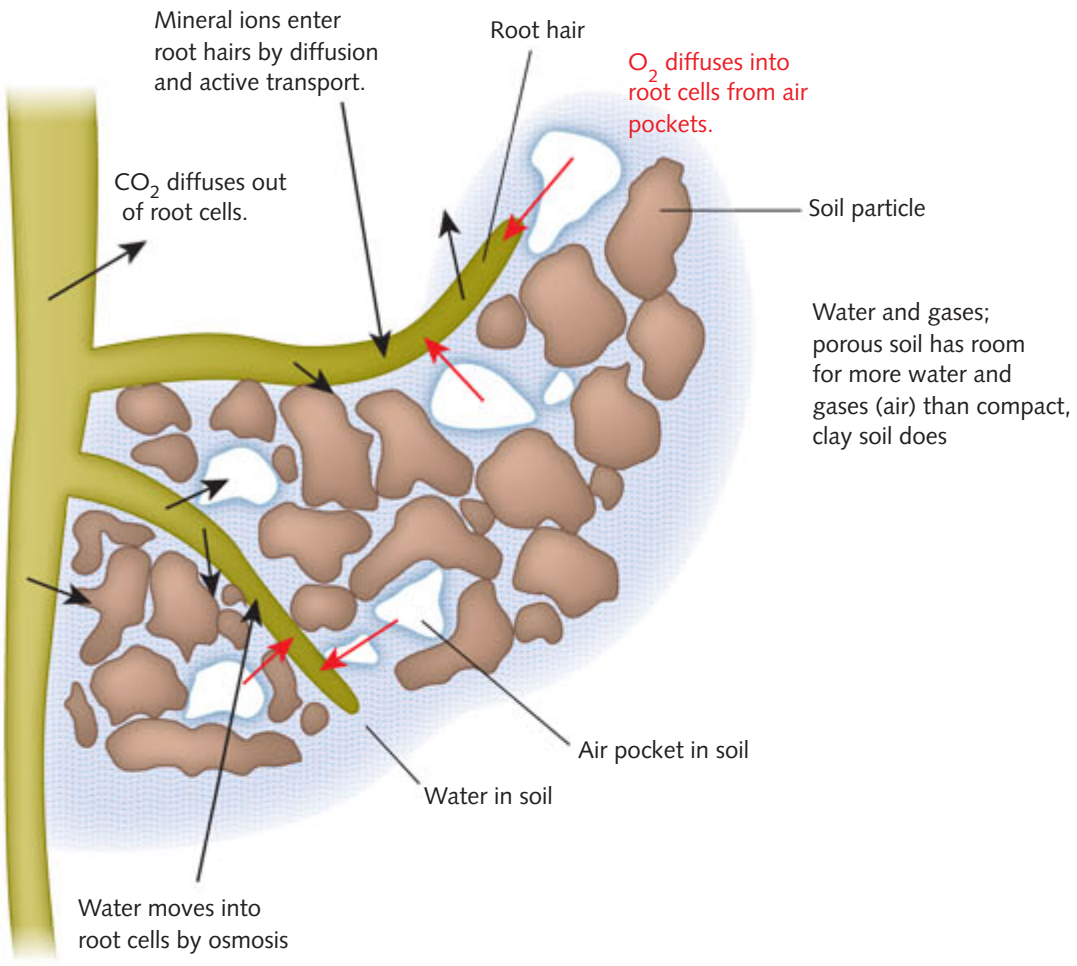

Figure 3.3 Water and dissolved ion uptake and gas exchange across root hairs in soil

are ideally suited for the transport of water. The dead xylem tissue forms the woody part of many plant stems. Wood is composed entirely of xylem tissue and provides the main support for most large plants such as trees.

Water intake by the root system

So how does the water in the soil reach the uppermost leaves of the plant? Some of these leaves can be more than 100 m above the ground. Part of the answer lies hidden below the ground in the plant's root system. Sometimes the root system is larger than the plant's entire shoot system.

The roots of a plant have several functions. Apart from absorbing water and dissolved minerals from the soil as shown in Figure 3.3, they support and anchor the plant and often provide the main storage tissue for starch and other complex substances produced by the plant. They also are an area for gas exchange between the root cells and air spaces in the soil.

As the roots provide the surface through which water and dissolved minerals are taken up, they are long and often fibrous to provide an adequate surface area for absorption. This surface area is greatly increased by the presence of thousands of **root hair cells** behind the tip of the root. Each root hair is a slender extension of a root epidermal cell. These are the cells that make up the **epidermis**, the surface layer of cells of the roots that separate the plant from its external environment. The long thin extension of the epidermal cell makes the cell highly specialised for its function of absorption. The root hairs penetrate between the soil particles and are surrounded by the soil water. The water moves from the soil into the epidermal cell through its cell wall and plasma membrane by osmosis, while the dissolved minerals move in by diffusion and active transport. The root tip region can absorb water six times faster than regions that are further back along the root. A plant's root hairs can provide an area which is up to 130 times greater than the surface area of its shoot.

WB
3.1.1 WATER TRANSPORT: XYLEM PAGE 57

CONNECT

Chapter 1 explained processes by which substances move into and out of cells.

Beneath the epidermis, large, thin-walled **parenchyma** cells make up the main root body. In the middle of the root, there is a core of vascular tissue that consists of several groups of xylem tissue that are distinct from the groups of phloem cells. The vascular tissues are arranged in such a way that, as the root grows into the soil, the vascular tissue also extends down the middle of the root, enabling the transportation of materials.

Once inside the root hair, the water moves to the parenchyma cells and into the xylem vessel via pits in the cell walls. The force of the water entering the root and 'pushing' its way into the cells creates pressure (Figure 3.4). If the stem of a plant is severed, the cut end will exude fluid for some time. This suggests that there is a force pushing water up the stem from the roots. This

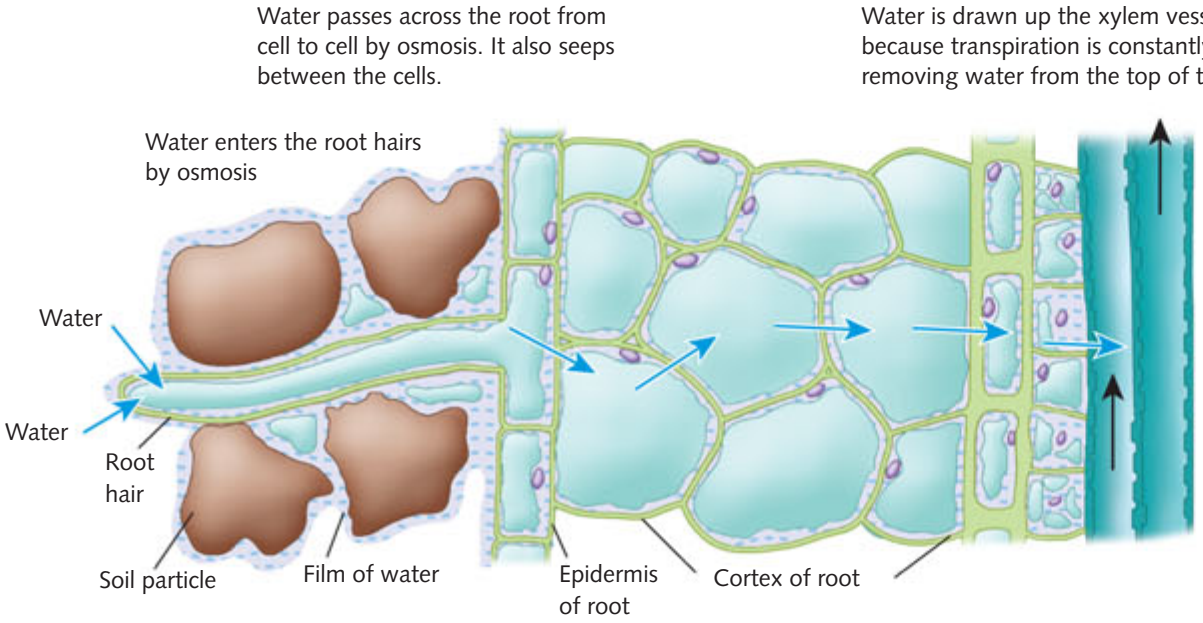

Figure 3.4 Movement of water through root epidermal cells, through the root cortex and into the xylem tissue where it moves upwards in the transpiration stream

force is known as **root pressure**, as discovered by Stephen Hales in 1727. Hales found that root pressure could be responsible for raising water to a height of over 6.4 m in a vine. This forces water into the plant and works to ensure that the water and minerals reach the vascular tissue of the stem. There are more processes involved in moving water from roots to leaves than just root pressure, which will be explained in the shoot system.

KEY CONCEPTS

- In plants there are two systems: the shoot system and the root system.
- Vascular tissue is involved in the transport of substances in plants. Vascular tissue is made up of xylem and phloem.
- Xylem is a water-conducting tissue composed of tracheids and vessels.
- Root hairs increase the surface area for water absorption.
- Water and dissolved ions enter the root from the soil by the process of osmosis for water molecules, and diffusion and active transport for dissolved ions.
- Phloem tissue transports sugars and other plant products around the plant.

Concept questions 3.1a

1 Describe the function of vascular tissue in plants.
2 Name the two types of vascular tissues in plants.
3 List three functions of roots.
4 Explain the features a plant has to increase its surface area for water absorption.
5 Explain using a flow chart how water and dissolved ions move from the soil solution into the xylem of the root of a plant.

HOT Challenge

6 Copy and complete Table 3.1 listing the properties of vascular tissues of plants.

Table 3.1 Vascular tissues of plants

Characteristic	Xylem	Phloem
Made of		Living cells
Cell wall thickness		Thin
Permeability		Permeable
Cytoplasm? Yes/no?		Yes
Transports		
	Leaves	Growing parts and storage organs such as tubers
Direction of flow		Upwards and downwards
Tissue also has …	Fibres	Companion cells

Water movement through the shoot system

Water and dissolved minerals continue their journey upwards to the leaves via the stem of the plant. The structure of the specialised cells and tissues of the xylem and their arrangement in the stem make this possible. These tissues, along with phloem tissue, are grouped into a series of **vascular bundles**, each rather like an electricity cable in the stem (Figure 3.5). The veins visible on a leaf are vascular bundles.

The way water moves through a plant involves many processes combined. Initially root pressure contributes to push the water as it enters the root cells, but what aids the movement of water up the stem as root pressure is reduced?

If you examine a glass of water, you can observe how water is curved up against the sides of the glass. It is easy to see this effect in a narrow measuring cylinder or glass tube. The curvature can be explained by **adhesion**, the forces of attraction between water molecules and the molecules that make up the sides of the container. The narrower the tube, the further the molecules reach up the side. Xylem vessels are very narrow, so water is drawn some distance up these tubes by adhesion forces alone. However, the problem is not only how to hold up the column of water, but also how to prevent it from breaking in the middle. What is responsible

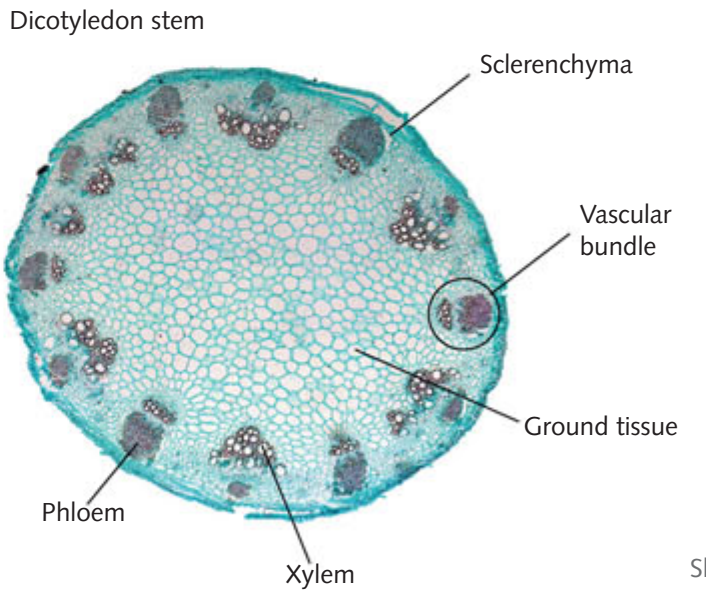

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Figure 3.5 Cross-section of vascular bundles in a stem showing the xylem and phloem present in each vascular bundle

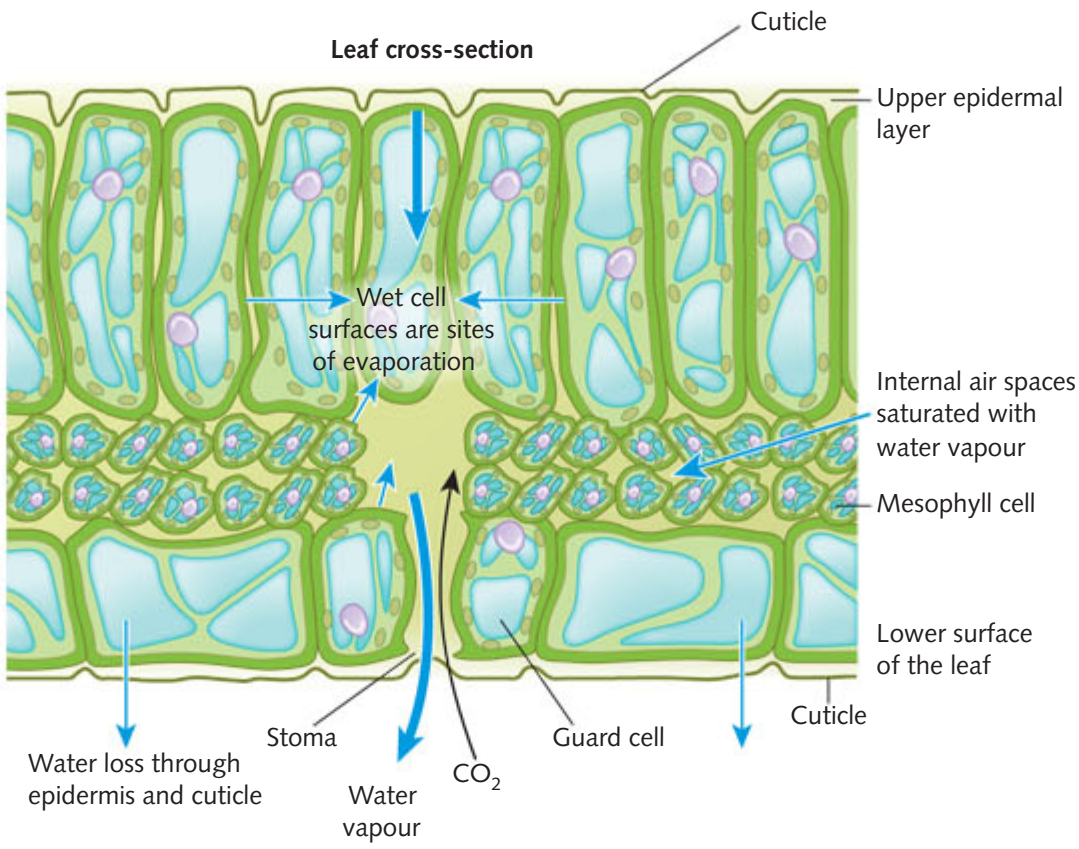

Figure 3.6 Movement of water vapour out of the leaf

EXAM TIP

Of all the contributions to movement of water upwards through the xylem, the most important is the heat energy of the Sun, not the light energy, although heat and light are both called radiant energy.

for this? Forces of attraction between the water molecules themselves help to pull the water column up the narrow xylem vessel. This is **cohesion**. But there is another problem. If you suck water up a straw too hard, the walls of the straw will collapse and the column of water breaks. In the xylem, the thickened, lignified walls prevent this from happening. The tension in the xylem of a tall eucalypt tree is extreme, but the strength of the lignified walls prevents their collapse. Therefore, the combined forces of root pressure, adhesion and cohesion ensure the continuous column of water movement through the xylem tissue in the stem of the plant.

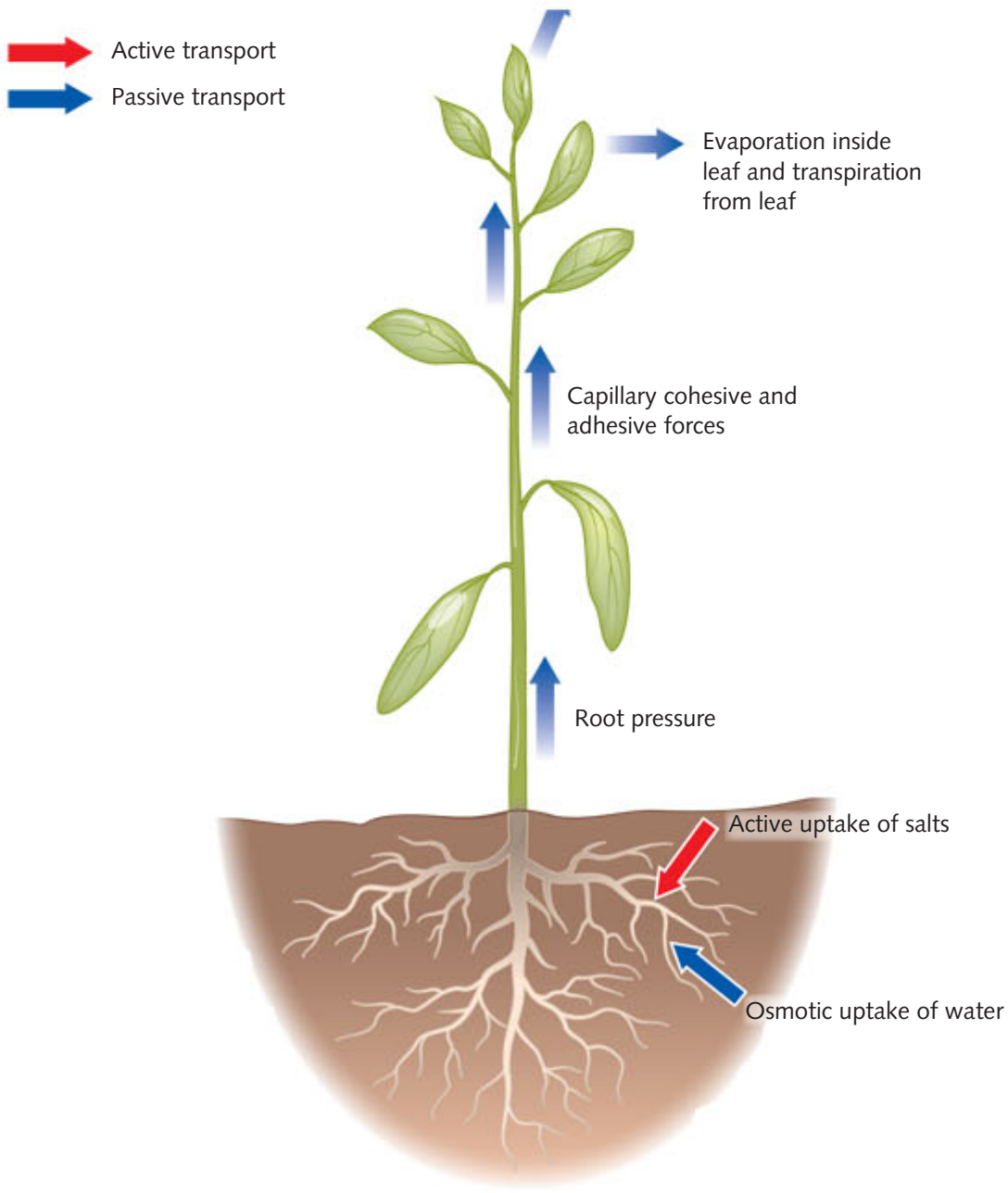

Figure 3.7 Diagram showing all forces involved in transpirational pull.

The major factor that contributes to the movement of the columns of water is, however, not a push from below but a pull from above. The constant upwards movement is driven by the evaporation of water from the the moist cell walls of the cells in the leaves and diffusion of the water vapour out of the leaves. This is called **transpiration**. The continuous column of water through the plant is known as the **transpiration stream**. Continuous columns of water therefore extend from the roots, up through the stem, to the leaves at the top of the plant. The major source of energy that causes the movement of these water columns upwards is the heat energy of the Sun. It causes evaporation from the surfaces of the cells inside the leaf and the subsequent diffusion of the water vapour from the leaves into the atmosphere (Figure 3.6). The process by which the water is pulled up vertically through the xylem is called **transpirational pull** and is depicted in Figure 3.7.

Water loss from the shoot system

WB
3.1.2
WATER LOSS
FROM THE SHOOT
SYSTEM
PAGE 58

Leaves of all plants are covered in a waterproof wax layer called the **cuticle**, through which a small amount of water is lost. Most water is lost through the pores in the leaves called **stomata** (stoma: singular). Each stoma consists of a pair of guard cells surrounding an opening, called a stomatal pore. The guard cells are highly specialised for their function, with a shape and thickened inner wall that aid in the opening and closing of the stomata at different times of day and night and in different environmental conditions. They also possess chloroplasts, unlike the surrounding epidermal cells. Inside the leaf, the walls of the mesophyll leaf cells are wet and the air spaces contain water vapour. When the stomata are open, gaseous exchange of carbon dioxide and oxygen takes place, and water vapour diffuses out of the leaf from the higher concentration inside to the lower concentration in the surrounding air.

Up to 98% of water absorbed by a plant can be lost through transpiration; only 2–5% is retained. The rate of transpiration is altered by three main environmental factors:

» Temperature: the higher the environmental temperature, the greater the rate of evaporation from the leaf cells. This results in a steeper water vapour concentration gradient between the inner leaf spaces and the surrounding air, and thus a greater loss of water vapour
» Humidity: the amount of water vapour in the surrounding air is higher on a humid day and, therefore, the rate of water vapour loss decreases
» Movement of the surrounding air: on a windy day or in any conditions of increased air movement, water vapour loss will be higher, as the water vapour diffusing out of the stomata is blown away. This increases the water vapour concentration gradient between the inside and outside of the leaves, resulting in the greater movement of water vapour out of the open stomata.

Many plants, particularly those that grow naturally in dry, arid or desert areas, have specific adaptations to increase water uptake or reduce water loss. These adaptations are discussed in Chapter 9.

SOUTHERN Biological Stress-tested by Southern Biological

INVESTIGATION 3.1

Plant transport systems

Water is an essential requirement for photosynthesis to occur. Because photosynthesis mostly occurs in the leaves of plants, water and the mineral ions dissolved in it move through the xylem in vascular plants from the roots to the leaves. Xylem consists of hollow cells of tracheids and vessel elements.

Aim

To examine how water is transported through a celery stalk and leaves

Materials

Each group will require:

» Stick of celery that has been standing in red food dye or eosin for several hours, cut 2 cm from its base
» Single-edged razor blade
» Microscope, stereo microscope or hand lens
» Microscope slides and coverslips
» Mounted needles (optional)
» Millimetre ruler
» Transverse and longitudinal stem sections of *Helianthus* (for Taking it further)

What are the risks in doing this investigation?	How can you manage these risks to stay safe?
Razor blades are sharp and can easily cut skin.	Handle razor blades carefully and report any injuries to your teacher immediately.
Food in the lab can be contaminated.	Do not eat the celery.

Method

1 Remove the celery from the coloured solution.
2 Examine the stalk and leaves for distribution of the dye by holding them up to the light. Observe the areas where the dye is concentrated. Draw the distribution of dye in the leaf.
3 Use the razor blade to cut thin transverse sections (1 mm) across the stem and any small branches from the stem and leaf as shown in Figure 3.8a. Arrange the sections onto a microscope slide (making sure the cut edges face upwards) with a drop of water and a coverslip. Undyed transverse sections should resemble Figure 3.8b.
4 Examine the sections under low power and construct diagrams in your logbook showing the distribution of the dye in each of the three regions: stem, shoots and leaves.
5 Cut another 1–2 mm piece of stem.
6 Use the razor blade to cut out a small piece of the area coloured by the dye and put this on a microscope slide.
7 Use a couple of mounted needles to tease the piece of tissue apart.
8 Add a drop of water and then a coverslip.
9 Use low power, then high power to see if you can find any 'spirals' or 'coils' of the thickened xylem vessels. Draw these structures into your logbook.

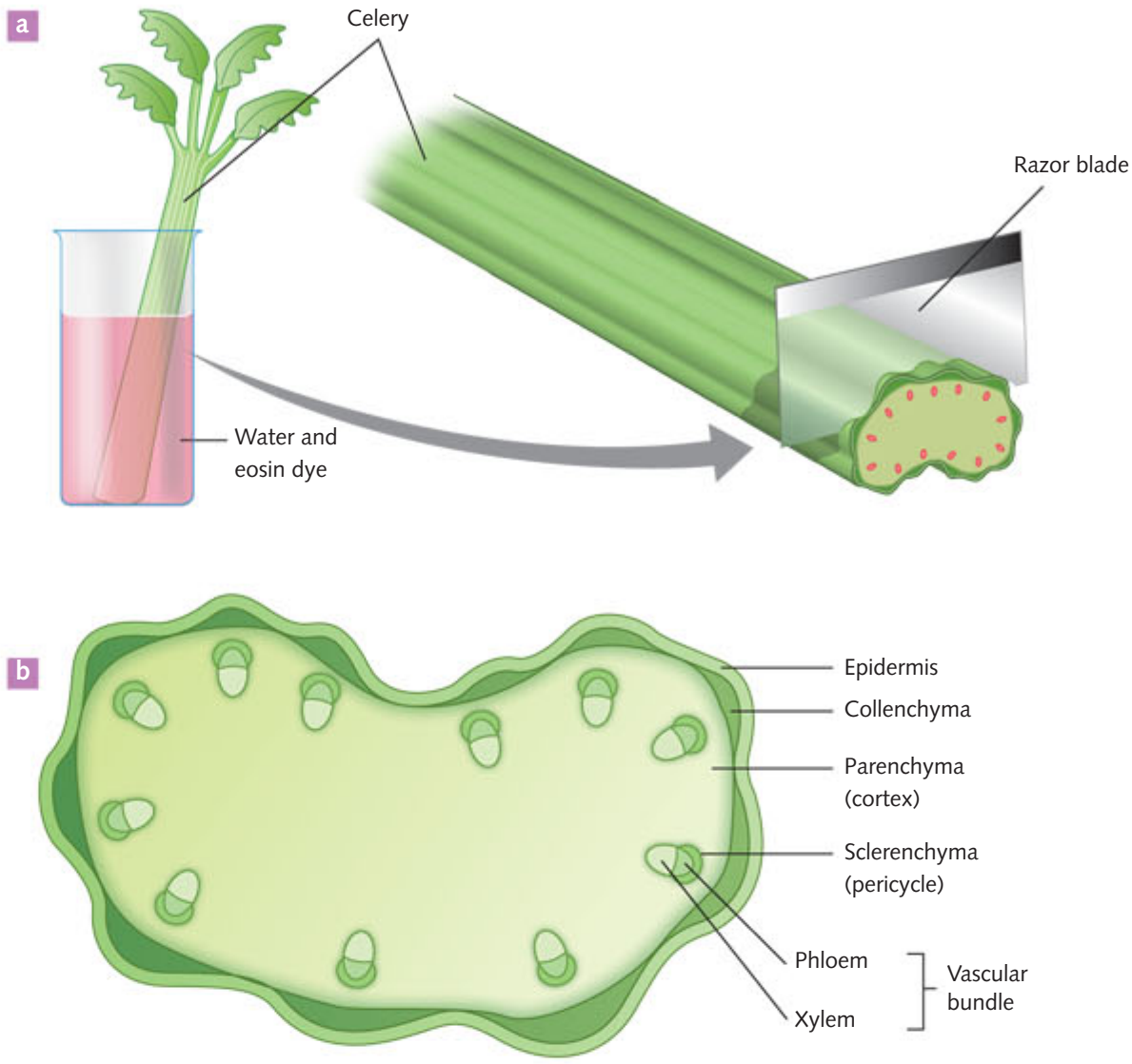

Figure 3.8 Movements of materials in xylem. a Investigation using celery to show the movement of materials in xylem b Transverse section through celery stem, showing tissue distribution (light microscope view)

Discussion

1 Describe how the dye is distributed in the plant. Has the whole stem turned a little pink or is the dye found in particular places? Explain your answer.
2 Discuss the assumption that the dye shows where the xylem is located.
3 Suggest what caused the dye to travel to the leaves.
4 If a stem is placed in Indian ink, which is a mixture of small black particles rather than a solution like the red dye, the colour does not reach the leaves. Explain why this would be the case.
5 a Name the type of tissue in which the coils and spirals would be located.
  b Name the substance that makes up the spirals.
  c Suggest a function for the spirals.

Taking it further

Examine prepared slides of transverse and longitudinal stem sections of *Helianthus* (sunflower) or another suitable plant. If the slide has been prepared with toluidine blue, lignin will be stained a greenish-blue colour while unlignified cell walls will be a reddish-purple.

1 Draw some diagrams from the transverse and longitudinal sections of the stem, showing where the regions of xylem (lignified areas) and phloem are located.
2 Look to see if any more spiral tissue can be seen, or lignin in other patterns. Where is it found: in the xylem or the phloem?

Nutrient transport: phloem

The other important tissue in the vascular bundle is the phloem. This consists of living cells, the sieve tube cells and the companion cells. The sieve tube cells are arranged in long tubes and their end walls are perforated to allow the cytosol to connect from one cell to the next. Although they are living cells, the sieve tube cells have no nucleus, and instead rely on the companion cells located next to them for cellular control (Figure 3.9).

The phloem transports organic substances, the products of photosynthesis, sucrose together with amino acids, and some mineral nutrients. Movement in the phloem is called **translocation** and transports the nutrients from a site of synthesis, such as the leaves, to a site of use or storage such as fruits or the roots, both up and down the plant, via the vascular tissue.

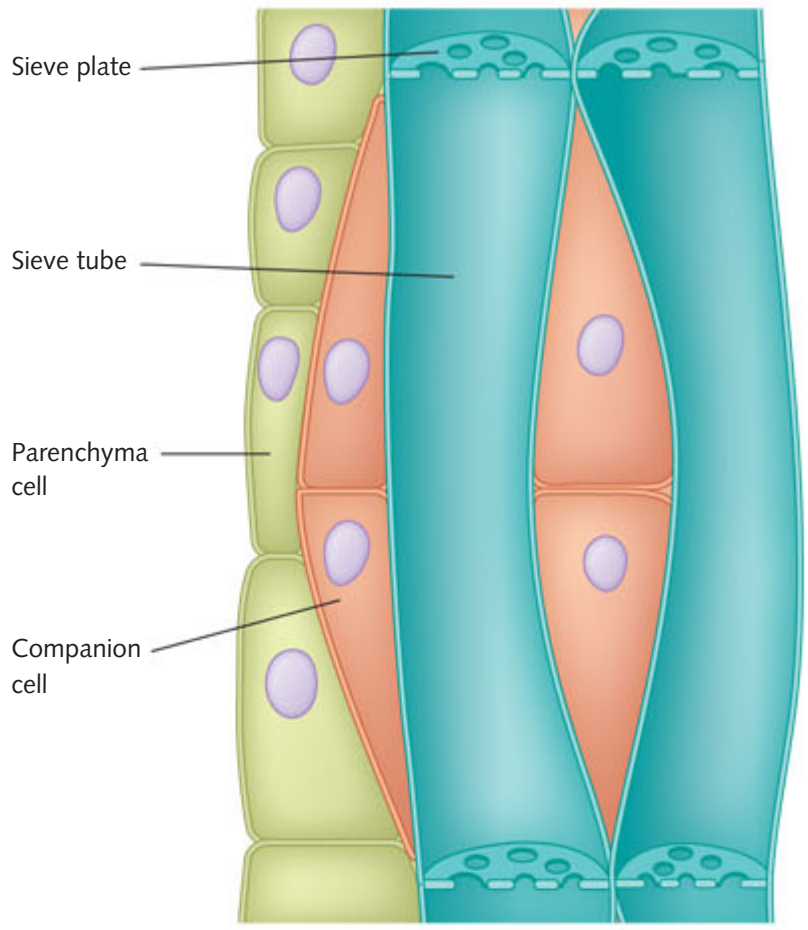

Figure 3.9 Phloem, showing types of cells found in it

WB 3.1.3 NUTRIENT TRANSPORT: PHLOEM PAGE 60
WB 3.1.4 TRANSLOCATION IN PLANTS PAGE 63
WB 3.1.5 INTERACTION OF TRANSPIRATION AND TRANSLOCATION IN PLANTS PAGE 64

KEY CONCEPTS

- Root pressure contributes to push the water upwards in the xylem after it enters the root cells by osmosis.
- The combined forces of adhesion and cohesion ensure movement of continuous columns of water upwards through the xylem tissue in the stem of a plant.
- Water evaporates from moist leaf cell walls and water vapour diffuses out via open stomata in transpiration.
- Movement through xylem is due to root pressure and mostly transpirational pull, and is always upwards.
- Water vapour diffusion out through the open stomata increases on a hot, dry or windy day.
- Phloem consists of living cells: the sieve tube cells and the companion cells.
- Phloem transports organic substances, the modified products of photosynthesis, sucrose together with amino acids, and some mineral nutrients.
- Movement in the phloem is called translocation and is both up and down the plant.

Concept questions 3.1b

1 List the features of xylem that make it effective in transporting water around the plant.

2 Transpiration is powered through the interaction of forces within the xylem to result in a transpirational pull. Describe the forces that are interacting, the structures that contribute and the materials that are being moved.

3 Explain where the energy for transpiration originates.

4 **a** What materials are transported in the phloem?

b What is the name of movement in the phloem and in which direction does it occur?

HOT Challenge

5 Photosynthesis and many other plant functions need to occur in a water-saturated environment. Explain how stomata contribute to a maintenance of around 100% humidity in the spongy mesophyll layer of the leaf on a hot day.

Weblink
How your digestive system works

Online Worksheet
How your digestive system works

3.2 Mammalian systems: digestive system

All organisms require access to complex organic nutrients (such as carbohydrates, proteins, fats, vitamins) and simple inorganic nutrients (such as water and mineral salts) that must eventually reach all living cells. **Heterotrophs** are organisms that cannot synthesise their own organic molecules from simple inorganic molecules and therefore depend on other organisms for their nutrients and energy. Multicellular heterotrophs possess **digestive systems** to break down ingested food and for absorption into the body. The digestive system consists of specialised cells grouped into tissues and organs that carry out specific roles in the processes of **digestion** and **absorption**. Using humans as an example, the structure and functions of the components of the digestive system can be explained in terms of cell specialisation and organisation. Much of the food ingested by humans is in the form of complex organic molecules. These complex forms are too large to pass across the plasma membrane and into the cells where they are required. Digestion is the process whereby the large complex molecules that make up our food are broken down into simple substances that are small enough to be able to move across the plasma membrane and into the **internal environment**.

There are two types of digestion.

» **Mechanical digestion** (physical digestion) occurs when large pieces of food are broken down into smaller pieces through chewing, muscular movement in the stomach, and the action of bile in the small intestine. This increases the surface area of the food so it can be acted on by enzymes in chemical digestion.

» **Chemical digestion** occurs when enzymes speed up the breakdown of complex molecules into simple molecules (such as carbohydrates to glucose, proteins to amino acids, and lipids to glycerol and fatty acids) so that absorption can then take place.

EXAM TIP
Mechanical digestion decreases the size of the food; chemical digestion decreases the size of the molecules.

Digestion takes place in the digestive system (also called the **gastrointestinal tract**). The digestive system has four main roles that involve the functioning of specialised tissues and organs within different regions.

WB
3.2.1 MECHANICAL DIGESTION PAGE 66

1 **Ingestion**: the taking in of nutrients
2 Digestion: the breakdown of large pieces of food to smaller pieces by mechanical digestion and then complex organic molecules into simple inorganic molecules by chemical digestion
3 Absorption: the movement of digested molecules into the internal environment of the body
4 **Egestion**: the removal of waste materials from the body.

In humans, the digestive system is one long tube, open at both ends, as shown in Figure 3.11. It consists of various regions made up of specific tissues and organs to carry out these four roles.

Ingestion

Humans, like most animals, ingest food through the mouth (Figure 3.10). Once food has entered the mouth, mechanical and chemical digestion commence. The molar teeth at the rear of the mouth help grind the food into smaller pieces to provide a greater surface area for enzyme action. Another organ, the tongue, is a strong muscle that helps to move the food around the mouth, thereby increasing the food's contact with the teeth and enzymes. The enzyme **amylase** is secreted from salivary glands situated near the base of the tongue. Amylase is present in saliva and speeds up the chemical breakdown of complex carbohydrates into simpler carbohydrates, such as starch into maltose. The secretory cells of the salivary gland contain extensive rough endoplasmic reticulum with many ribosomes for the synthesis of the enzyme amylase, a protein. They also contain numerous Golgi bodies for modifying and packaging the protein, and vesicles to transport the protein to the plasma membrane for secretion. Other salivary gland cells are similarly well suited for production of mucus containing the protein mucin. Mucus is a slippery liquid which, in the mouth, moistens the food and helps in swallowing.

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Figure 3.10 In humans, food is ingested through the mouth

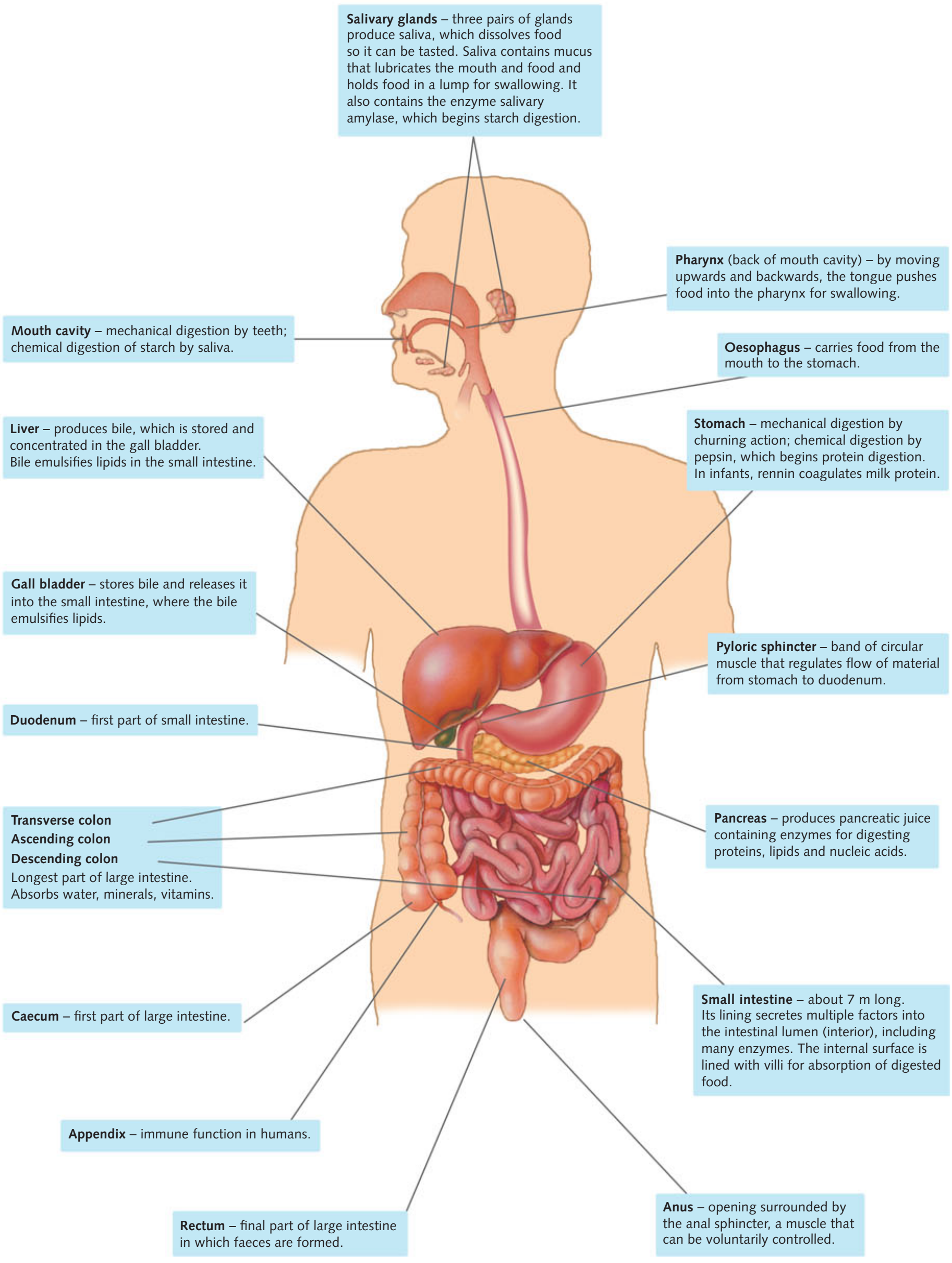


Figure 3.11 The structure and functions of parts of the digestive system

Digestion

Once the food is ready for swallowing, a ball of food, called a bolus, is pushed to the back of the mouth and swallowed with the assistance of the tongue. From there it enters the **oesophagus**. The oesophageal opening is extremely close to the opening of the trachea (windpipe). A small flap of tissue, the epiglottis, closes off the trachea, preventing food from entering the respiratory tract. The food moves down the oesophagus to the stomach with the aid of wave-like muscular contractions known as **peristalsis**. Some chemical digestion of starch will continue inside the food ball until it reaches the stomach.

In the stomach

WB 3.2.2 CHEMICAL DIGESTION PAGE 68

The stomach is a muscular sac in the gut with the potential to stretch significantly (Figure 3.12). In animals with specialised diets, this is a very useful ability. The vegetarian koala and wombat eat vast amounts of low-energy food and require a space where the digestion of hard plant material can take place. Circular muscles called **sphincters** regulate the movement of food into and out of the stomach. Sphincters act like the drawstrings on a bag: when the sphincter muscles contract, the opening closes.

Mechanical digestion occurs in the stomach as the muscles of the stomach wall relax and contract. The food is still in quite large pieces and the churning will aid physical breakdown into smaller pieces that provide more surface area for enzyme action.

WB 3.2.3 DIGESTIVE ENZYMES PAGE 70

The presence of food in the stomach stimulates the production of **gastric juice** from specialised secretory cells lining the stomach wall. This contains mucus, water, hydrochloric acid and the protein-digesting enzymes, **proteases** (pepsin). The presence of hydrochloric acid makes the environment of the stomach very acidic (**pH** 1.5–3.0), which is ideal for maximum gastric enzyme action. The proteases break down the long-chain **polypeptides** of proteins into smaller-chain polypeptides.

Mucus is also secreted by cells lining the stomach wall. It acts to protect the epithelial lining of the stomach from being digested by the enzymes, even though the cells that line the stomach also contain proteins. Food will remain in the stomach for up to 6 hours when the pyloric muscle sphincter at the exit of the stomach is closed, until it is reduced to a 'soupy' substance known as **chyme**. However, further digestion along the length of the gastrointestinal tube is required before the molecules that make up the chyme are in a small soluble form ready to be absorbed into the cells of the body.

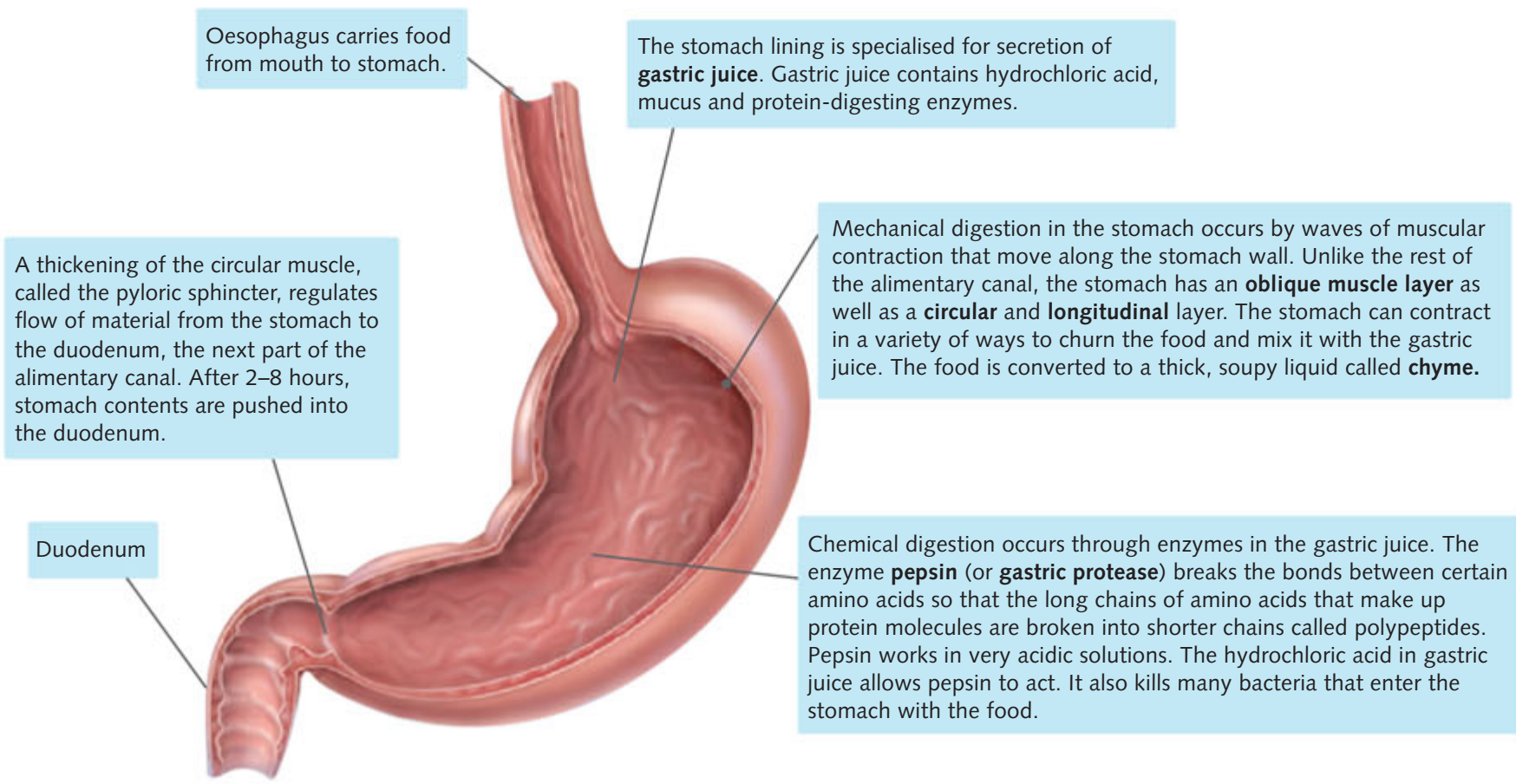


Figure 3.12 The stomach and its functions

Developed exclusively by Southern Biological

INVESTIGATION 3.2

Investigating the action of pepsin

Background

In this investigation, you will observe the action of pepsin on albumin, a globular protein. Pepsin is a digestive enzyme that is found in many organisms. It comes in many different forms, but in every case its function is to aid digestion by breaking proteins down via hydrolysis into their component amino acids.

Aim

To determine the optimal conditions for pepsin activity

Time requirement

45 minutes

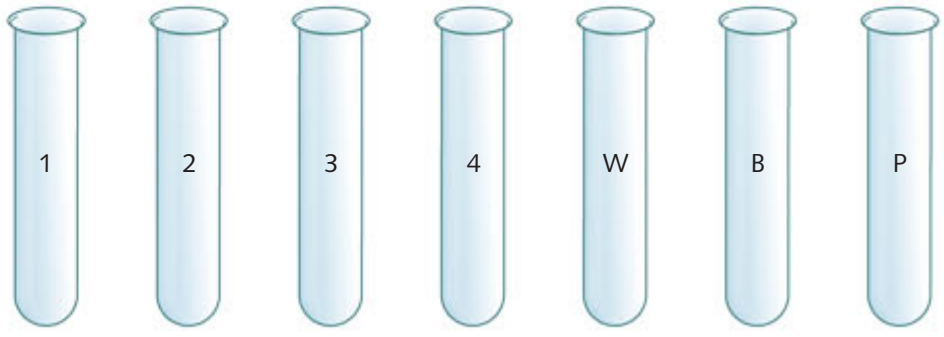
Materials

- 7 test tubes
- Test tube rack
- Bunsen burner
- Test tube holder
- 0.1M hydrochloric acid solution
- Albumin suspension
- Pepsin solution
- Plastic pipettes
- 250 mL beaker
- Hot plate
- Thermometer
- Distilled water
- Permanent marker
- Disposable gloves
- Clock/timer

What are the risks in this investigation?	How can you manage these risks to stay safe?
Bunsen burner flame can cause fire and/or severe burns.	Ensure safe use around Bunsen burners at all times.
Albumin may cause allergic reactions.	Alert your teacher if you have an allergy to egg.
Disposable gloves may pose allergy risk.	Use a type of glove that removes allergy risk and is suited to the chemicals being used.
Materials at high temperatures may scald or burn.	Use the test tube holder when handling the hot test tube. To prevent scalding, take care when working with water baths with water temperatures higher than 50°C. Do not touch the outside of the glass beaker.

Method

1. State a hypothesis and record it in your logbook.
2. Collect and label seven test tubes as shown in Figure 3.13.
3. Add 5 mL of the albumin suspension into each of the four numbered test tubes.
4. Add 5 mL of distilled water to the tube labelled W.
5. Add 2 mL of pepsin solution to the tube labelled B. Bring the contents of test tube B to the boil over a Bunsen burner flame. Hold the test tube at an angle as shown in Figure 3.14 and ensure it is pointing away from everyone.
6. Add 2 mL of pepsin to the tube labelled P.
7. Add three drops of distilled water to test tube 1.



Key
W = water
B = boiled
P = pepsin

Figure 3.13 Labelled test tubes

8 Add three drops of dilute hydrochloric acid to the test tubes numbered 2, 3 and 4.
9 Prepare a water bath by half-filling the 250 mL beaker with water and placing it on the hot plate. Maintain the water bath at a temperature of approximately 40°C by gently mixing the water then checking the temperature with a thermometer.
10 Place your labelled test tubes in the water bath for 5 minutes to warm them. It is only necessary to place test tube B in the water bath if it has cooled down.
11 Add 1 mL of the warmed water from test tube W to test tube 2.
12 Add 1 mL of the boiled pepsin solution from test tube B to test tube 4.
13 Add 1 mL of warmed pepsin solution from test tube P to test tubes 1 and 3.
14 Place test tubes 1–4 back into the water and set your timer for 6 minutes. After 6 minutes, remove the test tubes from the water bath and place them in the test tube rack.
15 Observe the contents of the numbered test tubes and compare their appearance. Record your observations in Table 3.2.

Figure 3.14 How to heat a test tube

Results

Copy Table 3.2 into your logbook and fill in the results of your investigation.

Table 3.2 Pepsin digestion results

Test tube	Contents	Results (appearance)
1	Albumin, pepsin, water	
2	Albumin, water, HCl	
3	Albumin, pepsin, HCl	
4	Albumin, boiled pepsin, HCl	

Discussion

1 Do the results support or refute your hypothesis?
2 Why was the water added to test tubes 1 and 2 in those particular quantities?
3 Why is the albumin suspension cloudy? What is suggested by the cloudy solution becoming clear?
4 What is suggested by the result in test tube 4?
5 What is suggested by the result in test tube 2?
6 Compare the results of test tubes 1 and 3. What can you infer from this comparison?
7 Antacids are basic tablets or powders that are taken orally to reduce the amount of acid in the stomach. This can reduce the discomfort associated with a highly acidic stomach environment. What might happen if more than the recommended number of antacid tablets were consumed in a short period?
8 Can you think of another beneficial function of stomach acid besides digestion?

Conclusion

Write a conclusion for this investigation based on your results.

Taking it further

Test the effect of different antacid medications on gastric enzyme function.

In the small intestine

From the stomach, digested food moves into the **small intestine** by the action of peristalsis through a small muscular opening, the **pyloric sphincter**. This controls the amount of food leaving the stomach and entering the small intestine and prevents too much food entering the small intestine too quickly. In adult humans, the small intestine varies in length but is approximately 7 m long with a very large surface area of 30–40 m^2. The small intestine has three defined regions as shown in Figure 3.15:

1. the duodenum (about 25 cm long)
2. the jejunum (about 2.5 m long)
3. the ileum (about 3.5 m long).

Two important accessory organs associated with the small intestine are the pancreas and the liver. Both contain specialised cells that produce substances essential to the chemical digestion that occurs in the small intestine. They are connected by ducts to the duodenum into which the secretory substances enter.

The secretion from the pancreas, known as **pancreatic juice**, contains a mixture of amylases, proteases (trypsin), lipases and bicarbonate. The acidic chyme entering the duodenum is neutralised by bicarbonate, which alters the pH of the duodenum (7.0–8.5). This stops the action of the protease enzymes such as pepsin from the stomach. At the same time, it provides the optimum pH medium for the enzymes in the pancreatic juice to be activated and function effectively.

Video
Chemical digestion

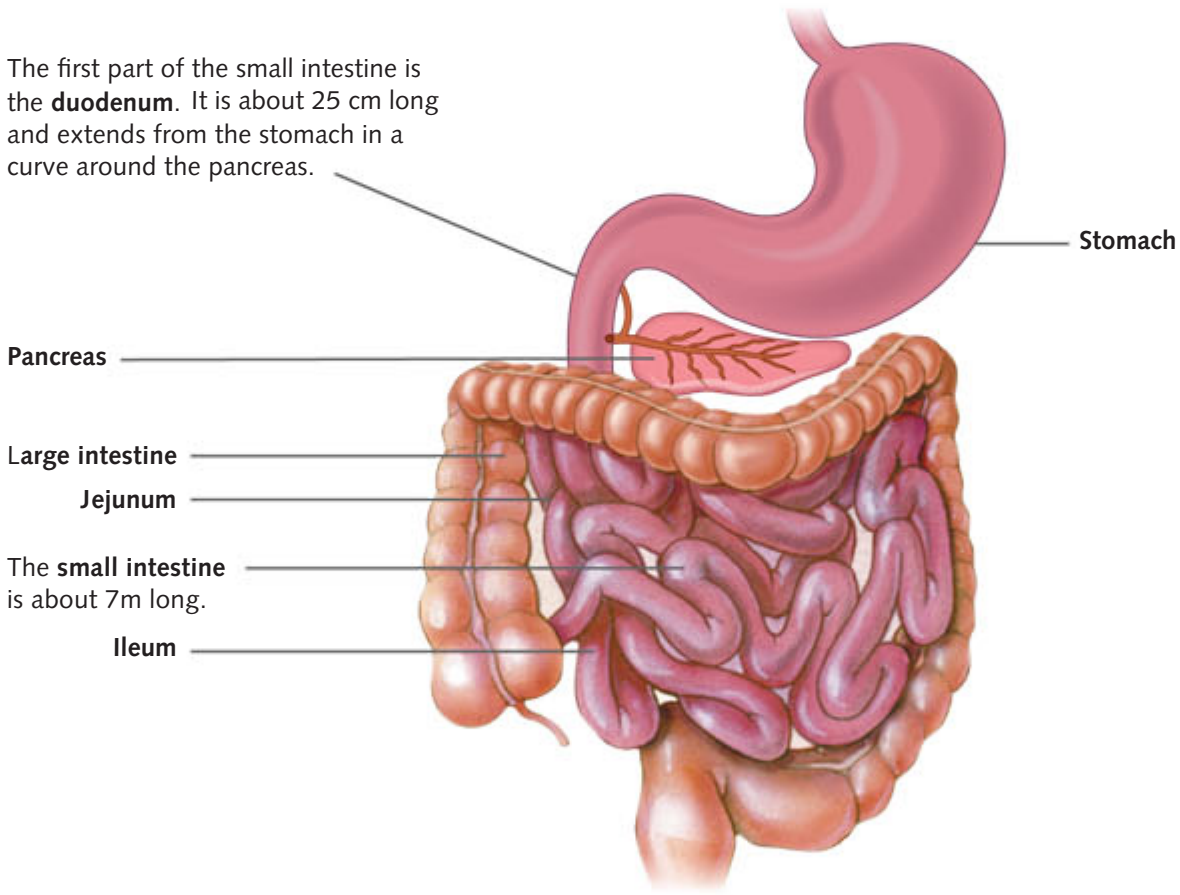


Figure 3.15 The location of the small and large intestines

Another accessory organ is the liver, which contains many different tissues for various functions. Its important role in digestion is to produce **bile**, which passes down the bile duct and into the duodenum. If there is no food to digest in the small intestine, the bile is stored in the **gall bladder**, attached to the liver. Bile is involved in the mechanical breakdown of fats. It is not an enzyme but instead has a detergent-like action on the fats. It acts mechanically to emulsify fats, breaking them down from larger globules into small droplets, increasing the surface area for the action of the enzyme lipase. Lipases act chemically to speed up the chemical breakdown of fats into fatty acids and glycerol.

EXAM TIP
Bile acts like a detergent to break globules of fat into smaller droplets, so its action is described as mechanical digestion, also called emulsification. It does not contain enzymes and does not break down the fat molecules chemically.

There are two groups of protease enzymes. The pancreas produces the protease enzyme trypsin, which acts on the long-chain polypeptides of proteins and breaks them down to shorter-chain peptides. A second group, erepsins, completes the digestion of the short-chain peptides by breaking them down into individual amino acids, the smallest unit of a protein (Figure 3.16).

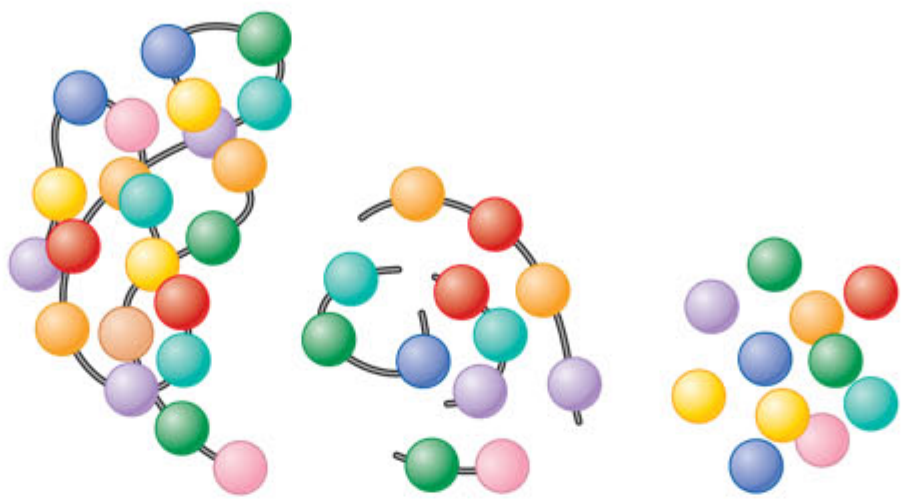


Figure 3.16 Action of protein-digesting enzymes: trypsin breaks long-chain polypeptides into smaller-chain polypeptides and erepsins break the short-chain polypeptides down into individual amino acids

From the duodenum, food enters the jejunum. The jejunum absorbs most of the digested food in the form of small, soluble molecules: simple sugars, amino acids, fatty acids and glycerol. The last section of the small intestine, the ileum, absorbs vitamin B12, bile salts and any other products of digestion not absorbed in the jejunum.

KEY CONCEPTS

- Digestion is the process that breaks down large complex foods into simple molecules for absorption.
- Mechanical digestion breaks down larger pieces of food into smaller pieces, thereby increasing the surface area of food particles on which digestive enzymes may act.
- In chemical digestion, digestive enzymes break apart large molecules, ensuring they are of a molecular form and small size that can be absorbed into the blood and lymph and then by cells in the body. The stomach provides the acid environment some of these enzymes need to act.
- Chemical digestion of starch starts in the mouth; chemical digestion of protein starts in the stomach; chemical digestion of fat starts in the duodenum of the small intestine.
- The pancreas secretes all three classes of digestive enzymes: amylases, proteases and lipases.
- Bile from the liver assists in the mechanical digestion of fat.

Concept questions 3.2a

1 Describe the main functions of the human digestive system.
2 Name the process and describe the way food is moved along the digestive tract.
3 Explain how gastric juice aids in digestion.
4 List the three regions of the small intestine and what occurs in each.
5 What main digestive enzymes are secreted by the pancreas?

HOT Challenge

6 Occasionally people lose their tongue through disease or an accident, yet they can still survive. What actions involved in digestion would they not be able to carry out?

Absorption

WB 3.2.4 ABSORPTION IN THE HUMAN GUT PAGE 72

The digestive tract is considered part of the **external environment** because it is a long tube connecting the external environment from one end to the other and substances in it are not in contact with the internal body fluids.

By the time the digestive enzymes have done their work, the products of digestion are in the form of small, simple, soluble molecules. They are ready to be transported across the plasma membranes of cells lining the small intestine into the internal environment, which consists of all the body fluids bathing the cells (tissue fluid, blood and **lymph**). Absorption of different molecules can occur all along the length of the gut. Substances such as alcohol and some drugs are absorbed through the stomach wall into the bloodstream. However, most digested food molecules are absorbed in the jejunum and ileum in the small intestine.

The structure of the small intestine is well adapted for absorption. It is very long and highly folded, providing a large surface area for absorption. The lining is moist and thin with a rich supply of blood and lymph vessels. Special structures, known as **villi**, project from the internal surface of the jejunum and ileum, greatly increasing the surface area of the gut lining. Villi are covered with microscopic **microvilli**, which further increase the surface area (Figure 3.17). Each villus is supplied with a network of capillaries that intertwine with lymph vessels called **lacteals** that transport materials (Figure 3.18). Simple sugars and amino acids are absorbed actively into the capillary network and then move into the blood. Fatty acids and glycerol are absorbed into the lacteals and enter the **lymphatic system**. Ninety per cent of the water in digested food is absorbed in the small intestine.

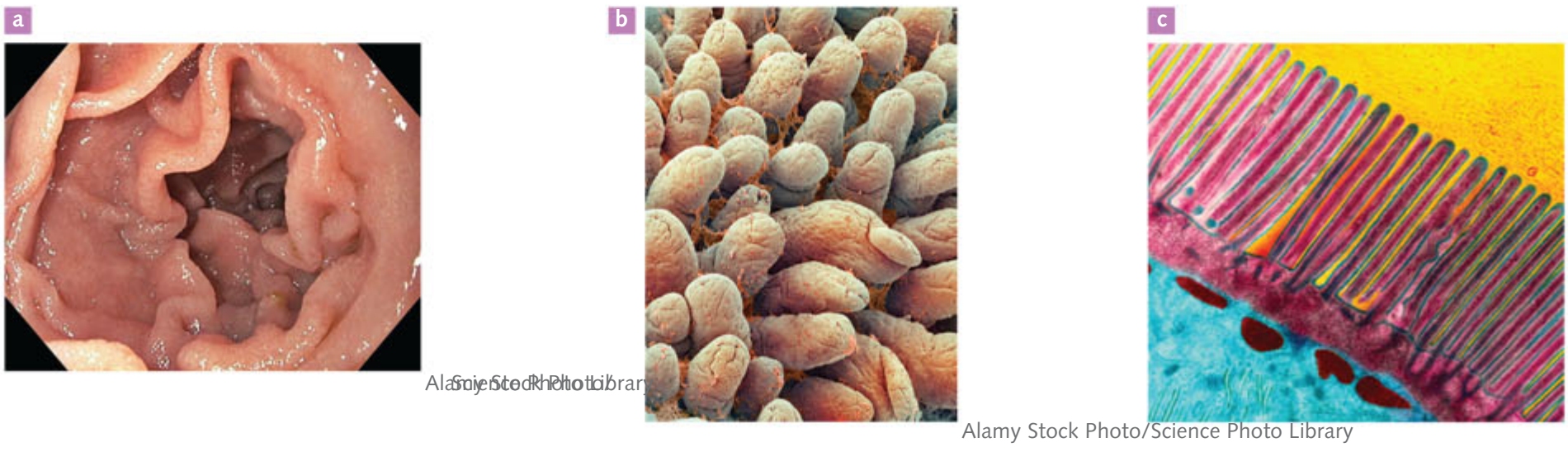


Figure 3.17a Folds of the mucosa on the inside of the small intestine; **b** Villi cover the internal surface of the small intestine as seen in this scanning electron micrograph; **c** Electron micrograph showing microvilli that cover the surface of each villus

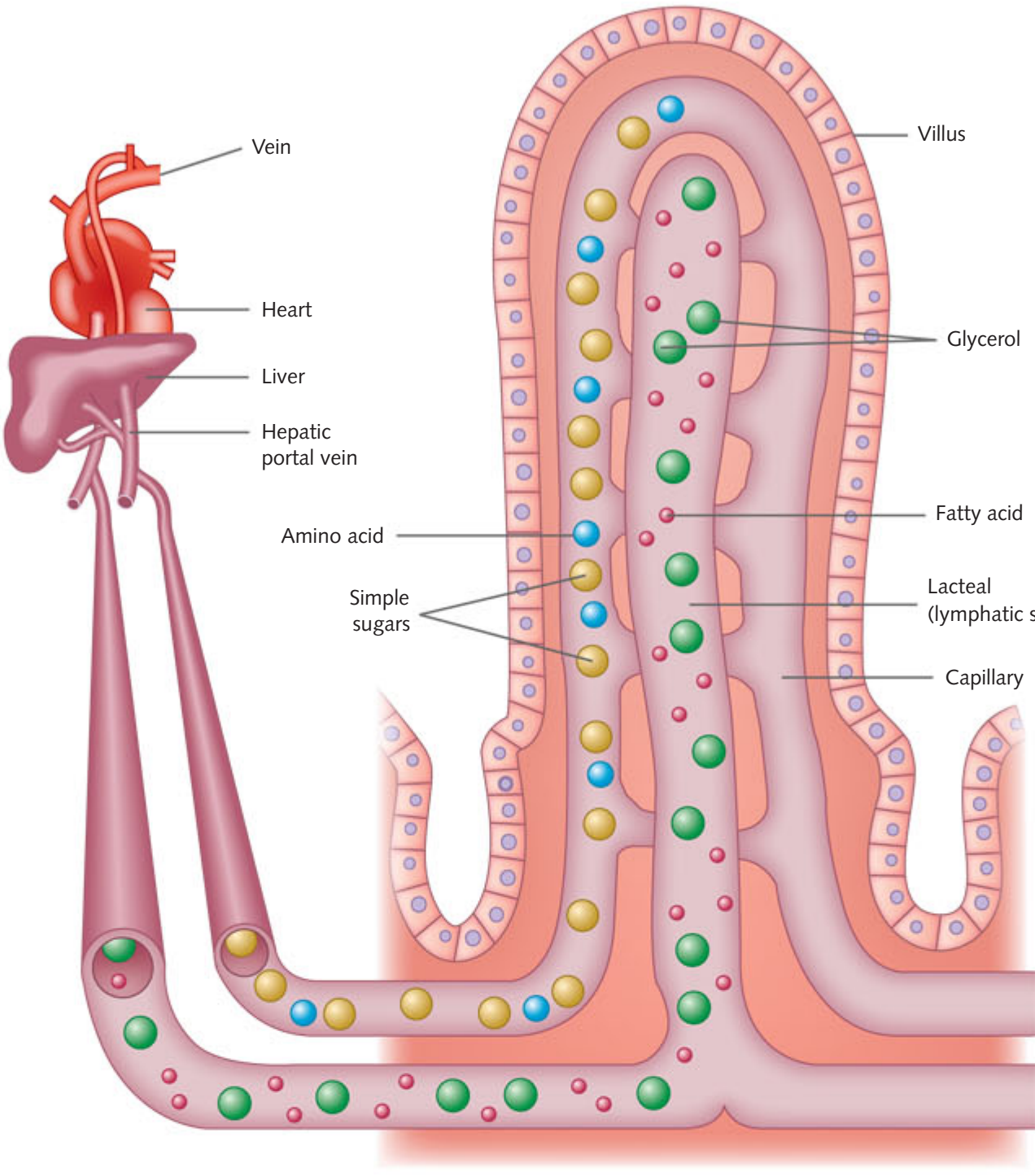


Figure 3.18 Cross-section of a villus showing how amino acids and simple sugars are absorbed into the blood capillaries in the villus and transported in the blood. Fatty acids and glycerol are absorbed into a blunt-ended lymph capillary called a lacteal and transported in the lymph.

Egestion

The **large intestine** is the final length of the gut. This section consists of two main parts, the **colon** and the **rectum** (Figure 3.19). The main functions of the colon are to absorb water and some salts back into the body and to compact undigested food material, such as dietary fibre (cellulose from plant cell walls). Bacteria present in the colon act on the undigested matter, producing vitamins A and K, which are absorbed through the lining of the colon. Peristalsis continues through the colon, pushing the waste material into the rectum where it is temporarily stored. This waste material, called **faeces**, contains about 75% water, together with undigested food matter such as cellulose (called fibre), dead and living bacteria, a small amount of protein and lipids, salts, mucus, some dead cells from the gut lining and bile pigments. It is eliminated from the body through the **anus** by egestion or defecation.

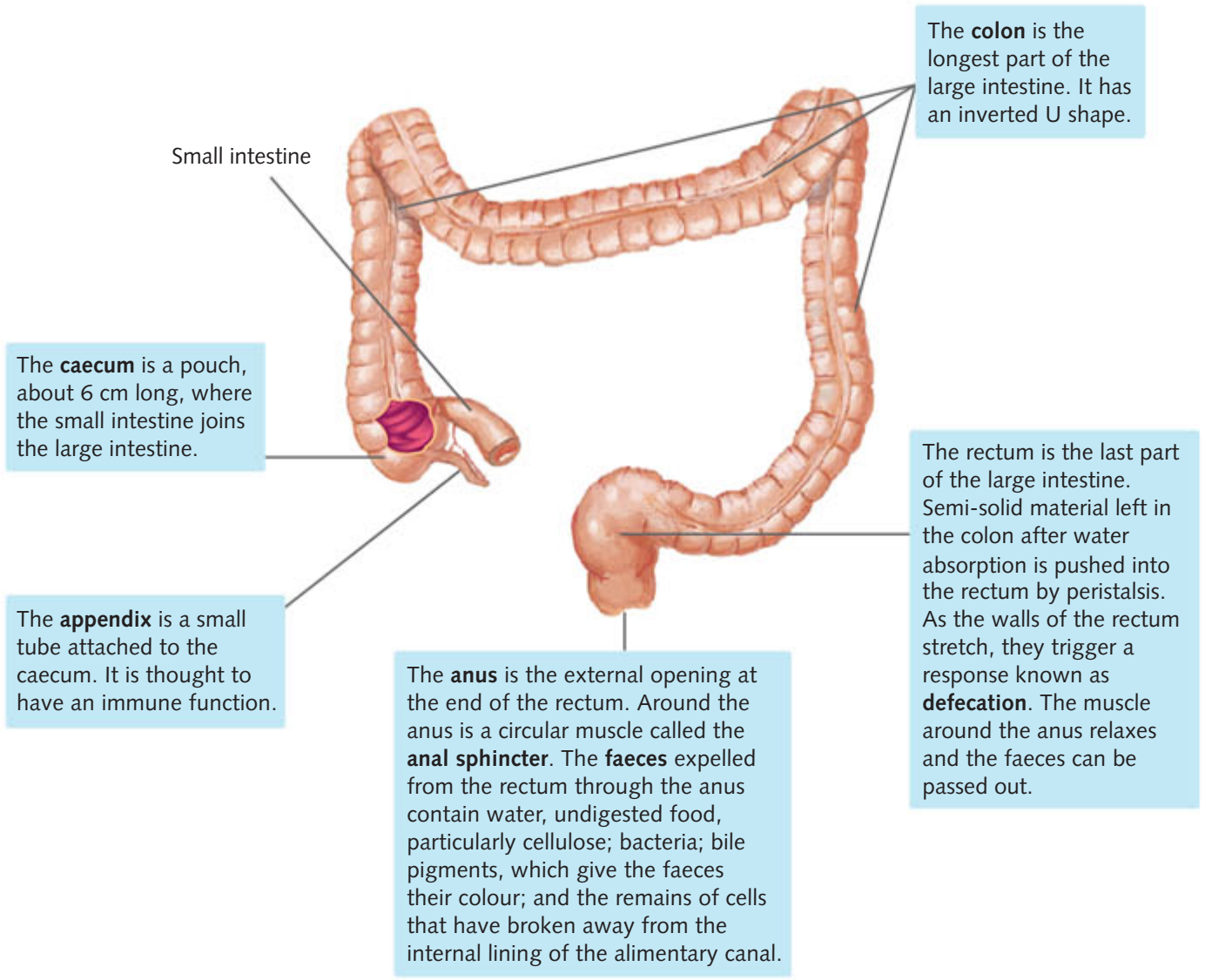


Figure 3.19 The parts of the large intestine and their functions

KEY CONCEPTS

- The products of digestion are absorbed from the external environment of the digestive tract into the internal environment of the blood and lymph in the small intestine.
- Villi and microvilli increase the surface area of the lining of the long small intestine, facilitating efficient absorption.
- In the large intestine, water and some salts are absorbed back into the body.
- Undigested food material is compacted for egestion through the anus.

Concept questions 3.2b

1. List, in order, the structures that food must pass through in a typical mammalian digestive system.
2. Describe the three processes by which absorbed nutrients leave the intestine and get into body cells.
3. Name structures that assist in increasing the surface area of the small intestine. Explain how their features facilitate absorption.
4. Draw an outline of a human and their digestive tract. Shade all areas that are considered part of the external environment.
5. Diarrhoea causes vigorous peristaltic action in the gut such that the motion of any contents is sped up towards egestion. How might this affect water and salt absorption in the colon and what would be the overall effect on the body?

HOT Challenge

6. Microflora found in the gut produce vitamin A and vitamin K, which are absorbed through the lining of the colon.
   a What are the functions of vitamins A and K?
   b How might a course of antibiotics affect the production of vitamins A and K?

3.3 Mammalian systems: endocrine system

The endocrine system is a communication system that puts together information that coordinates body functions. The endocrine system is like a sports team with the players (**endocrine glands**) that utilise signals (play calls) from the hypothalamus in the brain (the coach). Effective communication between the players (the glands) can result in the balanced hormone production that is essential for coordinated body functions.

In many cases, the cells that produce signals are not in the same part of the body as those that respond. Thus, information or signals must be transmitted to the cells that respond. This can be achieved by two different systems: the nervous system, an electrical/chemical system that transfers signals rapidly to specific sites via neuron (nerve cell) pathways; and the **endocrine system**, a system of long-distance chemical signals delivered by the signalling molecules known as **hormones**. Hormones are organic compounds produced in one part of the body that are transported in the bloodstream to other parts of the body, where they elicit a response. Some hormones, such as insulin, glucagon, thyroxine and anti-diuretic hormone, are made of proteins, polypeptides or amino acids. These hormones travel readily in the blood because they are water soluble and bind to receptors on the outside of the target cells that will respond to the hormone. Another group of hormones is made up of certain lipids called steroids; these include testosterone, oestrogen and cortisol. They are not water soluble so rely on protein carrier molecules to aid their transfer in the blood, but they are able to pass through the plasma membrane of target cells and bind with receptors in the cytosol. Only a small amount of a hormone is required to produce a significant effect on an organism's metabolism, growth or development.

Glands of the endocrine system

WB
3.3.1 ENDOCRINE SYSTEM PAGE 74

Hormones are produced and secreted by a collection of glands that make up the endocrine system. These organs secrete the hormones directly into the bloodstream. The word 'endocrine' means 'internal secretion', and the endocrine organs are therefore the 'glands of internal secretion'. Unlike salivary glands or sweat glands (called **exocrine glands**), which have a tube or duct through which their secretion passes, the endocrine glands have no ducts or tubes for exit of the hormone, and are therefore known as **ductless glands**. Once in the blood, the hormone is carried all over the body, but it only exerts its effect on specific cells that have the necessary receptor for the hormone, thereby producing a response (Table 3.3). Some effects are temporary, such as when adrenaline signals the release of glucose and increased heartbeat in the 'fight or flight' response. Regulatory mechanisms, such as those in foetal development, can have a longer-lasting effect. A target tissue may be a long way from the gland that secretes the hormone (Figure 3.20).

Table 3.3 Examples of human endocrine glands, a hormone they secrete and its function

Endocrine gland	Hormone secreted	Target tissue or organ	Function
Posterior pituitary	Antidiuretic hormone	Kidney	Stimulates reabsorption of water
Adrenal	Adrenaline	Kidneys, liver, blood vessels	Constricts blood vessels in kidney and liver; stimulates liver to release more glucose; prepares for 'fight or flight'
	Cortisol	Many tissues	Responsible for most of the body's physiological responses to stress
Thyroid	Thyroxine	Nearly all tissues	Increases metabolic rate, therefore increases oxygen consumption and heat release
Beta cells of pancreas	Insulin	Most body cells	Increases cell uptake of glucose thereby lowering blood sugar level, increases glycogen storage by liver, stimulates protein synthesis
Alpha cells of pancreas	Glucagon	Liver	Stimulates conversion of glycogen to glucose and its release

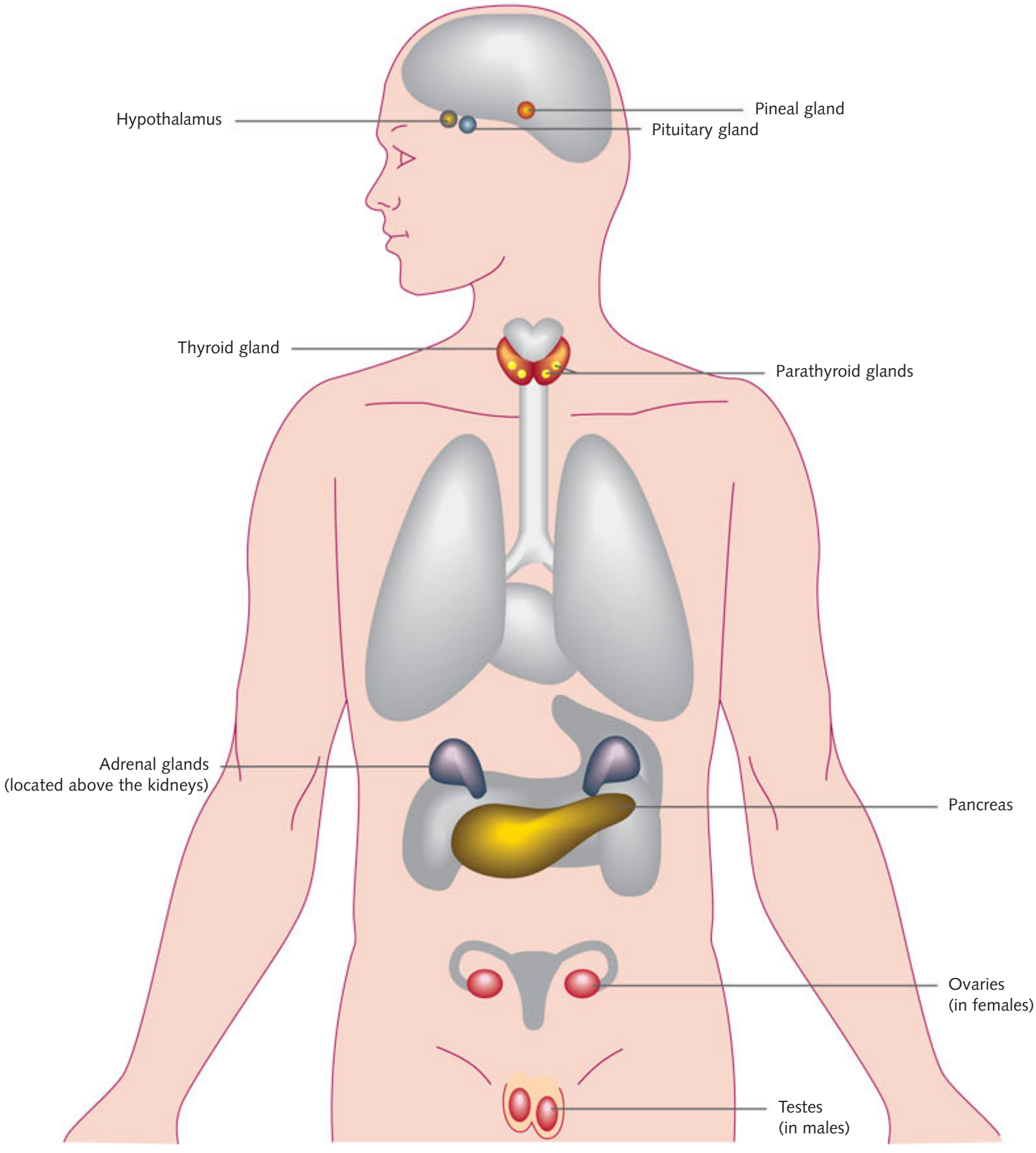


Figure 3.20 Location of the main endocrine organs in the human body

EXAM TIP

Do not get glucagon and glycogen confused. Glucagon is a hormone. Glycogen is a complex carbohydrate, the main way that excess glucose is stored in the body.

For example, antidiuretic hormone (ADH) is secreted from the pituitary gland in the brain and exerts its effects on the kidneys. It stimulates the reabsorption of water, helping maintain an appropriate water balance in the body.

CONNECT

Kidney function is discussed further in Chapter 4.

Figure 3.21 **The larger mouse on the left has inherited two copies of a mutant allele for an obesity gene, so it cannot produce the hormone leptin.**

Leptin is a signalling molecule produced and secreted by fat cells in adipose tissue. It travels in the blood reaching the brain, where it helps to regulate food intake and body weight. Figure 3.21 shows the result observed when a mouse cannot produce leptin.

Although many parts of the body make hormones, the major glands that make up the endocrine system are the hypothalamus, pituitary, thyroid, parathyroids, adrenals, pineal body, ovaries and testes (Table 3.3). The pancreas is also part of the system, having a role in hormone production (Chapter 4). Although these glands are widely separated from each other, they do not exist in isolation. They influence each other and are integrated into the highly coordinated endocrine system. Coordination of activities associated with the endocrine system is often connected to the pituitary gland.

Chapter 4 discusses the function of the hormones insulin and glucagon that are secreted and released by the pancreas, and their importance in regulation of blood glucose. Regulation of water balance in the kidney is also explained, with the hormone anti-diuretic hormone (ADH) playing an important role. In this chapter, we shall consider two other endocrine glands that are important for regulation and control in the body.

Hormone action: thyroid gland

The thyroid gland, situated in the neck, secretes the hormone **thyroxine**. Thyroxine is a complex organic compound containing iodine, which is obtained from the diet. Thyroxine is produced in specialised secretory cells in the thyroid gland and then passes directly into the bloodstream. It is responsible for controlling the **basal metabolic rate** of cells and is particularly important in growth.

Hormone action: pituitary gland

The pituitary gland plays an important role in regulating other endocrine glands by producing a number of hormones that help to regulate the production of other hormones around the body. For this reason, it is often called the 'master gland' of the body. Examples of this role include the release of hormones that activate the adrenal glands and the gonads (sex organs). The pituitary gland is in turn inhibited by the hormones secreted by those target organs. It is closely influenced by the brain and is located at the base of the brain, just above the roof of the mouth. There are two major lobes in the pituitary gland, called the anterior and posterior pituitary. Some anterior pituitary hormones affect more than just one specific endocrine gland. This is the case with human growth hormone (HGH), which influences the total growth of the body.

KEY CONCEPTS

- Hormones are important signalling molecules that are produced in one part of the body, travel in the bloodstream, and elicit a response in another part of the body.
- Hormones are produced and secreted directly into the blood from ductless endocrine glands.
- The endocrine system is made up of the endocrine glands, including the thyroid, pituitary and adrenal glands, and the ovaries and testes.
- Thyroxine is a hormone produced by the endocrine gland called the thyroid gland. It controls cell basal metabolic rate and is important in growth.
- The pituitary gland is called the 'master gland' of the body because it releases hormones that control other endocrine glands in the body.

Concept questions 3.3

1 a What are hormones?
b What are the two main types? What name is given to cells that respond to a specific hormone?
2 a What is a special feature of the glands that produce and secrete hormones?
b What are these glands called?
c What is the name of the system that consists of these glands?
3 Where is the thyroid gland located, what hormone does it produce and what does it regulate?
4 a Why is the pituitary gland called the 'master gland'?
b Where is it located, and why is it so important in the body?
5 What are the cell signals that indicate to the endocrine system that a response may be required?

HOT Challenge

6 Whereas the pituitary gland is called the 'master gland', the hypothalamus is often called the 'master switchboard'. Explain how these two glands interact and why they are both very important.

3.4 Mammalian systems: excretory system

EXAM TIP
The wastes produced by the digestive system are removed from the body as faeces through the anus. This is called defecation or egestion. The wastes produced by cellular metabolic processes are removed through the kidney in the process of excretion.

Cellular metabolic processes produce wastes such as **urea** and small amounts of **ammonia** dissolved in water. These waste products are removed by the **kidney**. The kidney functions not only to remove metabolic wastes, but also to regulate the concentration of body fluids. It does this by adjusting the amount of water reabsorbed back into the tubules and the amount of salt excreted in the urine.

Mammals, including humans, must include protein in their diet as a source of amino acids. However, excess amino acids cannot be stored in the body. When there is an excess, part of the amino acid is broken down and used for energy and the nitrogen-containing amine group is separated from the rest of the amino acid in a process called **deamination**. However, this converts the amine group to ammonia, which is toxic to cells. A build-up of 0.005 mg of ammonia is enough to kill a person. In the human body, cells in the liver convert the ammonia to the less toxic metabolic waste urea.

Urea is dissolved in the blood and carried to the organs that excrete it from the body, mainly as urine via the kidneys. The urea is excreted dissolved in water, so the kidneys need to maintain the delicate balance between preserving an adequate amount of water in the blood and using water from the body to excrete this nitrogenous waste.

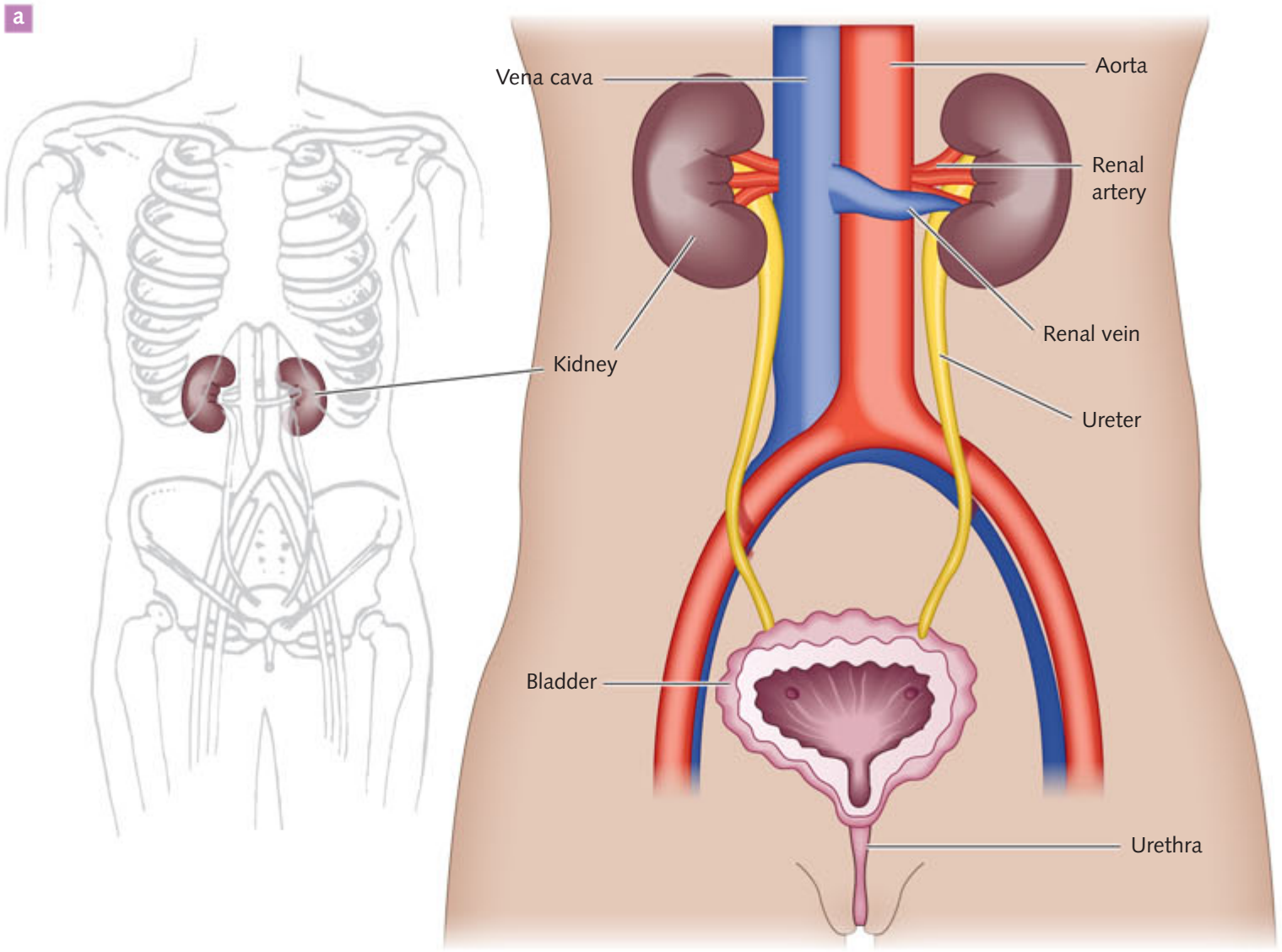
Human kidneys

The kidneys are two bean-shaped organs located in the back of the upper abdomen of the human body, either side of the spinal column (Figure 3.22). A branch of the aorta, the **renal artery**, brings blood containing nitrogenous waste and water, blood proteins, red blood cells, glucose, amino acids and minerals dissolved in the blood plasma to the kidneys. The kidneys are such important filtering organs in removing wastes from the blood for **excretion** that they may hold as much as 25% of the body's blood at any given time.

Nephron structure and function

Inside the kidney, the renal artery branches into smaller and smaller vessels until millions of capillaries are formed. Each capillary enters the cup-shaped end of a single slender tubule called a **nephron** where filtration of the blood occurs. Each kidney consists of approximately one million nephrons, extending from the cortex of the kidney down into the medulla (Figure 3.23). It is in the nephrons that water and solutes (such as glucose, amino acids, urea and mineral salts) are filtered from the blood due to the pressure of the blood. Some of these substances are then reabsorbed back into the blood further on in the nephron because they are essential to the body or are not in excess. How does this happen?

a



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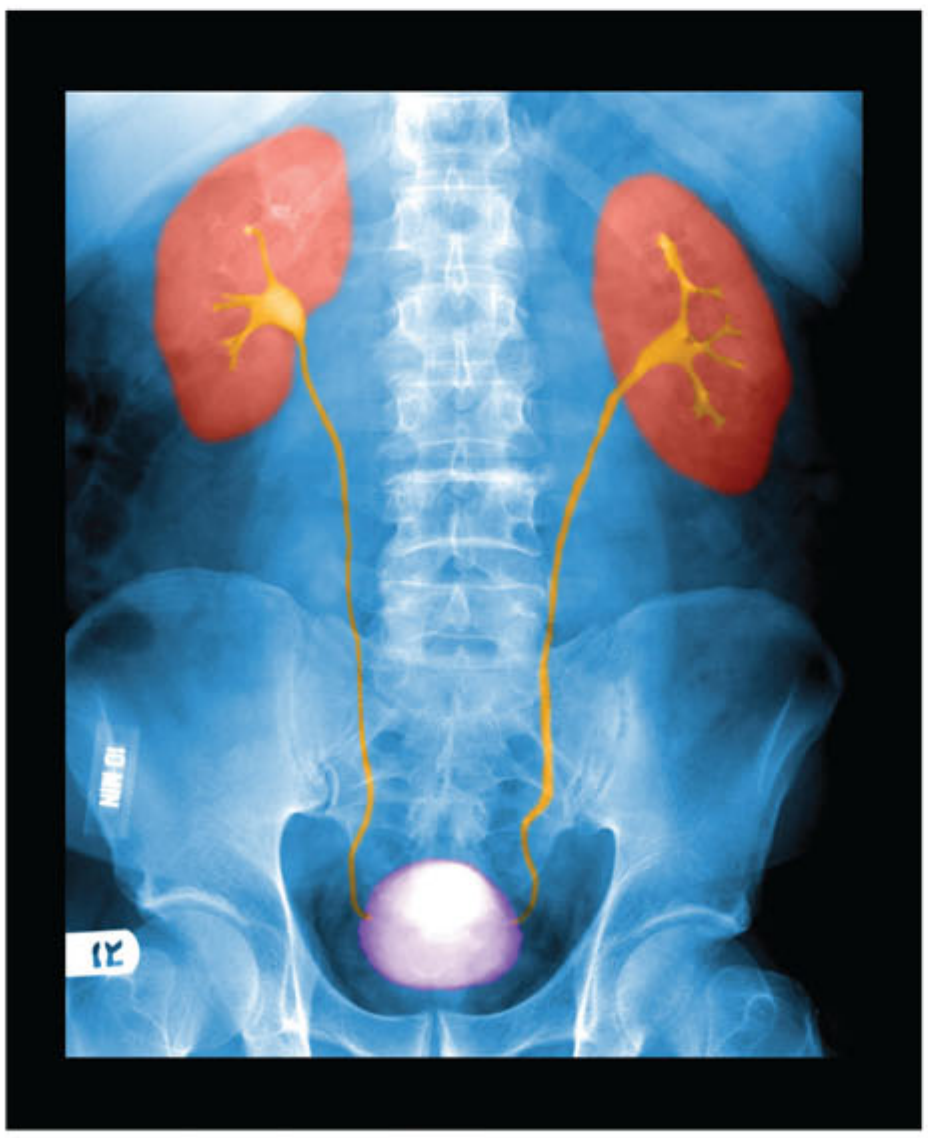
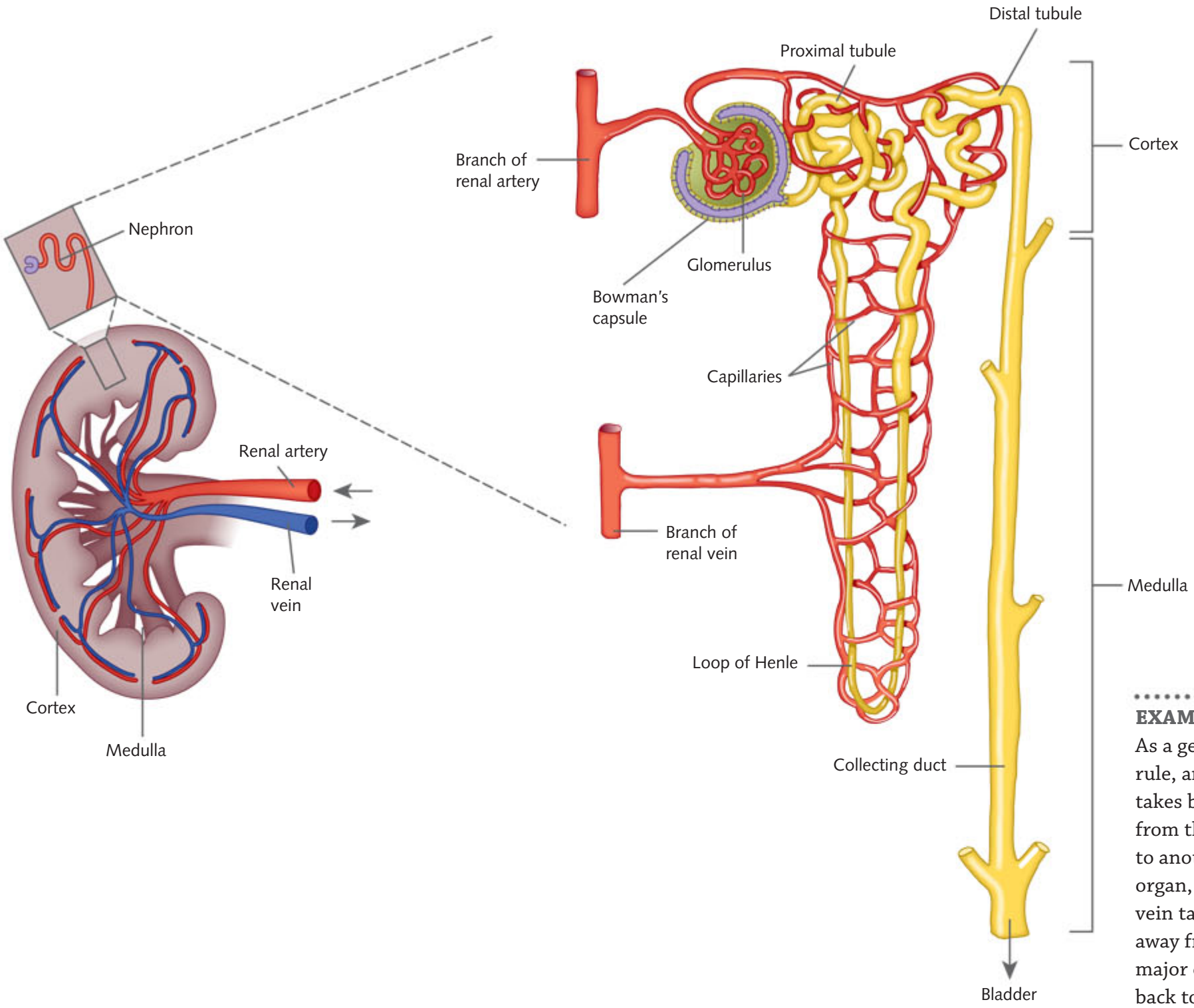


Figure 3.22 The human excretory system. **a** Diagram of the excretory system **b** Using a dye, this X-ray shows the tubes called the ureters that lead from the kidneys (top) to the bladder (bottom).

Alamy Stock Photo/Science History Images



EXAM TIP
As a general rule, an artery takes blood away from the heart to another major organ, whereas a vein takes blood away from a major organ and back to the heart.

Figure 3.23 Structure of the kidney and a functional unit, the nephron

Each nephron contains a ball of capillaries called a **glomerulus**. The glomerulus is situated inside the **Bowman's capsule**, which looks like a hollow rubber ball that has been pressed in on one side. The capillaries that form the glomerulus are tightly held in the cavity of the Bowman's capsule and blood in them is under high pressure from the renal artery. This pressure forces some of the water and solutes including glucose, amino acids, urea and mineral salts, out from the blood and through tiny pores into the Bowman's capsule. Large molecules of protein, and red blood cells and platelets, are too large to pass through so they remain in the blood. The two single layers of cells of the glomerulus and the Bowman's capsule act like a sieve, allowing only small soluble molecules and ions to pass through to form the glomerular filtrate. This **filtrate** has just moved from the internal environment, the blood, into the external environment, because this tube is eventually connected to the outside surroundings. If there are red blood cells, platelets or protein in the filtrate, it indicates kidney damage to the glomerulus and Bowman's capsule walls.

WB 3.4.1 STRUCTURE OF THE EXCRETORY SYSTEM PAGE 76

The filtrate moves to the **proximal tubule**, then to the hairpin-shaped **loop of Henle** and finally to the **distal tubule**. The capillaries inside the glomerulus have continued out of the Bowman's capsule to form a second capillary network around these tubules and the loop of Henle. In this area, reabsorption takes place in which all essential substances (such as glucose and amino acids) are reabsorbed back into the blood by active transport; some water and mineral salts are also reabsorbed, the amount depending on how much is needed by the body to maintain a relatively constant concentration in the body fluids. In these

tubules, more urea also passes from the blood into the fluid forming in the tubules. Dissolved in the water, this urea and other wastes will then form the urine. The longer the loop of Henle, in which much of the water reabsorption occurs, the greater the ability of an organism to reabsorb water from the glomerular filtrate and concentrate its urine as is necessary in drier environments. Table 3.4 summarises the roles of all these kidney parts.

WB
3.4.2 COMPOSITION OF FLUIDS IN THE KIDNEY PAGE 78

There are more than ten different types of kidney cells. They vary in shape from flattened to cuboidal (square) to columnar (long). They are all well adapted for their functions in filtration and reabsorption by the presence of a selectively permeable membrane which only allows certain molecules to pass through. Some have surface extensions to increase surface area and, together with the extended length of the tubules and the spherical cup-shape of the Bowman's capsule, provide an enormous surface area over which filtration and absorption can occur.

On average, about 600 mL of fluid flows through each kidney every minute. Approximately 20% of the fluid, 120 mL, is filtered in the nephron. If all this fluid were excreted, it would be necessary to drink at least 1 L of fluid every 10 minutes just to maintain water balance. Fortunately, reabsorption ensures that 119mL of the 120 mL of filtrate, along with some essential materials, are returned back into the body. The remaining 1 mL becomes the urine. Urine is approximately 95% water, with the remaining 5% consisting of dissolved salts, urea and a few other substances. Even drugs such as penicillin are excreted. A typical adult excretes approximately 25 g of urea per day.

Table 3.4 Summary of the roles of each part of the nephron

Name and structure	Function
Glomerulus: a cluster of capillaries that carry blood from the renal artery	Filtration: pressure of blood forces about one-fifth of fluid out through the capillary walls; mostly water along with substances small enough to pass through: urea, glucose, amino acids and mineral salts. No red blood cells, platelets or large proteins can pass through into the filtrate due to their size. Filtered substances enter the cavity of the Bowman's capsule.
Bowman's capsule: a hollow, cup-shaped end of the nephron with walls one cell thick	Filtration: fluid made up of water and dissolved materials is forced by the pressure of the blood into the hollow space of the Bowman's capsule. This glomerular filtrate then passes into a tubule.
Proximal tubule: a hollow, winding, large-diameter tube	Reabsorption: glucose, sodium ions, calcium ions, phosphate ions and amino acids are actively pumped back into the surrounding capillaries. The urea stays inside the fluid in the tubule.
Loop of Henle (descending): straight part of loop moving away from the proximal tubule	Reabsorption: the concentration of water inside the tubule is greater than that of the surrounding blood in the capillaries, so water flows out of the tubule fluid and back into the blood by osmosis. Urea stays inside the tubule.
Loop of Henle (ascending): straight part of loop leading to the distal tubule	Reabsorption: sodium ions are actively pumped out of the tubule fluid and back into the blood capillaries. Walls of the ascending loop of Henle are impermeable to water so it remains inside.
Distal tubule: a hollow, winding, large-diameter tube	Reabsorption: a final adjustment of water and dissolved materials takes place. If the body is dehydrated, the permeability of the distal tubule is increased to allow more water to return to the capillaries by osmosis. If the body is not dehydrated, permeability decreases so water remains within the tubule and dilutes the urine that leaves the body.
Collecting ducts: a system of urine-collecting ducts that widen as they near the renal pelvis	Secretion: other wastes are transferred from the capillary network into the duct. Reabsorption: water moves by osmosis from the duct into the surrounding blood capillaries.

The body adjusts for excess water intake by decreasing the volume of water reabsorbed and therefore increasing the volume of dilute urine excreted. Conversely, it adjusts for increased exercise or decreased water intake by reducing the amount of water reabsorbed, therefore producing a smaller volume of more concentrated urine. The kidneys not only prevent the build-up of wastes, but are also essential organs for helping to maintain water balance in the body through their control of the volume and composition of body fluids (osmoregulation).

The urine from all the collecting tubules in one kidney is collected in the **renal pelvis** and empties into a ureter. The ureters from each kidney carry the urine to be temporarily stored in the bladder. At intervals, the muscle sphincter of the bladder relaxes, releasing the urine through the urethra to the outside in the process of urination.

SOUTHERN Biological Developed exclusively by Southern Biological

INVESTIGATION 3.3

Modelling kidney function

Background

Urine is formed through a process of filtration, reabsorption and secretion in the nephrons and associated collecting ducts. The kidneys interact with other systems to produce urine, removing unwanted cellular waste, metabolic wastes, excess salts and toxins from the blood. Using dialysis tubing and simulated kidney blood, we can model how the glomerulus selectively filters substances based on their size and characteristics. Substances that are too large are unable to pass through the membrane, whereas smaller substances can be detected in the surrounding liquid. While the filtration that occurs within the kidney is far more controlled, this investigation provides a good illustration of how filtration occurs in the production of urine.

Aim

To investigate how the kidneys interact with other systems to form urine by building a model of the kidney

Time requirement

50 minutes

Materials

- 2 pipettes
- 2 microscope slides
- Compound microscope
- 2 coverslips
- 250 mL glass beaker
- 2 salt test strips
- 10 mL simulated kidney blood
- 20 cm section of dialysis tubing
- 25 mL graduated cylinder
- Bulldog clip or similar
- Clock or timer
- Disposable gloves
- Distilled water
- Paper towel

What are the risks in this investigation?	How can you manage these risks to stay safe?
Simulated kidney blood will stain skin and clothing.	Avoid any direct contact with skin and clothing and wear appropriate PPE, such as gloves and lab coat.
Broken glass can cause cuts.	Inspect and discard any chipped or cracked glassware, no matter how small the damage. Sweep up broken glass with brush and dustpan; do not use fingers.

Method

1. Write a hypothesis for this investigation into your logbook.
2. Pour 100 mL of water into your beaker.
3. Place the tip of your salt test strip into the water for 3 seconds and gently swirl. To remove excess liquid, lightly tap the strip on the edge of your beaker or gently pat dry with a paper towel. After 3 minutes, determine the results and record them in the data table into your logbook.
4. Tie one end of the dialysis tubing into a knot. Ensure the knot is pulled tight but do not allow the tubing to tear.
5. Measure 10 mL of simulated blood using a graduated cylinder and carefully pipette this into the dialysis tubing. Once the tubing is filled, twist to close the end and seal using a bulldog clip.

6 To ensure there is no simulated blood on the surface of the prepared dialysis tubing model, rinse it with tap water.
7 Place the dialysis tubing model into the water in the beaker and add additional water until the filled portion of the dialysis tubing is fully submerged as shown in Figure 3.24. Allow to it rest in place for 30 minutes.
8 Place one drop of simulated blood on a microscope slide, using a pipette. Place a coverslip on top, and observe under the microscope. Sketch what you observe into your logbook.
9 After 30 minutes, test the salt content of the filtrate in the beaker using a new test strip. Place the strip in the liquid for 3 seconds and swirl gently. Remove excess liquid from the strip and wait 3 minutes to determine the results. Record the salt content results and any colour changes in the results table.
10 The fluid surrounding the tubing represents the filtrate. Place one drop of this fluid from the beaker on a new microscope slide using a pipette and place a coverslip on top. Observe the slide under the microscope and sketch what you observe into your logbook.

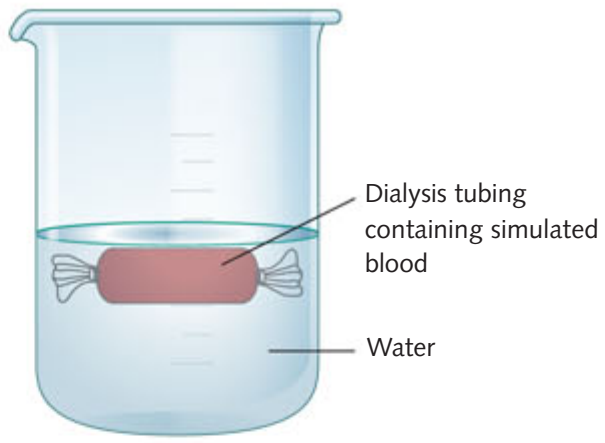


Figure 3.24 Set-up for dialysis tubing in beaker

Results

Copy Table 3.5 into your logbook and complete it.

Table 3.5

Test	Prediction	Observation
Initial water colour	N/A	
Filtrate colour (after 30 minutes)		
Initial colour of dialysis tube contents	N/A	
Colour of dialysis tube contents (after 30 minutes)		
Salt in plain water		
Salt in filtrate (after 30 minutes)		

Discussion

1 Which portion of the nephron were you modelling in this investigation? Explain.
2 Why was it necessary to test the water for salt before you added the dialysis tubing?
3 Imagine you left the tubing model in the beaker for 2 days. How would the salt content in the filtrate change?
4 Compare the dialysis tubing and kidneys. Discuss how the dialysis tubing functioned like a kidney and the ways in which it did not.
5 What did the dialysis tubing retain? What was able to pass through the membrane?
6 Explain the difference between the solution within the dialysis tubing and surrounding water that allowed substances to travel through the membrane.

Conclusion

Write a conclusion consistent with your observations.

Taking it further

1 Kidney disease can be described as a systemic disease despite directly affecting the kidneys. In what ways can the whole body be impacted by kidneys that do not function adequately?
2 Explain how the following systems interact with the excretory system.
   a Circulatory
   b Digestive
   c Respiratory
3 When blood is present in urine it can be an indication of several disorders, such as high blood pressure. How could high blood pressure be responsible for the blood in the urine?
4 Explain the interaction that occurs between the circulatory system and kidneys to form urine.

Sweating out waste material

The skin is the largest organ in the body. Figure 3.25 shows its main structural features. In addition to its functions in providing protection from microbes and the elements and sensitivity to touch, heat and cold, it plays a special role in temperature regulation. During sweating, nitrogenous wastes and mineral salts are removed, so the skin also acts as an excretory organ. The composition of sweat is similar to blood plasma, except that sweat does not contain proteins. As the sweat moves along the sweat duct to the skin surface, some sodium and chloride ions are reabsorbed into the bloodstream. Sweat loss, therefore, causes an increase in the salt concentration of the blood. On days of increased sweating, fluid intake must be increased. It is important to remember that sweating is mainly a temperature control mechanism rather than a way of removing nitrogenous wastes.

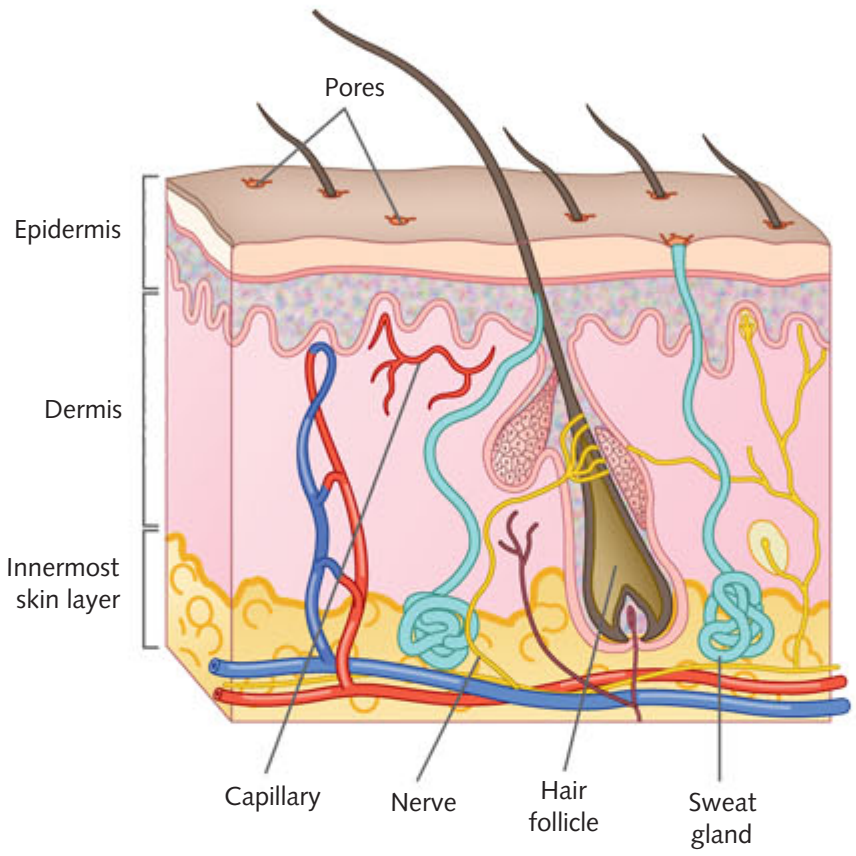


Figure 3.25 A section of skin showing sweat glands

KEY CONCEPTS

- The excretory system removes cell metabolic wastes from the internal environment. Kidneys are the excretory organs that remove cell metabolic wastes from the internal environment. The kidneys also remove excess fluid and so play an important role in regulation of the body's fluid concentrations.
- Kidneys have many nephrons that collect and concentrate the filtrate that is forced out of the capillaries of the glomerulus.
- The start of a nephron is cup-shaped (Bowman's capsule). It continues as three tubular regions (proximal tubule, loop of Henle, and distal tubule) that then empty into a collecting duct.
- Urine forms in the nephron by filtration, reabsorption and secretion.
- The skin produces and removes nitrogenous wastes and mineral salts via sweating.

Concept questions 3.4

1 List, in order, the pathway that the nitrogenous waste urea takes, starting from blood and ending with the collecting duct.
2 Name the structure where the final amount of water is reabsorbed.
3 Draw a labelled diagram showing the structure of a nephron. On your diagram, indicate where filtration, reabsorption and secretion occur.
4 Explain what happens in filtration within the nephron.
5 When a person has their urine tested, substances that are tested for include sugar and protein, which should not be present in the urine. How might a positive result in either of these factors have occurred in a urine sample?

HOT Challenge

6 Antidiuretic hormone (ADH) is the hormone produced in the hypothalamus that controls mammalian excretion of water through the kidneys. The process is called osmoregulation. What does osmoregulation mean in terms of a mammalian excretory system?

BRANCHING OUT

Weighing up the evidence for a weight loss supplement

Many health companies are now using social media to advertise their products. They use marketing strategies to make you want their product. One product advertised frequently on social media is a weight loss supplement called *Garcinia cambogia*. It is named after the fruit from which the active ingredient is extracted (Figure 3.26) and is a chemical called hydroxycitric acid (HCA). But how do we know if this product works and if it is safe? These questions should be investigated before using health supplements.

Shutterstock.com/siripaibo

Figure 3.26 ***Garcinia cambogia*, the plant that is supposed to help us lose weight**

Advertisements tell us it is safe

According to advertisements, this health supplement is safe to use. However, the advertisements do not include valid and reliable evidence, so a consumer cannot easily check this claim. The advertiser tells us the product is 100% natural plant extract to support the claim that the product is safe. This is not a good argument for safety. Plants produce their own defensive chemicals as natural pesticides. Many of the chemicals we extract from plants, including caffeine, are actually used by plants to kill or deter predators. Natural does not always correlate with safe.

Most advertisements advise that you consult with a doctor prior to using *Garcinia cambogia*. It can have adverse effects when taken with other medications and is not recommended for people with diabetes or if you are pregnant. One advertisement mentions that people who have exceeded the recommended dose have experienced side effects including nausea, diarrhoea, digestive tract discomfort and headaches.

Therapeutic Goods Australia (TGA) is the regulatory body that oversees which products can be sold legally as drugs in Australia. It has determined that *Garcinia cambogia* is safe and of appropriate quality to be used as an ingredient in lower-risk medicines. TGA warns consumers to always check that a supplement and the company making it are listed on their website. TGA only lists products that contain approved low-risk ingredients. They also check to make sure the product is manufactured safely. However, the products themselves are not tested for their safety. Also, TGA does not test supplements to see if they work. They only do this for medical drugs. It is up to the consumer to look for evidence that the health supplement works.

Advertisements tell us it works

Companies selling *Garcinia cambogia*-derived HCA as a weight loss supplement claim that it works in two ways: by reducing production of fat cells, and by suppressing the appetite. Advertisements may tell us that 'studies show' or 'it is known' to suppress fat synthesis without providing any evidence. Some companies provide links to studies (Han et al., 2016) where HCA was found to block the action of an enzyme called citrate lyase in chickens. This enzyme is involved in fat synthesis and blocking its action inhibits the production of fat. The chickens treated with HCA lost weight. Other referenced studies, such as that by Lopez et al. (2014), report that HCA raises levels of serotonin. This chemical acts on nerve pathways to enhance the mood and suppress emotional eating. However, what works in chickens does not always work in humans.

Critically assessing the science to determine if this product works

Advertisements about *Garcinia cambogia* tell us it works and is safe. However, advertisements are not always scientifically accurate. They often fail to provide all information and this distorts the science. Many fail to provide evidence, so consumers can't assess whether the claims are accurate.

Consider a trial conducted on 135 obese human subjects (Heymsfield et al., 1998). In this trial, half the subjects were given *Garcinia cambogia* and the other half a placebo, which is an alternative substitute given to some participants that contains no active ingredients. This was a blind study. The participants did not know if they were taking the supplement or the placebo. All participants were on low-kilojoule diets and took mild exercise. Overall, the placebo group and the *Garcinia cambogia* group contained subjects that were fairly well matched for age and gender. The results are shown in Figure 3.27.

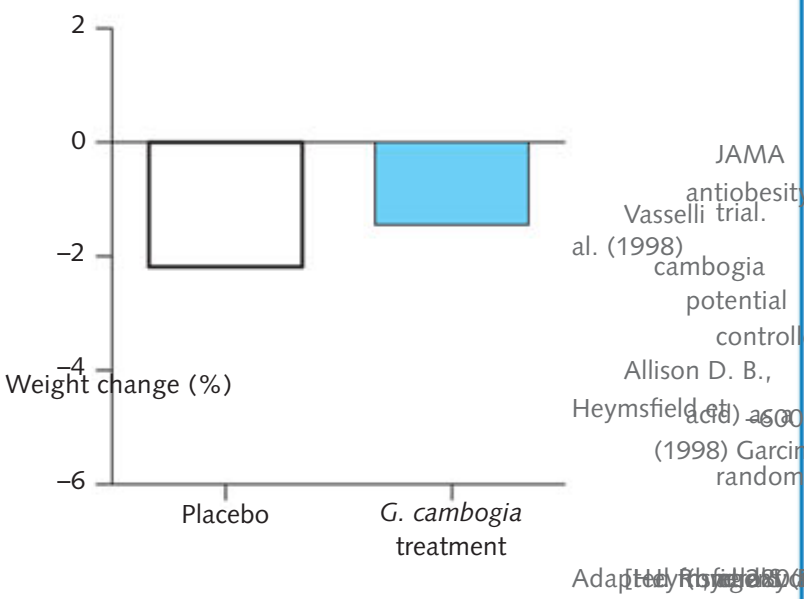


Figure 3.27 **Weight change after 12 weeks of G. *cambogia* or placebo treatment. Results shown are means for 69 individuals in the placebo group and 66 individuals in the treatment group.**

Questions

1 What devices do advertisers use to sell their products? Critically analyse each of these devices.

Examine the results provided in Figure 3.27 and answer the following questions.

2 Summarise the change in weights over the 12-week study period in the two groups.

3 Is there a clear difference between the means of the two groups?

4 What questions do you have about the design of this study that may have influenced its results?

5 Do these results support the use of *Garcinia cambogia* as a weight loss supplement? Have the advertisements been giving their consumers the full story?

References

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Online Key Concepts
Chapter 3 summary of key concepts

3 Summary of key concepts

3.1 Vascular plants

KEY CONCEPTS

p. 93

- In plants there are two systems: the shoot system and the root system.
- Vascular tissue is involved in the transport of substances in plants. Vascular tissue is made up of xylem and phloem.
- Xylem is a water-conducting tissue composed of tracheids and vessels.
- Root hairs increase the surface area for water absorption.
- Water and dissolved ions enter the root from the soil by the process of osmosis for water molecules, and diffusion and active transport for dissolved ions.
- Root pressure contributes to push the water upwards in the xylem after it enters the root cells by osmosis.
- The combined forces of adhesion and cohesion ensure movement of continuous columns of water upwards through the xylem tissue in the stem of a plant.
- Water evaporates from moist leaf cell walls and water vapour diffuses out via open stomata in transpiration.
- Movement through xylem is due to root pressure and mostly transpirational pull, and is always upwards.
- Water vapour diffusion out through the open stomata increases on a hot, dry or windy day.
- Phloem consists of living cells: the sieve tube cells and the companion cells.
- Phloem transports organic substances, the modified products of photosynthesis, sucrose together with amino acids, and some mineral nutrients.
- Movement in the phloem is called translocation and is both up and down the plant.

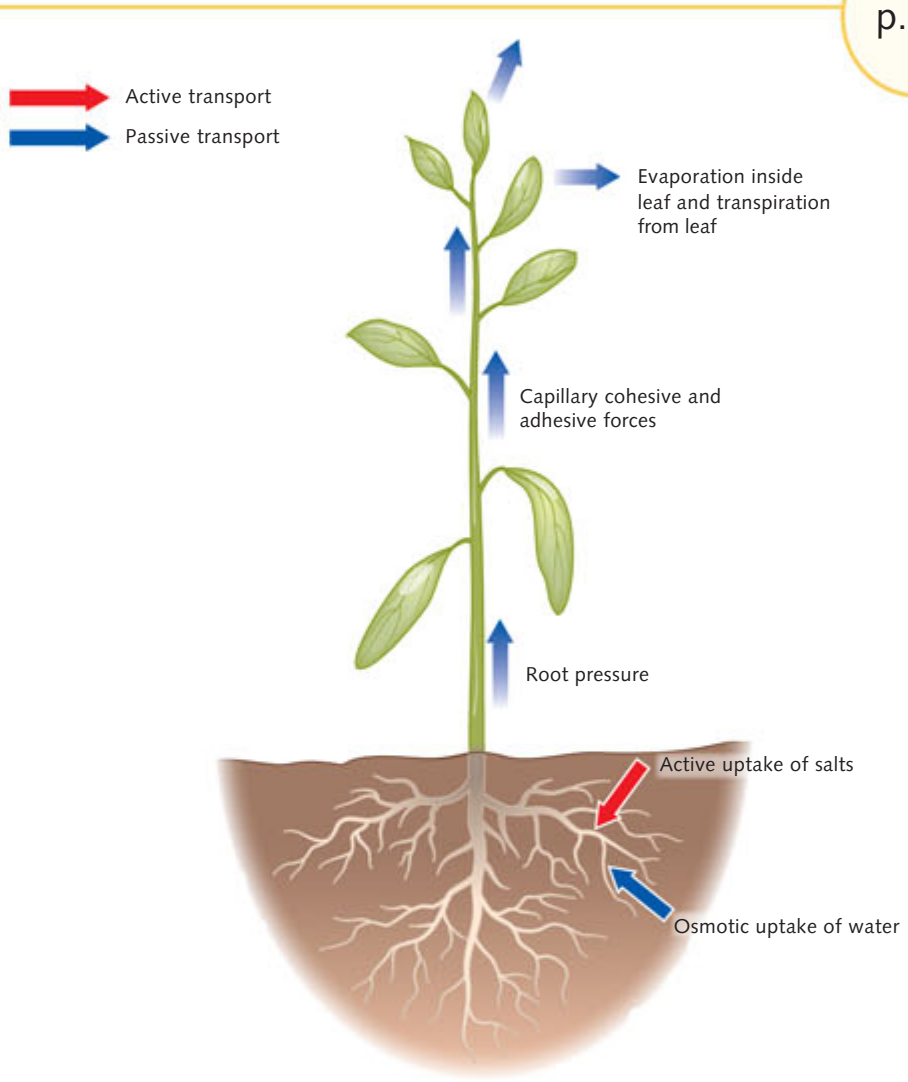


Figure 3.7 Diagram showing all forces involved in transpirational pull.

3.2 Mammalian systems: digestive system

KEY CONCEPTS

p. 100

- Digestion is the process that breaks down large complex foods into simple molecules for absorption.
- Mechanical digestion breaks down larger pieces of food into smaller pieces, thereby increasing the surface area of food particles on which digestive enzymes may act.
- In chemical digestion, digestive enzymes break apart large molecules, ensuring they are of a molecular form and small size that can be absorbed into the blood and lymph and then by cells in the body. The stomach provides the acid environment some of these enzymes need to act.
- Chemical digestion of starch starts in the mouth; chemical digestion of protein starts in the stomach; chemical digestion of fat starts in the duodenum of the small intestine.
- The pancreas secretes all three classes of digestive enzymes: amylases, proteases and lipases.
- Bile from the liver assists in the mechanical digestion of fat.
- The products of digestion are absorbed from the external environment of the digestive tract into the internal environment of the blood and lymph in the small intestine.
- Villi and microvilli increase the surface area of the lining of the long small intestine, facilitating efficient absorption.
- In the large intestine, water and some salts are absorbed back into the body.
- Undigested food material is compacted for egestion through the anus.

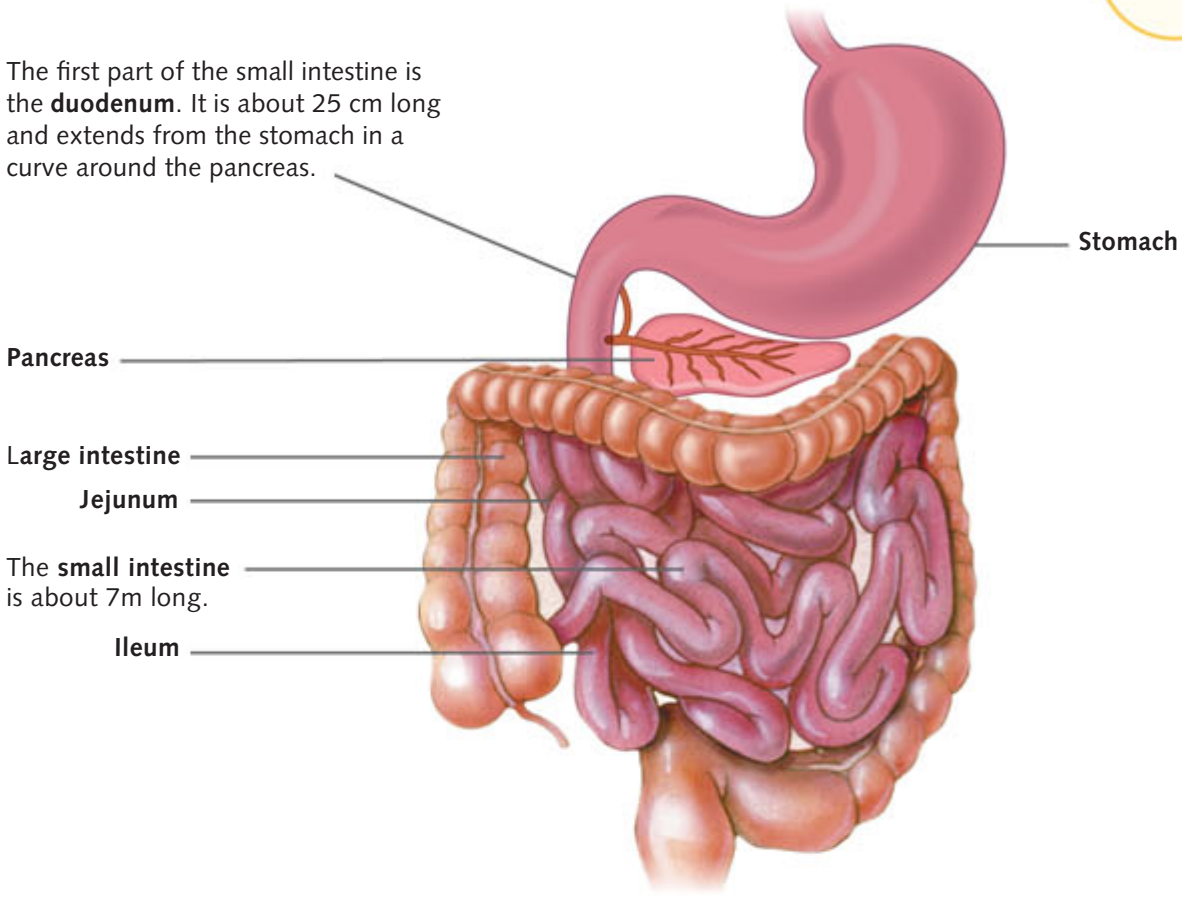


Figure 3.15 The location of the small and large intestines

3.3 Mammalian systems: endocrine system

KEY CONCEPTS

p. 110

- Hormones are important signalling molecules that are produced in one part of the body, travel in the bloodstream, and elicit a response in another part of the body.
- Hormones are produced and secreted directly into the blood from ductless endocrine glands.
- The endocrine system is made up of the endocrine glands, including the thyroid, pituitary and adrenal glands, and the ovaries and testes.
- Thyroxine is a hormone produced by the endocrine gland called the thyroid gland. It controls cell basal metabolic rate and is important in growth.
- The pituitary gland is called the 'master gland' of the body because it releases hormones that control other endocrine glands in the body.

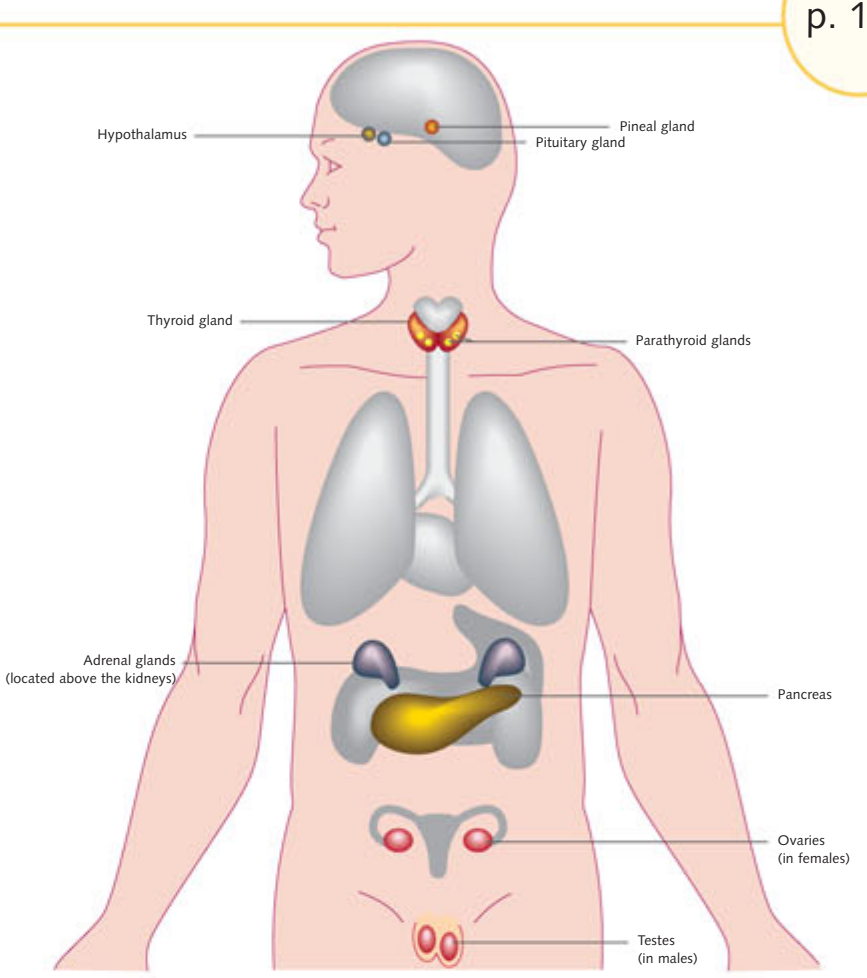


Figure 3.20 Location of the main endocrine organs in the human body

3.4 Mammalian systems: excretory system

KEY CONCEPTS

p. 113

- The excretory system removes cell metabolic wastes from the internal environment. The kidneys are the excretory organs that remove cell metabolic wastes from the internal environment. The kidneys also remove excess fluid and so play an important role in regulation of the body's fluid concentrations.
- Kidneys have many nephrons that collect and concentrate the filtrate that is forced out of the capillaries of the glomerulus.
- The start of a nephron is cup-shaped (Bowman's capsule). It continues as three tubular regions (proximal tubule, loop of Henle, and distal tubule) that then empty into a collecting duct.
- Urine forms in the nephron by filtration, reabsorption and secretion.
- The skin produces and removes nitrogenous wastes and mineral salts via sweating.

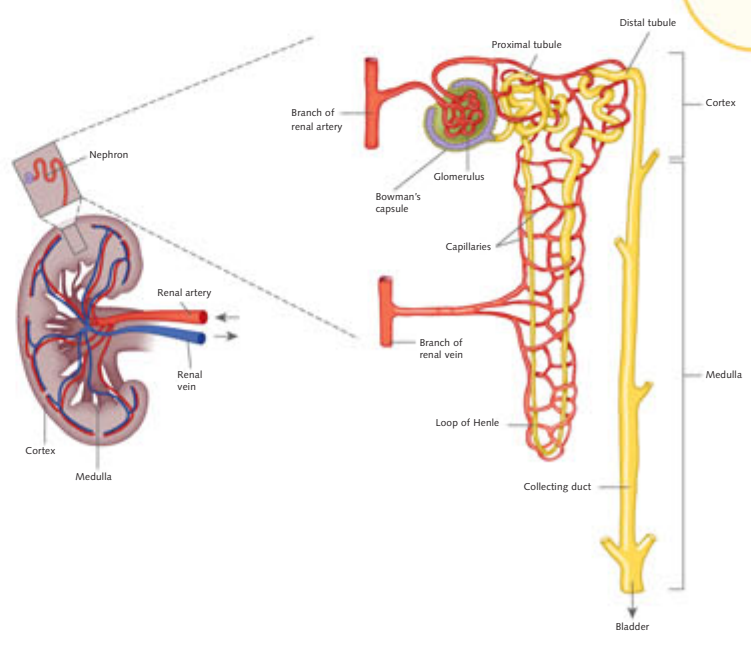


Figure 3.23 Structure of the kidney and a functional unit, the nephron

3.5.1
KEY TERMS
Page 80

3 Chapter glossary

absorption the movement of small, simple, soluble digested food molecules from the digestive tract into surrounding blood and lymph vessels

adhesion attraction between water molecules and the walls of xylem vessels that creates an upwards pull for water in the xylem

ammonia a nitrogenous-based waste produced during protein metabolism in cells

amylase a group of carbohydrate-digesting enzymes present in saliva and pancreatic juice

anus the end point of the gastrointestinal tract and a passage for faeces to be egested or eliminated out of the body

basal metabolic rate the rate at which the body uses energy to maintain vital functions while at rest

bile a substance produced by the liver and transported into the duodenum. It is not an enzyme; it is instead involved in mechanical digestion of fats due to its detergent-like action

Bowman's capsule the structure in which the glomerulus is found, where filtration occurs at the beginning of the nephron

chemical digestion a process in which large, complex molecules are broken down into small, soluble molecules by enzyme action

chyme 'soupy' contents of the stomach consisting of partially digested food

cohesion the strong forces that exist between water molecules and aid water movement upwards in the xylem

colon the first section of the large intestine, where water, minerals and vitamins are absorbed into the blood

cuticle the waterproof wax layer that covers the leaves of plants

deamination a process that separates the nitrogen-containing amine group from the rest of the amino acid

digestion the breakdown of large pieces of food to smaller pieces (mechanical digestion) and the breakdown of large complex molecules into simple soluble molecules (chemical digestion) for absorption

digestive system the place where digestion takes place; also known as the gastrointestinal tract or gut

distal tubule the portion of the nephron between the loop of Henle and the collecting duct

ductless gland a gland that has no duct or tube for exit of hormones, so the hormone is secreted directly into the bloodstream

egestion the removal of faeces from the digestive system through the anus; also called elimination or defecation

endocrine gland a ductless gland that produces hormone(s) and releases it directly into the blood

endocrine system the collection of ductless glands that produce hormones and secrete them directly into the bloodstream

epidermis the surface layer of cells in plants and animal cells, generally responsible for separating and protecting the organism from its external environment

excretion removal of metabolic wastes from the internal environment of the body

exocrine gland a ducted gland that secretes substances through a tube onto an epithelial surface; for example, sweat glands, salivary glands

external environment the environment surrounding an organism and inside the digestive, respiratory and excretory systems

faeces the waste material eliminated from the body through the anus

filtrate the fluid that passes from the glomerulus through the wall of the Bowman's capsule into the tubule in a nephron

gall bladder the organ that stores bile

gastric juice liquid containing substances produced due to the presence of food in the stomach; contains mucus, water, hydrochloric acid and protease enzymes such as pepsin

gastrointestinal tract *see* digestive system

glomerulus a network of capillaries located in the Bowman's capsule and site of filtration of the blood in the nephron

heterotroph an organism that cannot make its own complex organic food molecules and so must take in food from other organisms

hormone an organic compound produced in one part of the body, which is transported in the bloodstream to another part of the body, where it produces a response

ingestion the taking in of complex organic compounds

internal environment all the fluids that surround and bathe the cells, including extracellular (tissue) fluid, blood and lymph

kidney an organ that removes cell metabolic wastes and helps to control the body's fluid balance

lacteal a blunt-ended lymph capillary that absorbs fatty acids and glycerol in a villus of the small intestine

large intestine the final length of the gut; consists of the colon and the rectum. It functions to absorb water and some salts back into the blood and to compact undigested food material to form the faeces, which are temporarily stored

lignin a complex polymer substance found in xylem cell walls where it provides strength and structure to the cell wall and the plant

loop of Henle the portion of a nephron that connects the proximal convoluted tubule to the distal convoluted tubule and where much reabsorption occurs

lymph a colourless fluid that circulates through the lymphatic vessels and delivers excess tissue fluid back into the blood; it transports fatty acids and glycerol from the villi where they are absorbed

lymphatic system a drainage system in the body that assists in the maintenance of a balanced fluid level

mechanical digestion the process of breaking large pieces of food down into smaller pieces of food

microvilli tiny projections on the surface of villi that increase the surface area of the gut for absorption

nephron one of the millions of small units of each human kidney where filtration and reabsorption occur

oesophagus the muscular tube that transports food from the mouth to the stomach

organ a structure made up of different types of tissues working together

pancreatic juice the secretion from the pancreas into the duodenum that contains amylase, lipase, protease and bicarbonate

parenchyma large, thin-walled cells that make up the cortex of a plant

peristalsis waves of muscular contractions that push food down the oesophagus and through the length of the gut to the anus

pH a scale from 0 to 14 used to measure acidity and alkalinity of solutions where 7 is neutral

phloem vascular tissue in plants composed of living cells that is responsible for the transport of sugars and other plant substances in all directions around the plant

polypeptide a chain of many amino acids linked together forming a protein or part of a protein

protease a protein-digesting enzyme

proximal tubule the section of the tubule in the nephron that leads from the Bowman's capsule to the loop of Henle and where much reabsorption occurs

pyloric sphincter the small muscular ring at the lower end of the stomach that controls the amount of food that can leave the stomach and enter the small intestine

rectum the final section of the large intestine, where faeces are stored prior to egestion

renal artery the blood vessel that brings blood from the heart to the kidney

renal pelvis the section of the kidney where urine is collected and directed to the ureter

root hair cells a root cell with an elongated tubular extension to increase water and mineral ion absorption

root pressure the force that contributes a small amount of force to push water up the stem from the roots

small intestine the longest part of the gastrointestinal tract, where digestion is completed and most absorption of digested food occurs

sphincter a circular muscle that when constricted closes a natural body passage and relaxes as required to allow the flow of substances through the passage

stomata (singular: stoma) the holes or openings in leaves and some stems that open and close to control the movement of gases into and out of the plant and control water loss

system a number of organs that work together to perform a function

terrestrial land dwelling

thyroxine a hormone produced in specialised secretory cells in the thyroid gland that is responsible for controlling the basal metabolic rate of cells and is particularly important in growth

tissue a group of specialised cells working together to perform a specific function

tracheid an elongated dead cell in the xylem of plants that is involved in water and mineral salt transport

translocation movement in the phloem that transports sucrose, along with some amino acids and some mineral salts, from a site of synthesis to a site of use or storage

transpiration the loss of water from plants through evaporation from the moist inside cells of a leaf and diffusion of water vapour out of open stomata

transpiration stream the continuous columns of water in the xylem that run the length of the plant, from roots to leaves

transpirational pull the force arising from the evaporation of water from leaves that is transmitted down the xylem

urea the compound into which most nitrogenous wastes (produced from the oxidation of amino acids) are converted; it is excreted in water as urine

vascular bundle a combined group of xylem and phloem tissues in plants

vascular plant a plant containing vascular tissue: phloem and xylem

vascular tissue (in plants) the plant tissue for the transport of water, nutrients, sugars and other substances in the xylem and phloem

villi the finger-like projections on the internal surface of the small intestine that greatly increase the surface area available for absorption of digested food

xylem one of the vascular tissues in plants, mainly composed of dead cells, responsible for transport of water and dissolved mineral ions from the roots to the leaves

xylem vessel element a type of cell comprising xylem tissue of vascular plants that are dead lignified cells that join end-to-end to form tubes for transport of water

WB
3.5.2
PRACTICE TEST
QUESTIONS
Page 83

3 Chapter review

Remembering

1 What is the purpose of digestion in humans?
2 Name the two types of vascular tissues in plants.
3 Name the structures in which xylem and phloem are located in most plants.
4 Compare phloem and xylem.
5 List the organs that make up the following body systems.
   a Digestive system
   b Excretory system
   c Endocrine system

Understanding

6 Name the body systems that ensure all body cells receive or achieve the following.
   a Glucose
   b Amino acids
   c Lipids
   d Removal of waste products from the blood
7 The gut is a term commonly used to describe the gastrointestinal tract. Prepare a table that lists all the sections of the gut and describes what occurs in each section.
8 Define the following terms and describe their role in the human kidney.
   a Nephron
   b Loop of Henle
   c Collecting duct
9 What, in order, are the three main steps of urine formation?

Applying

10 The sun provides the energy to transport water from the roots to the crown of a tall tree. What other factors are involved and how do those factors enable the water column to reach the leaves?
11 You have eaten a meal of fish. Fish contains a lot of protein. Outline how the structure and function of your digestive system will assist the digestion of the fish protein to make delivery of amino acids to your body cells possible.

Analysing

12 When transplanting plants, it is important to take some of the natural soil still clinging to the roots with them. Suggest reasons for this by using information learnt about root hairs.
13 Explain how the uptake of mineral ions differs from the uptake of water from the soil.
14 Is the material egested from the digestive system moving out of the internal or external environment? Give reasons for your answer.
15 The kidney uses more energy proportionally than the heart. With your understanding of diffusion and active transport, explain how filtration and absorption in the kidney nephron might account for this observation.

16 Explain how the kidneys assist in maintaining water balance in the blood.

17 Animals that live in hot, dry environments have nephrons that have a long loop of Henle. Explain how this is an adaptation to their environment.

18 Hormones can be steroid based or protein based. How might their molecular make-up affect how they are transported in the body and to the cells?

19 The effect of hormones on their target site is said to be long lasting. What does this mean?

Evaluating

20 One major function of the large intestine is to absorb water. If you are suffering from diarrhoea you might absorb 10 mL of water over 4 hours. If you are suffering from constipation you might absorb 100 mL over 4 hours. Predict the amount of water you would absorb if you were not suffering from either condition.

21 Table 3.6 lists results on three patients recorded in a hospital pathology unit.

Table 3.6

Name	Urine volume (mL)	Fasting plasma glucose (mM)	Urine glucose (mM)	Urine potassium (mEq L^{-1})
Casey	125	8.2	4.3	35
Juan	132	5.0	0	75
Travis	132	4.9	0	110

Normal urine volume: 100–150 mL

Normal plasma glucose: 3.5–6.0 mM

Normal urine potassium: 25–125 mEq L^{-1}

a Which patient has an abnormal urine sample?

b Which factors are abnormal?

c It was decided to treat one of the patients with insulin injections. Insulin acts to remove excess glucose from the blood. Which organ in the body was possibly not functioning properly?

d One of these patients could be treated with doses of antidiuretic hormone, which prevents the reuptake of water. Which patient?

22 Explain why the rate of transpiration decreases if a plant is enclosed in a plastic bag.

23 What are the main steps of absorption in the ileum?

24 Figure 3.28 demonstrates water loss in a plant undergoing three different treatments. In terms of transpiration rate, answer the following.

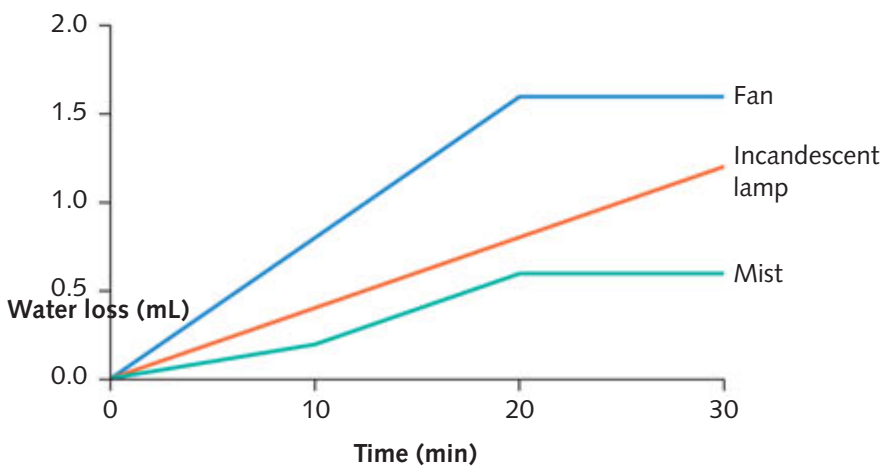


Figure 3.28 Transpiration rate in a green plant receiving three different treatments

a Which treatment produces the highest transpiration rate in the plant?
b Suggest why the fan and mist treatments have similar curves but the magnitude is so different.
c Explain what effect the incandescent lamp is having on the plant.

25 Horses, cats and humans are all mammals. Their body tissues are remarkably similar in make-up, yet their food sources are very different. Horses are herbivores, cats are carnivores and humans are omnivores. Explain how it is that their body tissues are so similar although their food is so different.

Creating

26 On a page of A4 paper, draw each of the organs of the digestive system in random places, using correct proportional sizes. Inside each write what its pH is, what foods are digested by what enzymes, or their function in the system. Include accessory organs in a different colour and write in their contribution to the process of digestion. Then cut out your drawings and paste them in their correct relative positions on a second sheet of paper.

4 Regulation of systems

By the end of this chapter you will have covered the following material.

Key knowledge

Regulation of systems

- » regulation of water balance in vascular plants pp. 135–137
- » regulation of body temperature, blood glucose and water balance in animals by homeostatic mechanisms, including stimulus-response models, feedback loops and associated organ structures pp. 137–155; 159–162
- » malfunctions in homeostatic mechanisms: type 1 diabetes, hypoglycaemia, hyperthyroidism. pp. 155–158, 163–165

Key science skills

Develop aims and questions, formulate hypotheses and make predictions

- » formulate hypotheses to focus investigation pp. 148–149
- » predict possible outcomes pp. 148–149

Plan and conduct investigations

- » design and conduct investigations; select and use methods appropriate to the investigation, including consideration of sampling technique and size, equipment and procedures, taking into account potential sources of error and uncertainty; determine the type and amount of qualitative and/or quantitative data to be generated or collated pp. 148–149, 153–154
- » work independently and collaboratively as appropriate and within identified research constraints, adapting or extending processes as required and recording such modifications pp. 148–149, 153–154

Comply with safety and ethical guidelines

- » demonstrate safe laboratory practices when planning and conducting investigations by using risk assessments that are informed by safety data sheets (SDS), and accounting for risks pp. 148–149, 153–154
- » apply relevant occupational health and safety guidelines while undertaking practical investigations pp. 144–145, 149–150
- » demonstrate ethical conduct when undertaking and reporting investigations pp. 148–149, 153–154

Generate, collate and record data

- » systematically generate and record primary data, and collate secondary data, appropriate to the investigation, including use of databases and reputable online data sources pp. 153–154
- » record and summarise both qualitative and quantitative data, including use of a logbook as an authentication of generated or collated data pp. 148–149, 153–154
- » organise and present data in useful and meaningful ways, including schematic diagrams, flow charts, tables, bar charts and line graphs pp. 153–154
- » plot graphs involving two variables that show linear and non-linear relationships pp. 153–154

Analyse and evaluate data and investigation methods

» process quantitative data using appropriate mathematical relationships and units, including calculations of ratios, percentages, percentage change and mean pp. 148–149

» identify outliers, and contradictory or provisional data pp. 148–149, 153–154

» repeat experiments to ensure findings are robust pp. 148–149

» evaluate investigation methods and possible sources of personal errors/mistakes or bias, and suggest improvements to increase accuracy and precision, and to reduce the likelihood of errors pp. 148–149

Construct evidence-based arguments and draw conclusions

» use reasoning to construct scientific arguments, and to draw and justify conclusions consistent with the evidence and relevant to the question under investigation pp. 153–154

Analyse, evaluate and communicate scientific ideas

» use appropriate biological terminology, representations and conventions, including standard abbreviations, graphing conventions and units of measurement pp. 153–154

» discuss relevant biological information, ideas, concepts, theories and models and the connections between them pp. 148–149, 153–154

To access resources below, visit www.nelsonnet.com.au

Online Chapter Map:
- Chapter 4 map (p. 132)

Online Key Terms:
- Chapter 4 flashcards (p. 134)

Weblinks:
- Factors affecting transpiration (p. 135)
- Homeostatic loops (p. 146)

Online Worksheets:
- Factors affecting transpiration (p. 135)
- Homeostatic loops (p. 146)

Video:
- Osmoregulation (p. 160)

Online Key Concepts:
- Chapter 4 summary of key concepts (p. 168)

Online Chapter Map
Chapter 4 map

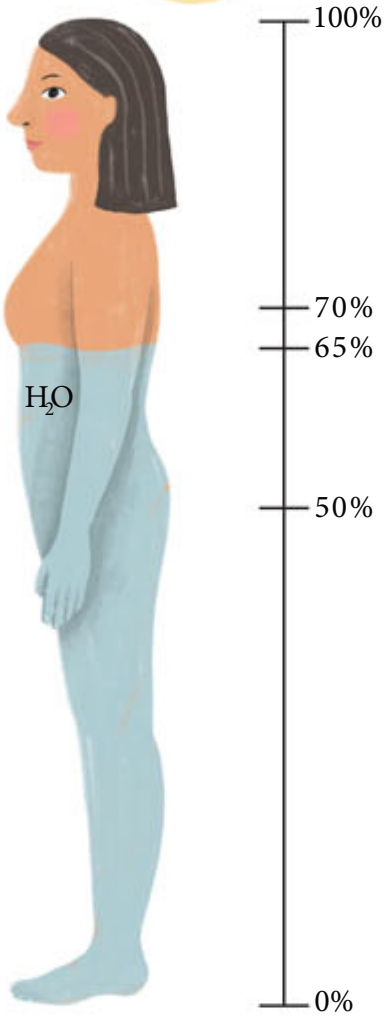
4 Regulation of systems

A car cannot run efficiently if its fuel lines are not clean and if the wheels are not aligned properly. It is the same with your body. The interlinked systems of complex multicellular organisms need to be functioning efficiently and be well coordinated if the organism is to thrive at maximum efficiency.

p. 155

4.4 Regulation of blood glucose levels

Glucose is needed for cellular respiration. The hormones insulin and glucagon work together to adjust the level of glucose in the blood by a process called negative feedback. If this fails, a person may have type 1 diabetes.



p. 159

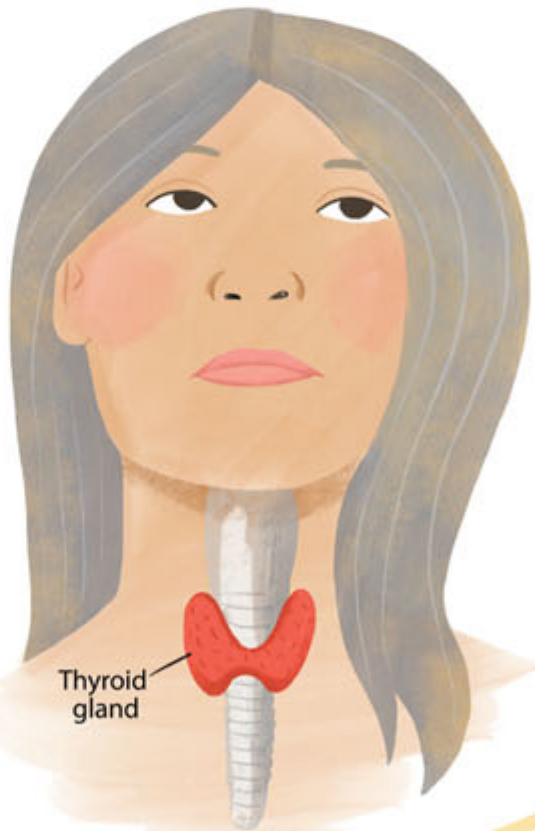
4.5 Water balance regulation

Our body is about 65% water. We continually take in water in food and by drinking; we lose water through our kidneys, lungs and skin. Kidneys control the amount of water in the blood.

p. 163

4.6 Regulation and control of basal metabolic rate and growth by thyroid hormones

The hormone thyroxine affects physiological processes like the rate of cell metabolism. The amount of thyroxine in your blood is tightly regulated by your brain and the pituitary and thyroid glands.



Vigilant regulation of our body systems is necessary to achieve a balance that can exist within a range of environments. This is the role of our brain and homeostatic mechanisms.

Online Key Terms
Chapter 4 flashcards

Know your key terms

antidiuretic hormone (ADH)
arrector pili muscle
brown fat
conduction
convection
effector
endothermic
evaporation
exteroceptor
feedback mechanism
glucagon
glycogen
heat balance
homeostasis
hyperglycaemia
hyperthermia
hyperthyroidism
hypoglycaemia
hypothalamus
hypothermia
hypothyroidism
insulin
interoceptor
interstitial fluid
negative feedback
optimum range
osmoreceptor
osmoregulation
physiological stress
radiation
response
set point
stimulus
stimulus–response model
thermoregulation
thyroid-stimulating hormone (TSH)
thyrotrophin-releasing hormone (TRH)
thyroxine
tolerance range
vasoconstriction
vasodilation
vasopressin
water potential

Remember

This chapter will build on the following concepts that you will have already met. Take the time to refresh these concepts before you start this chapter.

WB
REMEMBER
PAGE 86

1 Plants move water from their roots to their leaves through xylem vessels.
2 The endocrine system produces hormones that move from ductless endocrine glands into the blood where they move around the body and target specific tissues and organs.
3 The excretory system involves removing cellular metabolic wastes and excess water from the blood by the kidneys.

Water makes up approximately 90–95% of the living tissue of plants. Plants cannot move around to find water and they are often in situations where they are continually losing water. So that their cells can function efficiently, they have features that help them to obtain water, retain adequate water and reduce water loss if necessary. In environmental conditions of water shortage, plants maximise water uptake and conservation and minimise water loss to maintain water balance in their tissues.

Similarly, animals need to be able to detect changes in their environmental conditions and respond to them appropriately to ensure that their cells are kept within certain limits of temperature and water concentration. Anything beyond these limits could compromise the efficiency of cell function and therefore the function of the organism as a whole.

Timoteo Images/E Getty

Figure 4.1 Plants and animals need to balance their water intake to ensure that their cells function efficiently.

4.1 Regulation of water balance in vascular plants

Water balance in vascular plants involves the uptake of water by the root system and loss of water by the leaves of the shoot system. Plants generally have an extensive root system that enables them to absorb water. Numerous root hairs at the end of each root provide a large surface area for water to pass into the root cells by osmosis. Some plants can gain access to an even greater amount of water and dissolved mineral ions as they have a mass of fungal filaments around their roots. The fungal filaments extend further into the soil to absorb more water for the plant's use. Most of the water absorbed through the roots by plants is lost from the surfaces of the plant. A small amount is lost from the surface of the stem and shoots by evaporation. Most is lost from the leaf surface through the open pores in the leaves called stomata. In many plants, all or most of the stomata are located on the undersurface of the leaves. The loss of water that evaporated from the moist cells inside the leaf and passed out of the open stomata by diffusion is a process called transpiration. Movement of water upwards from the roots to the leaves is called the transpiration stream. The rate of transpiration is affected by factors such as temperature, humidity and movement of air around the plant.

When a plant loses more water through transpiration than it takes up through its roots, it wilts and is said to suffer from water stress. If there is a high loss of water from the leaves due to hot, dry or windy conditions, the tension of the water columns in the xylem will increase, resulting in an increase in the **water potential** gradient from the soil (high water potential because higher water concentration) to the xylem (lower water potential because lower water concentration). This will result in the roots absorbing more water by osmosis from the soil. If the soil is dry, the flow of the water into the roots will slow down and so stomata in the leaves will close, thereby keeping water loss to a minimum.

CONNECT

Refer to Chapter 3 for a discussion on the intake and loss of water in plants.

WB 4.1.1 WATER BALANCE IN VASCULAR PLANTS PAGE 86

Weblink
Factors affecting transpiration

Online Worksheet
Factors affecting transpiration

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Figure 4.2 Photos showing **a** when plentiful water is available to a sunflower through to **b** when not enough water is available and the plant is wilting, then **c** the plant is dead

The opening and closing of the stomata are controlled by the swelling and shrinking of the two guard cells surrounding the stomatal pore. This is caused by a variety of factors, including ion exchange. The stomata close due to the shrinking of the guard cells when ions move out of the guard cells, followed by water due to osmosis. The guard cells become flaccid so that, due to their kidney-bean shape and thicker inner walls, their loss of turgidity closes the space between them. This response is relatively rapid and regulated by a complex of signalling molecules, one of the most important ones being a plant hormone called abscisic acid (ABA). Once the stomata are closed, water loss is reduced to a minimum.

WB
4.1.2 STOMATAL CONTROL AND WATER BALANCE PAGE 90

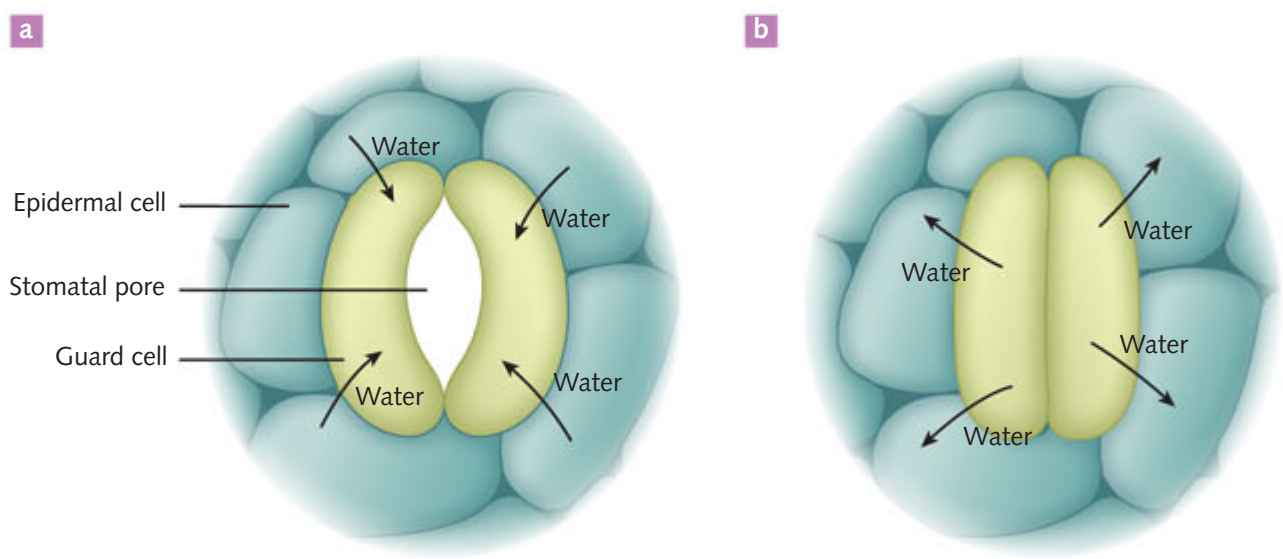


Figure 4.3 Guard cells control the opening and closing of the stomata, in turn controlling water loss from a plant. **a** Open stoma with turgid guard cells **b** Closed stoma with flaccid guard cells

KEY CONCEPTS

- Water balance in vascular plants involves water uptake through the root system and water loss through the stems and, mainly, the leaves of the shoot system.
- For their cells to function efficiently, vascular plants have features that help them to obtain water, retain adequate water, and reduce water loss if necessary.
- If a plant loses more water through transpiration than it takes up through its roots, it wilts and is said to suffer from water stress.
- Movement of water by osmosis into and out of the guard cells, controls the opening and closing of the stomata.

Concept questions 4.1

1 **a** Why is water balance essential in a vascular plant?
b How is it maintained?

2 **a** What happens to a plant if more water is lost than is taken up?
b What is this called?

3 The turdigity and flaccidity of guard cells aids in the water balance of a vascular plant. Explain how these two states ensure water balance.

4 List, in order, the steps a water molecule might go through from being in the soil solution around the roots to transpiration from a leaf stoma. (Assume the molecule was not used as an input for a biochemical process in the plant.)

5 Water stress may not result in the death of a plant. Write down at least three activities that a plant might undertake to avoid water stress.

HOT Challenge

6 In common with all living things, plants have a set of factors that contribute to their health. These factors need to be within specific ranges or the plant will not survive. Some vascular plants are described as salt tolerant while others are known to not be salt tolerant. Many environments in Australia are deemed to be saline ('salty'). Consider a vascular plant that is not salt tolerant and is planted in a garden bed near the sea.
a What type of soil solution would you expect to be present?
b Would you expect water to move from the root cells into the soil or from the soil into the root cells?
c In this case, in which direction would the water in the root hair cells be moving?
d Comment on what events you would expect to be occurring inside the root hair cells as the plant starts to die.

4.2 Human survival in a range of environments

In 1988 Mark Dorrity went on an 8 km run in extreme heat in New South Wales. During the run, his body overheated to 42.8°C and he didn't drink water to stay hydrated. As a result, his body could not regulate its temperature and water balance. Mark's muscles generated more heat than could be lost from his body and he suffered a rare condition known as rhabdomyolysis. His thigh muscles liquefied and released toxic proteins into his blood, causing kidney failure. Dehydration resulted in thickening of his blood to a point where it could not flow freely in some parts of his body. Every organ in his body was affected; he became delirious, brain damage occurred, his lungs barely functioned and his heart stopped at least once. Within an hour, he collapsed into a coma that lasted 3 months, during which time he was on kidney dialysis and had one leg amputated due to gangrene.

Under normal conditions Mark's body systems would have worked together to enable him to function efficiently. In the extreme environmental conditions, his body's ability to maintain heat balance became impaired. His judgement and behaviour overrode the warning signs and his coordinating systems were unable to regulate his physiological responses to heat.

Fortunately, few people engage in this kind of activity in such extreme conditions. The human body has mechanisms to keep the internal environment relatively stable despite changes in the external environment. This allows the body cells to function efficiently for survival in changing conditions.

This section explores the regulatory mechanisms in humans that enhance human survival and enable them to exist in a wide range of environments. Regulation of body temperature, blood glucose concentration and water balance will be discussed in terms of the organ systems and mechanisms involved. Diseases will be considered that may result if malfunction of these regulatory mechanisms occurs.

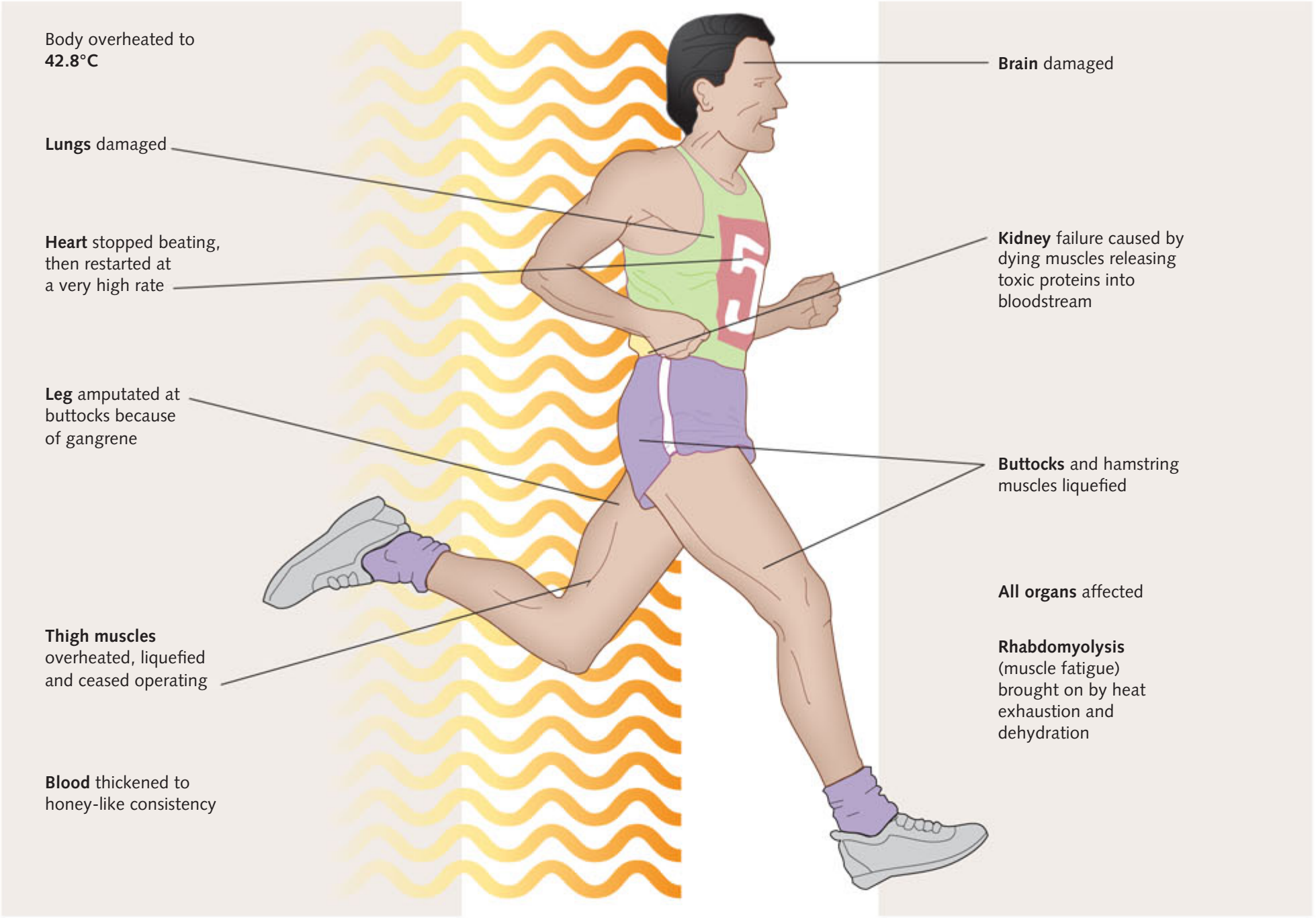


Figure 4.4 A near fatal mistake led to malfunctioning of the body systems involved in regulation of body temperature and water balance

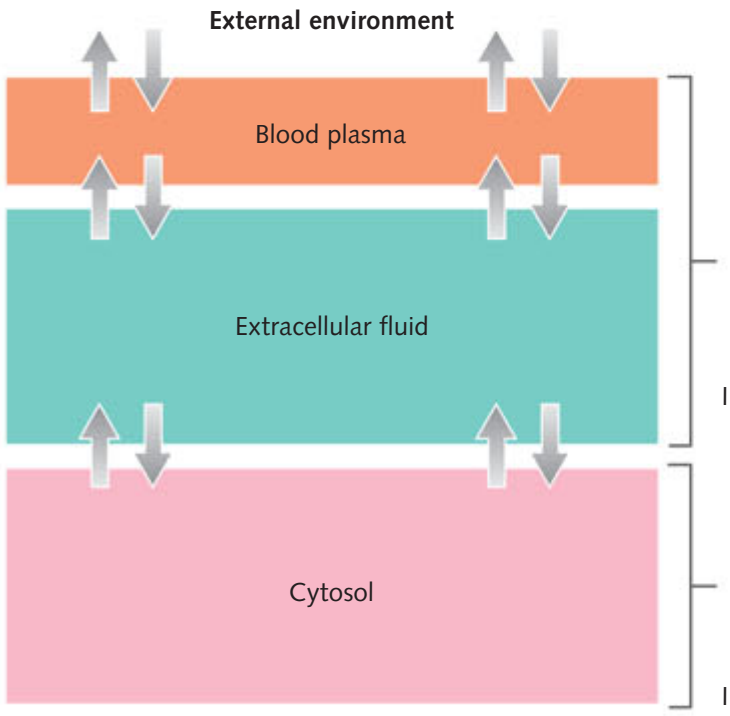


Figure 4.5 By constant movement of substances across membranes, organisms regulate their internal conditions despite changes to the internal and external environmental conditions.

There are few, if any, places on Earth where environmental conditions are stable throughout the year, or from one year to the next, or even from one hour to the next in one day. Humans must have appropriate structural, physiological and behavioural adaptations that enable them to successfully survive in these changing environments. They also need regulatory mechanisms to coordinate all their body systems for maximum efficiency in functioning, growth and survival.

Internal and external environment of the human body

In everyday language, 'environment' tends to mean the physical space or surroundings in which an organism lives. For humans, this is principally the air that surrounds them in their terrestrial environment. This is called the external environment. However, there are other areas in the body included in the external environment: the inside of the respiratory system, including the air in the alveoli and bronchiole tubes; the inside of the digestive system from the mouth to the anus; and the inside of the tubules in the excretory system, including the inside of the bladder and urethral duct to the outside.

Although these systems are inside the body, they still contain inputs and outputs that have not crossed the membrane barriers separating the external environment from the internal environment.

The internal environment of the body consists of all the fluids that surround and bathe the body cells. There are three main types of fluid: the extracellular fluid, which is also called the tissue or **interstitial fluid**; the blood plasma; and the lymph fluid. These fluids provide the essential inputs to the cells (such as nutrients, oxygen and water) and remove the cell wastes (such as carbon dioxide, water and urea), as well as transporting other molecules needed by the human body, such as hormones. The internal environment of the cells contains the intracellular fluid, which is separated from the fluids of the internal environment by the selectively permeable plasma membrane.

The internal environment of the body must remain relatively stable for efficient cell functioning, whereas the conditions in the external environment can fluctuate widely. When there is a change in the external environment, an adjustment may then need to be made to the internal environment if it also changes.

WB 4.2.1 INTERNAL AND EXTERNAL ENVIRONMENT OF THE BODY PAGE 92

EXAM TIP
The cells and their cytoplasm are not considered part of the internal environment; nor are the insides of the digestive, respiratory or excretory systems.

Optimum and tolerance ranges

For many factors in the environment, such as temperature, concentration of oxygen and carbon dioxide, and amount of glucose and water in their body fluids, humans have an **optimum range**. This is the range in which humans thrive and function at their best. If the conditions vary outside the optimum range, the body enters a **tolerance range** in which humans can survive, but not thrive. If the conditions are outside the tolerance range, the human will begin to suffer **physiological stress**. This is the point at which the mechanisms that humans possess to deal with fluctuations break down and, if the situation does not change, they will die.

WB 4.2.2 OPTIMUM AND TOLERANCE RANGES PAGE 93

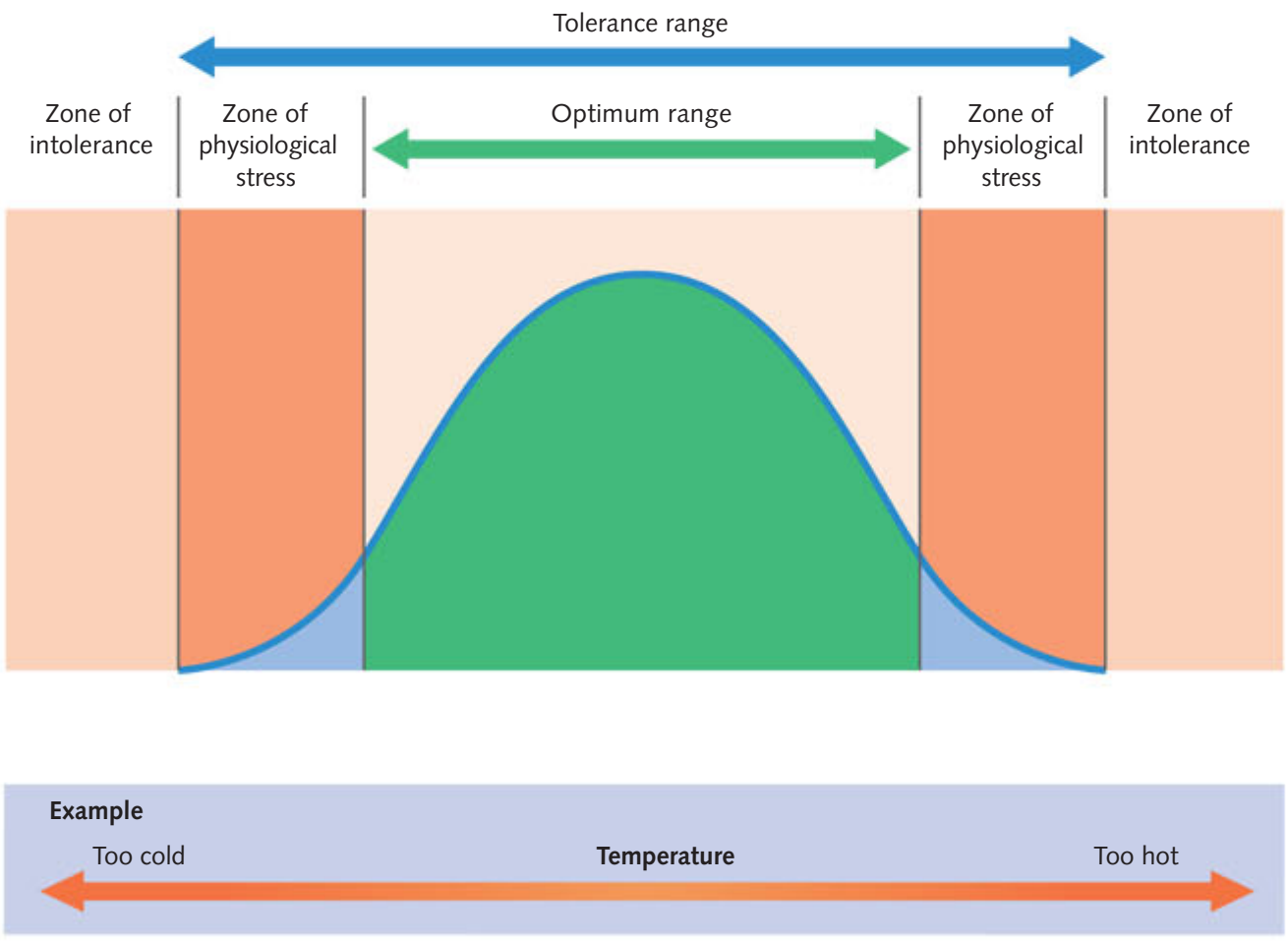


Figure 4.6 The optimum range for a factor is the range within which the human functions best.

KEY CONCEPTS

- The bodies of organisms must regulate their internal environments within narrow limits for survival. These are known as tolerance limits.
- Each organism has an optimum range in which it functions best; outside this range is the zone of physiological stress.

Concept questions 4.2a

1 Why is it important for humans to be able to regulate their internal environment?
2 Define tolerance range, optimum range and physiological stress.
3 Is the fluid bathing the cells part of the internal or external environment? Explain your choice.
4 List the components of the external environment of the human body.
5 What constitutes the internal environment?
6 Explain why it is important that the human body is able to regulate its body temperature, blood glucose level and water concentration.
7 How is physiological stress different from the zone of intolerance?
8 If an organism can operate within tolerance ranges and optimal ranges, its chances of survival are more favourable. If the organism is operating outside its tolerance limits, death is usually fairly swift. Provide three reasons why death is fairly swift for an organism operating outside its tolerance limits.

HOT Challenge

9 Research the temperature ranges that would lead a health practitioner to classify a patient as having:
a fever
b hyperthermia
c hypothermia
d normal core temperature.

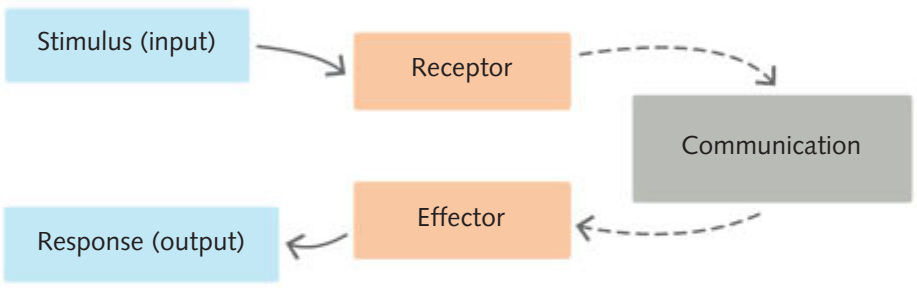


Figure 4.7 The stimulus–response model relies on the transfer of information between the receptor and effector.

Stimulus–response model

In explaining how the cells and organ systems of the human body respond to changes in the external and internal environment, it is useful to apply a **stimulus–response model**. The **stimulus** (plural: stimuli) is the detectable change in a physical or chemical factor in the human's internal or external environment. It is detected by a receptor that is specific for that stimulus, which can be internal or external. The message is then transferred or communicated via the nerves or hormones to an **effector**, which is the body tissue or organ that will carry out the response. Effectors in humans are usually glands or muscles. The **response** or reaction that occurs will be a change in the structure, functioning or behaviour of the human that will increase that human's chances of survival.

WB 4.2.3 STIMULUS–RESPONSE MODEL PAGE 95

Detection of stimuli from the external and internal environments

The human body can detect signals from the external environment using **exteroceptors**. These can work as individual receptors or together as a group and can be distributed evenly over the body (such as pain receptors), located in special areas (for example, taste buds), or concentrated in organs (such as the eye).

Interoceptors receive signals from within the body's internal environment. Examples of internal signals are changes in carbon dioxide concentration, body temperature, blood glucose and water concentration and pH levels. With the aid of interoceptors, the internal environment is maintained within narrow limits, allowing maximum cellular functioning. Table 4.1 lists some examples of exteroceptors and interoceptors.

WB 4.2.4 DETECTION OF STIMULI FROM THE EXTERNAL AND INTERNAL ENVIRONMENTS PAGE 97

If a person touches something hot (stimulus), the nerve endings in their skin (receptor) will detect the high temperature, send a nerve message rapidly via the unconscious part of the brain (communication) to their arm muscles (effector), and they will pull their hand away (withdrawal response). This is an example of a stimulus–response model. Note that in such a model, the response produced will not alter the stimulus or make it go away. It will, however, prevent damage to the receptor (skin).

Table 4.1 Some examples of exteroceptors and interoceptors

Type of receptor	Stimuli	Location in animals
Chemoreceptors (detects chemicals)	Exteroceptors: Substances that have smell (olfactory receptors) or taste	Nose, mouth
	Interoceptors: Oxygen and ion levels	Aorta, carotid arteries
	Blood glucose concentration	Pancreas
	Blood water concentration	Hypothalamus
Mechanoreceptors (detects pressure, touch)	Exteroceptors and interoceptors: Pressure, touch, tension, sound vibrations, balance	Ear, skin
Photoreceptors (detect light)	Exteroceptors: Light	Eyes, light-sensitive cells in body surface of some invertebrates
Thermoreceptors (detect heat)	Exteroceptors: External temperature variations	Skin
	Interoceptors: Internal temperature variations	Hypothalamus
Pain receptors	Exteroceptors and interoceptors: Pain	Free nerve endings in the skin

KEY CONCEPTS

- The stimulus–response model involves a stimulus detected by a receptor, then transmission of the message via nerves or hormones, to an effector that carries out a response.
- Organisms detect signals through interoceptors (internal signals) and exteroceptors (external signals).

Concept questions 4.2b

1 Define the following.
   - **a** Stimulus
   - **b** Receptor
   - **c** Effector
   - **d** Response

2 Using Figure 4.7 as a guide, draw a flow chart showing what happens when an athlete hears the starter's gun.

3 Distinguish between exteroceptors and interoceptors.

4 Provide three examples of exteroceptors and three examples of interoceptors.

5 What is the aim of the stimulus–response model in terms of survival of the individual?

HOT Challenge

6 **a** Stimuli are often categorised as 'inputs', and responses are categorised as 'outputs'. Why is this a useful way of conceptualising parts of the stimulus–response model?
   - **b** Refer to Figure 4.7. What is meant by the term 'transfer of information'?
   - **c** Reflex arcs are examples in the human body of stimulus–response pathways. State the stimulus, the receptor, the effector and the response for the following.
     - **i** Blinking
     - **ii** Standing on a pin

Homeostasis and human body systems

Changes in the internal environment act as stimuli and are detected by internal receptors. The message about the disturbance may be transferred to a control centre with the use of the nervous system, or the message may be carried directly to the effector, as in the case of the hormonal (endocrine) system. A control centre interprets and coordinates incoming information and sends out a message to the appropriate effector to carry out a specific response. In this situation, the response will either counteract or reinforce the stimulus. This process is referred to as a **feedback mechanism**.

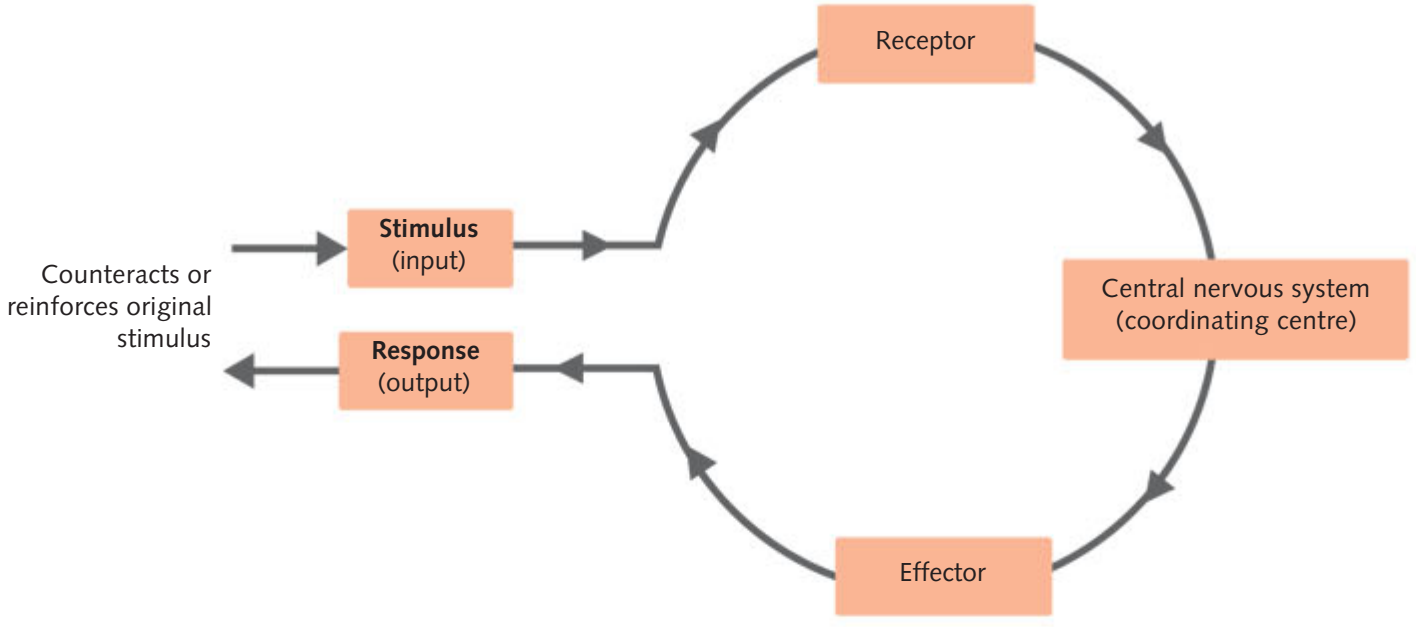
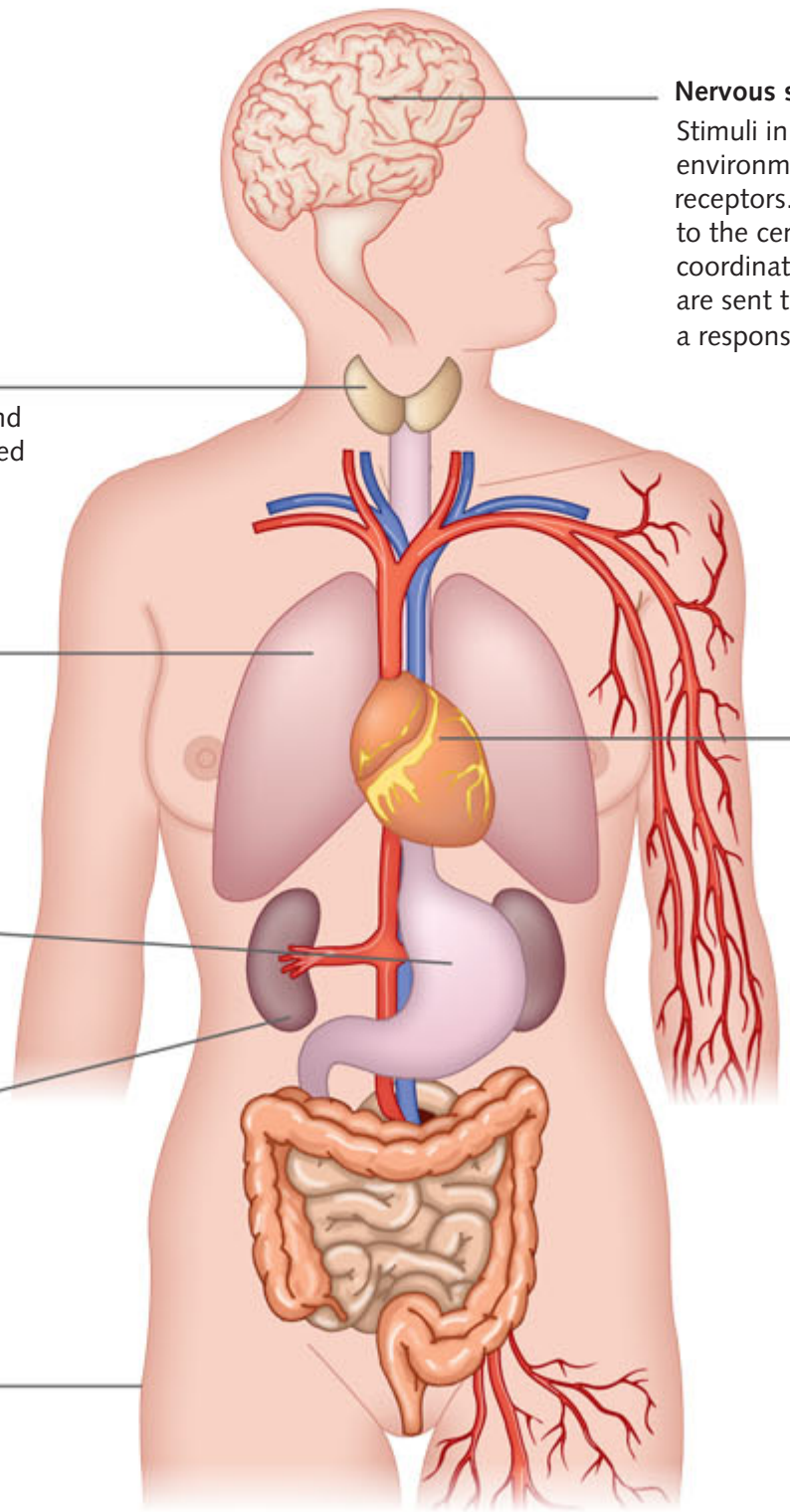


Figure 4.8 A feedback mechanism occurs when a response counteracts or reinforces the original stimulus.



Nervous system
Stimuli in the external and internal environments are detected by receptors. Electrical impulses travel to the central nervous system where coordination takes place. Impulses are sent to effectors that carry out a response.

Hormonal (endocrine) system
Hormones are released directly into the bloodstream and transported throughout the body. Target tissues involved in regulating cell activities respond.

Respiratory system
Oxygen from the air diffuses from the lungs into the capillaries and is carried to all cells. Carbon dioxide from the cells is carried to the lungs in the blood and diffuses into the alveoli from where it is exhaled. Removal of CO_2 helps regulate pH.

Digestive system
The products of digestion (simple molecules) are absorbed into the blood and lymph vessels in the wall of the intestine, from where they are supplied to other parts of the body. Undigested material is eliminated.

Excretory system
Nitrogenous wastes (urea), excess water and salts are excreted from the body in urine. Water balance (osmoregulation) is regulated in this way.

Integumentary system (skin)
Evaporation of sweat from the surface helps regulate temperature. The skin is a barrier between the internal and external environments and reduces the chance of entry of microorganisms.

Circulatory system
Blood distributes warmth, hormones, O_2, nutrients (including glucose, fatty acids and amino acids) to cells and removes wastes including CO_2.

Figure 4.9 Human body systems involved in regulation of the internal environment

Internal conditions in the tissue (extracellular) fluid and blood plasma that affect cell functioning and therefore need to be kept within narrow limits include:

- temperature and pH (hydrogen ion concentration), which affect enzyme action and therefore cell metabolism
- the concentration of solutes such as glucose and amino acids, and gases such as oxygen and carbon dioxide, which all affect biochemical processes
- the concentration of water and ions such as sodium, potassium and chloride, which affect movement across membranes and other cell activities.

Responding to changes in these internal factors is essential for efficient functioning of the human body, at the cellular level, and involves most of the human body systems.

Homeostasis using negative feedback mechanisms

WB
4.2.5 HOMEOSTASIS USING NEGATIVE FEEDBACK MECHANISMS PAGE 98

Once a change in an internal factor is detected, it is important for an action to occur to produce a change in the opposite direction so that the factor is kept relatively constant within narrow limits. This is called **negative feedback** and involves a system of control in which, when a change in a variable is detected, a response occurs to produce a change that counteracts or reverses the stimulus (Figure 4.10). For example, if a person's body temperature is above the optimum, the person may respond by sweating. This response will reduce or reverse the stimulus that triggered the sweating. If the person's temperature goes below the optimum, they may move in front of a heater, so their body absorbs more heat. This response will result in reducing or reversing the stimulus of low body temperature. Such mechanisms are essential so that organisms can maintain a relatively constant internal environment within a small tolerance range, despite changes in the internal or external environment. This maintenance of the internal environment is called **homeostasis**.

For example, when a bar of chocolate is ingested, blood glucose levels rise above the optimal level, known as the **set point**. The body's response is to lower the blood glucose level back towards the optimum level by increasing absorption of glucose into the body cells and converting any excess into stored **glycogen**. The decreasing level of glucose, however, often overshoots the optimum. This stimulus, decreasing blood glucose, will be detected and another response will occur to reverse the stimulus, and result in increasing glucose levels again. Exercising vigorously or fasting also decreases blood glucose levels below the set point. The body responds by breaking down stored glycogen and returning glucose into the blood, thus increasing blood glucose levels back towards the optimum. Negative feedback is extremely important in homeostasis because the response always aims to restore the internal environment to optimal levels.

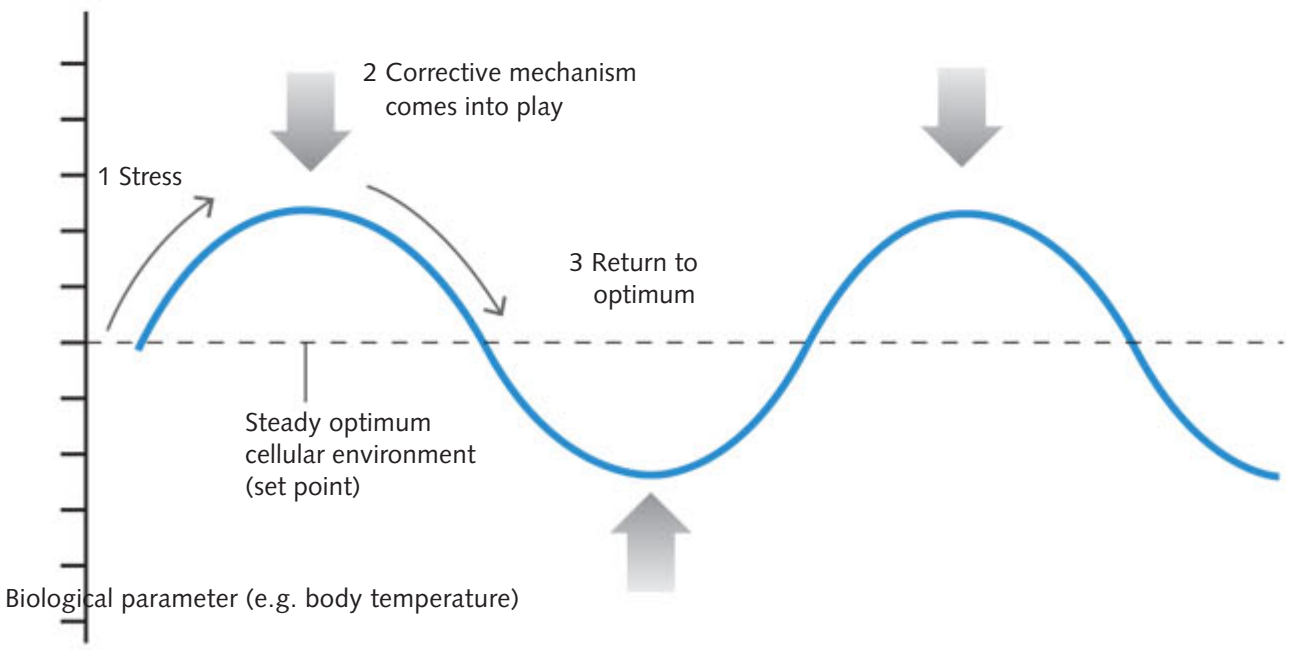


Figure 4.10 Homeostasis is maintained through negative feedback mechanisms

KEY CONCEPTS

» Homeostasis is the maintenance of a relatively constant internal environment within narrow limits, despite changes in the external and internal environments.
» A negative feedback mechanism is a system of control in which, when a change is detected in a variable, a response occurs to counteract or reverse the stimulus; that is, an action occurs to produce a change in the opposite direction, thereby maintaining a relatively constant internal environment.

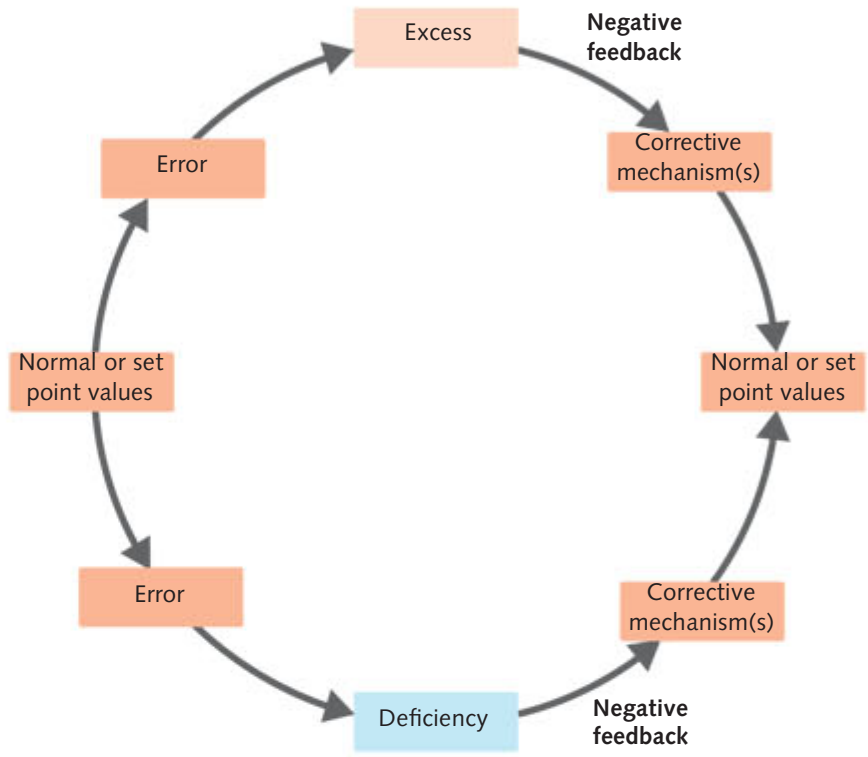
Concept questions 4.2c

1 Define homeostasis and outline its importance in the human body.
2 Describe negative feedback and give an example.
3 What is the set point?
4 In Figure 4.10, the stimulus is represented in the diagram as a 'stress'. Why would that be?
5 In a negative feedback loop, what happens to a variable (such as blood glucose) when it increases past its normal concentration?

HOT Challenge

6 *Imagine the body is a factory that makes Product X at a rate of 10 products per hour. Product X is fed into shelves at the end. Making too much of Product X is expensive and wasteful. On one particular day, 120% of Product X is made, resulting in 20% too much. There is no room on the shelves. Immediately the factory slows production and then stops. Stopping the factory is expensive and causes the owner of the factory financial problems if it continues. The next day there is space on the shelves again and production restarts.*

Figure 4.11 summarises two negative feedback loops, one when there is an excess of product and one when there is a deficiency of product. Use this figure to analyse the above story and answer the questions below.



Adapted from Moodle

Figure 4.11 A generalised homeostatic regulatory process

a In the story, on the first day, identify:
  i the stimulus
  ii the receptor
  iii the processing centre
  iv the effector
  v the response.
b On the second day, what is happening?

4.3 Temperature regulation in the human body

The human body maintains internal core temperature at a relatively constant 37°C using negative feedback mechanisms. Because humans are **endothermic** organisms, they gain most of their body heat from cell metabolic reactions, especially aerobic cellular respiration and other breakdown reactions in the cells. If the temperature of their surroundings is greater than their body temperature, humans will also gain heat from their surroundings. Figure 4.12 illustrates the principal mechanisms. Heat transfer depends on the temperature gradient between the internal and external environments. When there is a balance between heat gain and heat loss, the organism is said to be in **heat balance**. The purpose of **thermoregulation** is to maintain a relatively constant body temperature, described as homiothermic, by using the body structures and functioning, and by the way the person behaves. Structural, physiological and behavioural adaptations are therefore important in this process of homeostasis (Figure 4.13).

CONNECT
Refer to Chapter 9 for more extensive discussion of these adaptations in a variety of animals, including humans.

An organism that is hotter than its surroundings may lose heat energy in a combination of four ways, and an organism that is cooler will gain heat in the same four ways:

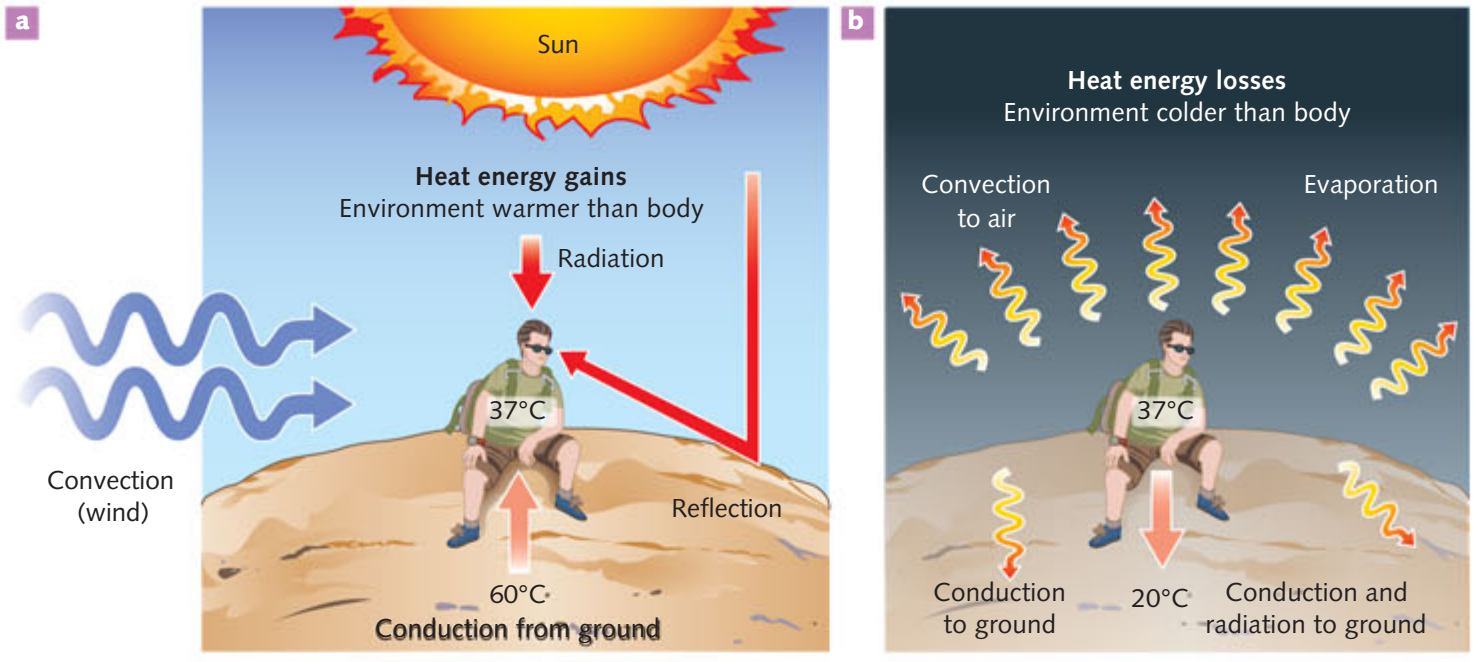


Figure 4.12 Heat transfer during **a** the day and **b** the night

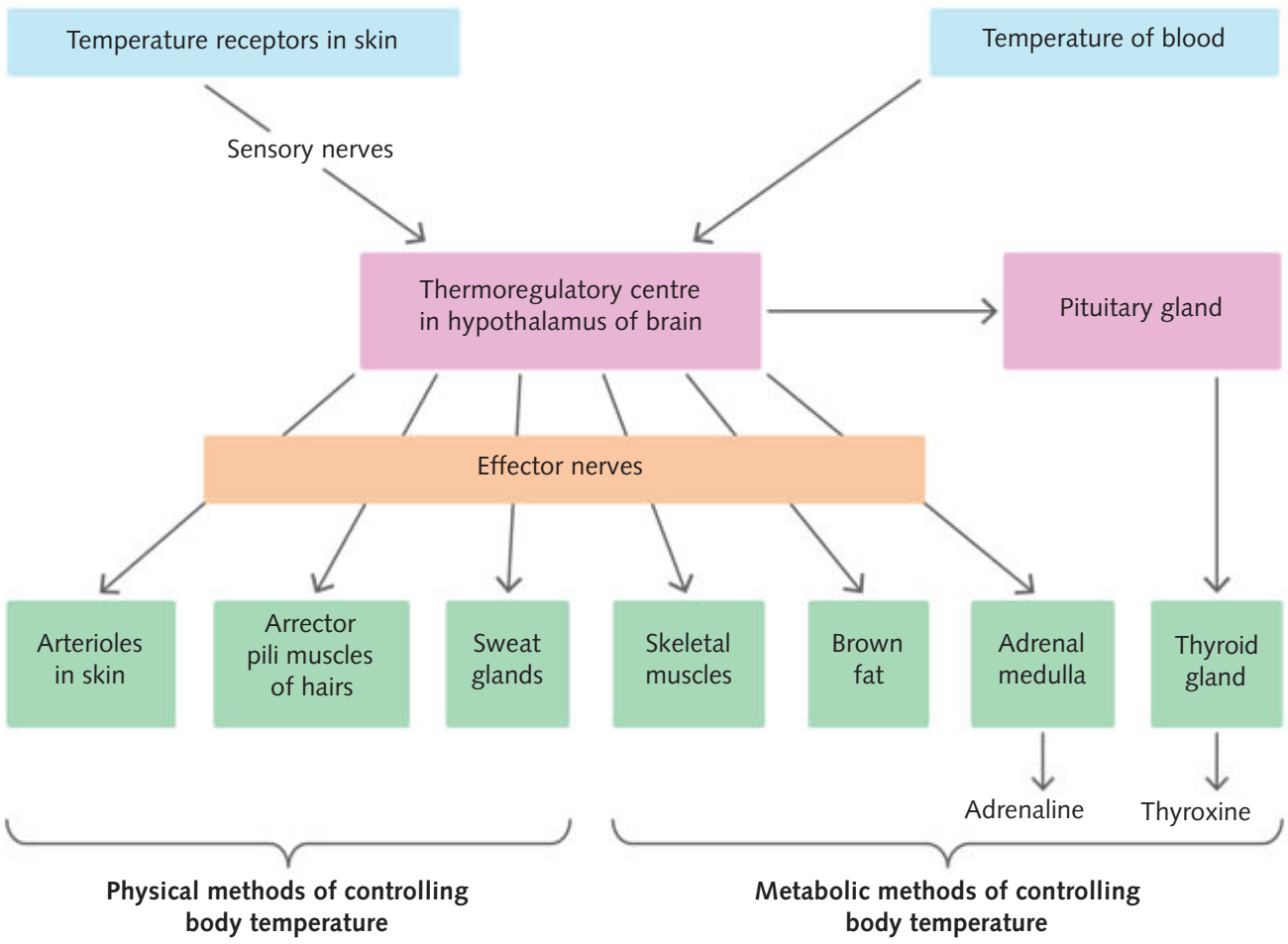


Figure 4.13 Various homeostatic mechanisms the human body may employ to maintain temperature balance

» **Radiation**, which involves heat transfer from an object such as the Sun or a radiator by infrared energy waves
» **Conduction**, which is the transfer of heat energy from a hotter to a cooler object by direct contact such as cuddling a hot water bottle
» **Convection**, which transfers heat when hot air or water rises and is replaced by an inflow of cooler air or water
» **Evaporation**, when liquid water turns into water vapour heat energy is used, cooling the surface.

In hot conditions a person may lie out flat in the shade, thus exposing a greater surface area for heat loss by radiation. Their face might be flushed or look redder than usual as blood vessels in the skin dilate to bring more warm blood near the body surface to increase heat loss. They may feel damp around their neck and underarm as sweating occurs at a higher rate for evaporative cooling.

EXAM TIP
Muscle contraction when shivering doesn't generate heat to warm the body; rather it is the increase in cellular respiration that provides the energy for contraction and warming the body.

If a person is cold, they may shiver, as the increased cellular respiration rate for increased muscle contraction will also generate heat. Their skin may be paler and feel cool because the blood vessels constrict, reducing the flow of blood to the surface and therefore heat loss by radiation. They may be hunched up, clasping their arms to reduce surface area for heat loss, put on a woollen jumper for more insulation, or turn up the heater for more radiant heat.

4.3.1
THE HYPOTHALAMUS AS A THERMOSTAT
PAGE 100

The hypothalamus as a thermostat

Skin thermoreceptors detect temperature changes in the external surroundings of humans. Appropriate responses are voluntary activities such as moving to a different area or altering clothing. The **hypothalamus** acts as a thermostat for internal or core temperature. The hypothalamus is a small region of the brain, located at the base of the brain, near the pituitary gland. It has three main regions: the anterior region, which releases hormones, many of which interact with the nearby pituitary gland; the middle region, involved in controlling appetite and in growth and body development; and the posterior region, involved in temperature control by causing shivering and blocking sweat production.

Weblink
Homeostatic loops

Online Worksheet
Homeostatic loops

The hypothalamus is able to act as the thermostat because it has thermoreceptors that are sensitive to the temperature of the blood flowing through it, and it responds by sending messages to the appropriate effectors. If the temperature of the blood is higher than normal, the thermoregulatory centre in the hypothalamus detects this and activates processes that cool the body. If the temperature is below normal, the centre initiates processes that warm the body.

Thermoregulation is an example of a homeostatic system involving negative feedback (Figure 4.14). Human body temperature constantly fluctuates very slightly on either side of the set point, rather than being fixed at that point.

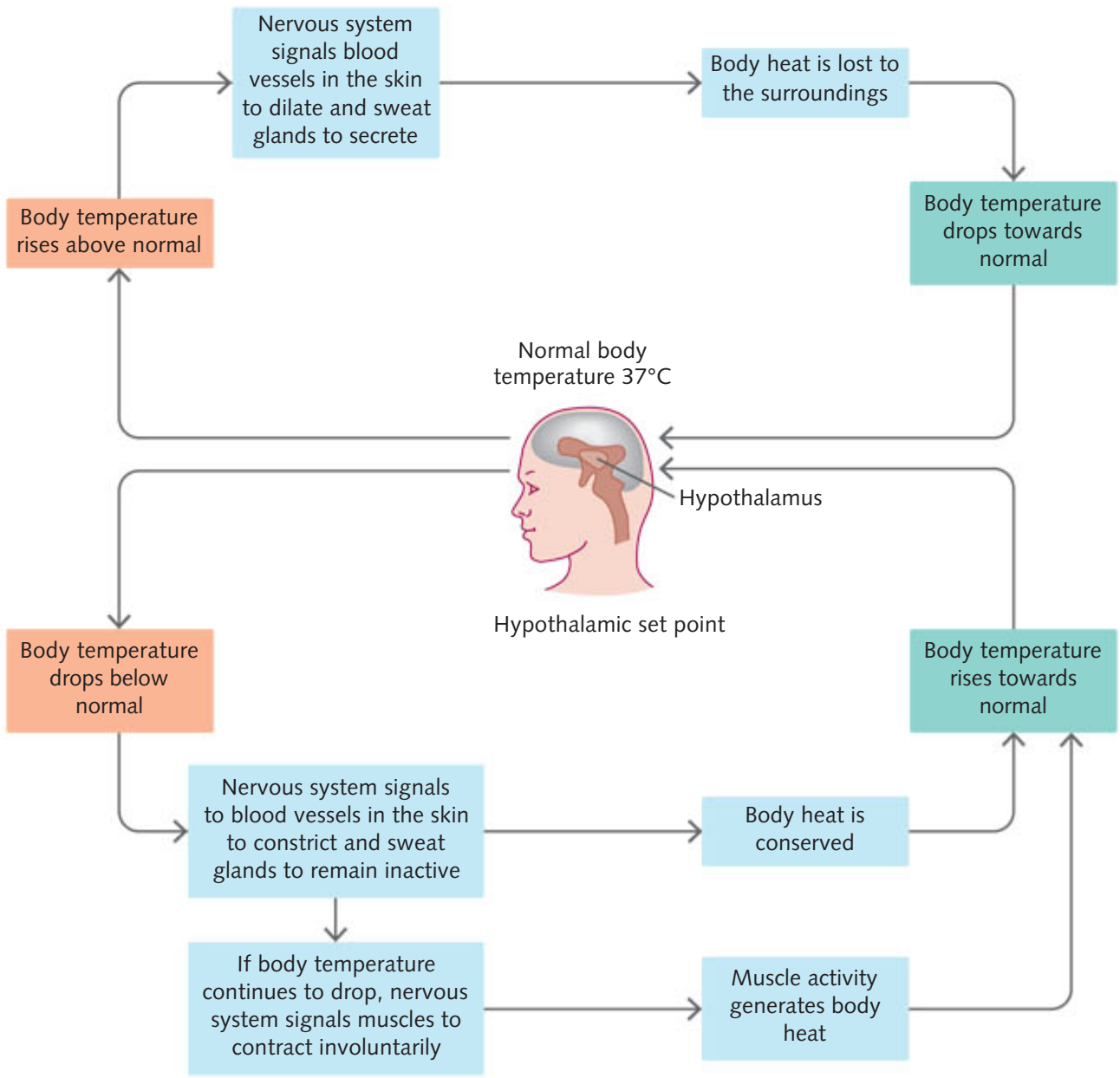


Figure 4.14 Homeostasis and temperature control

Keeping cool

Metabolism is the sum of all the chemical reactions that occur within an organism's cells to maintain life. Metabolic activity is not only responsible for the breakdown or synthesis of molecules, it also produces internal body heat. An increase in metabolic activity will result in an increase of internal temperature because of the energy released in the reactions.

Thermoreceptors in the brain detect the increased internal temperature during times of high metabolic activity, such as exercise. Skin thermoreceptors detect high external temperatures, such as on a hot summer's day. If the internal temperature increases above 37°C, numerous responses may occur that involve increased heat loss or decreased heat gain. Responses may be physiological, as shown in Figure 4.15, or behavioural. In addition, the body may show structural adaptations to living in a hot environment.

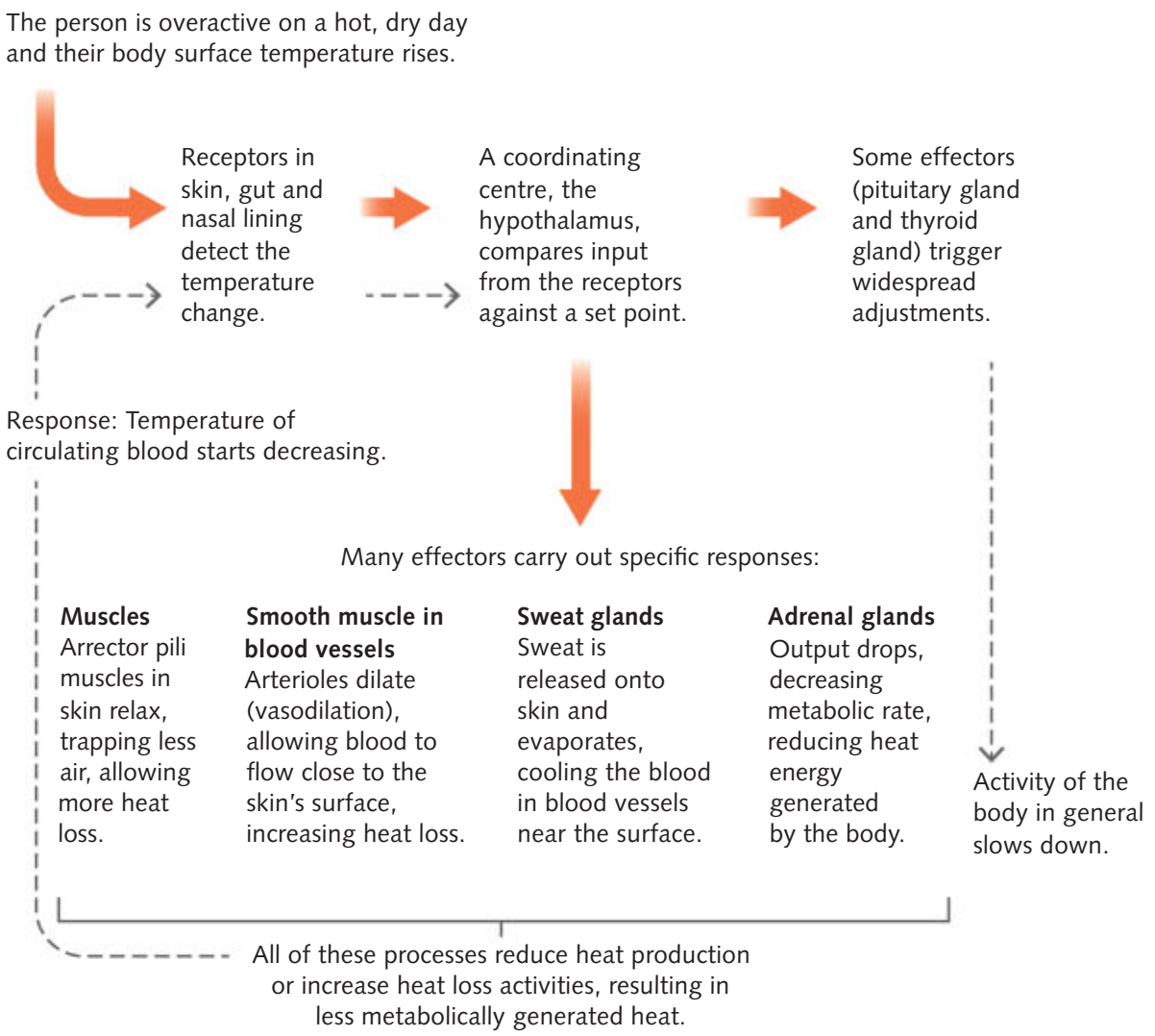


Figure 4.15 Homeostatic control of human body temperature on a hot day

Mechanisms to increase heat loss

» Hair on the skin is lowered by relaxation of the **arrector pili muscles** in the skin so less air is trapped between the hairs. Insulation is therefore reduced, and heat energy can be lost more readily by conduction, radiation and convection.

» Nerve impulses stimulate the arterioles near the skin surface to dilate (**vasodilation**), allowing more blood flow close to the skin's surface, increasing heat loss.

» Increased sweating occurs: sweat gland ducts open to release sweat, containing water and salt, onto the skin. Evaporation of water from the moist skin cools the blood that flows through capillaries near the surface. The cooling effect of sweating depends not only on the temperature of the surrounding air but also on its relative humidity. In humid conditions the air contains a high percentage of water. This reduces evaporation of sweat and hence reduces cooling of the blood. If there is air movement, the breeze can remove the layer of humidity that builds up around the body after a long period of sweating and allow more evaporation to take place. Sweating is most effective as a heat loss mechanism in hot, dry and windy conditions.

WB
4.3.2 INVESTIGATING THE BODY'S RESPONSE TO A SUDDEN DROP IN EXTERNAL TEMPERATURE PAGE 101

Mechanisms to reduce heat gain

» The metabolic rate decreases, so less heat energy is generated by the cells of the body. There is, however, a limit to how far the metabolic rate can decrease. A base rate must continue to provide enough energy for basic cell functions, so some heat energy will always be generated.

Developed exclusively by Southern Biological

INVESTIGATION 4.1

Thermoregulation in *Daphnia*

Background

Daphnia, commonly known as 'water fleas', are small freshwater invertebrate animals with an exoskeleton and paired appendages. *Daphnia* are translucent, making them an excellent organism in which to observe digestion and to study metabolic rates. This also makes *Daphnia* a great organism for studying homeostasis because its clear external skeleton (carapace) allows clear visibility of its heart, located in its back. Homeostasis is the maintenance of a stable internal environment. Homeostatic mechanisms within animals are triggered by increases in cellular respiration. These mechanisms increase breathing and heart rate, so that more oxygen is available to cells and more carbon dioxide is removed from cells.

Aim

To observe the relationship between temperature and metabolic activity and how feedback mechanisms maintain homeostasis in *Daphnia*

Time requirement

45 minutes

Materials

- *Daphnia* culture
- Plastic pipette with the end cut
- Cotton wool
- Concavity slides
- Compound microscope
- Stopwatch
- Paper towels
- Access to a refrigerator and to a warm water bath at 40°C

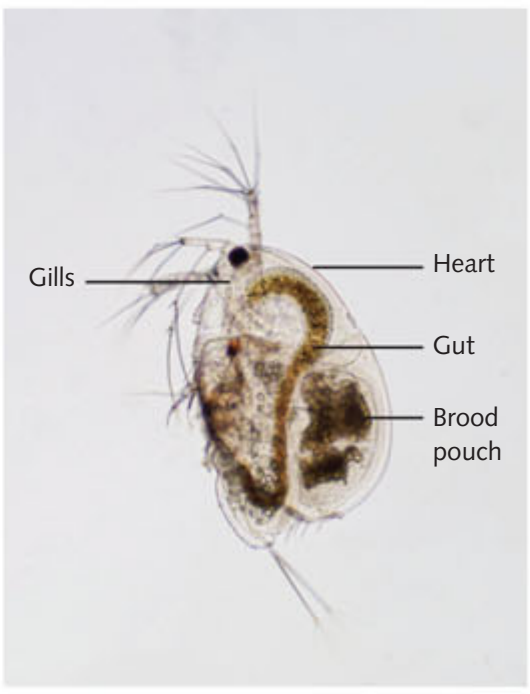
What are the risks in this investigation?	How can you manage these risks to stay safe?
Daphnia are harmless to humans, but swamp or pond water may contain pathogens.	Wash hands after touching *Daphnia*.

Method

1. Place a tiny piece of cotton wool in the centre of a concavity slide. This will slow the movement of the *Daphnia* and allow you to observe it more easily.
2. Using a plastic pipette, carefully transfer a *Daphnia* along with one drop of the culture liquid onto the slide (on top of the cotton). Keep the liquid to a minimum to prevent the *Daphnia* from swimming out of your field of view when observing the *Daphnia* under the microscope. If necessary, you may use a paper towel to draw off some water, but be sure to leave at least a drop.
3. Place the slide under the compound microscope and adjust the focus until the *Daphnia* is in clear view. You should be able to see the beating of the heart clearly. Use Figure 4.16 as a guide.
4. Ensure the microscope light is turned off to avoid overheating the *Daphnia*.

Measuring control heart rate

5. Using a stopwatch, count the number of heart beats you observe in 10 seconds. You may like to do this in pairs so you can count the heartbeats as your partner keeps time. Try to take your measurements as quickly as possible because the *Daphnia* will become stressed when kept in a small volume of water for an extended period.



iStock/Getty Images

Figure 4.16 ***Daphnia***

6 Copy Table 4.2 into your logbook and fill in the number of heart beats in 10 seconds. Multiply the number by six to find the number of heart beats per minute.
7 Repeat this test another two times until you have three separate heart rate measurements. Calculate the mean heart rate of the three measurements. This will serve as your control (room temperature).

Measuring heart rate at low temperatures

8 State your hypothesis.
9 Return your *Daphnia* to the culture jar and place the jar in the refrigerator for 5 minutes to expose it to a cold environment.
10 Repeat the same test procedure on the *Daphnia* using a fresh prepared slide until you have another three heart rate measurements. Calculate the mean and fill in your results in your table.

Measuring heart rate at high temperatures

11 State your hypothesis.
12 Return your *Daphnia* to the culture jar and place it in the incubator for 1 minute to expose it to a hot environment.
13 Repeat the same test procedure on the *Daphnia* using a fresh prepared slide until you have another three heart rate measurements. Calculate the mean and record it in your results table.

Results

Table 4.2 Heart rate of *Daphnia* at various temperatures

	Temperature (°C)					
	Room (control)		Cold		Hot	
Trial	10 s	BPM (×6)	10 s	BPM (x6)	10 s	BPM (× 6)
1						
2						
3						
Mean						

1 Did you observe any change in heart rate in the different environmental conditions? Explain.
2 At which temperature was the *Daphnia* heart rate the fastest?
3 At which temperature was the *Daphnia* heart rate the slowest?
4 Did you observe any change in the behaviour of the *Daphnia* itself? Was it more or less active and, if so, under what conditions?

Discussion

1 Did your results support or refute your initial hypothesis under each condition?
2 Evaluate the accuracy of your counting method. Suggest how the accuracy of the procedure might be improved.
3 What is thermoregulation? What do the results suggest about *Daphnia*'s ability to thermoregulate?
4 Explain why *Daphnia* would be more active in warmer environments.
5 What is the difference between ectothermic and endothermic organisms?
6 What types of animals are ectothermic and which are endothermic? Would Daphnia be classed as an ectothermic or endothermic animal?
7 Compare *Daphnia* and human thermoregulation. How do they differ?

Taking it further

Explore how different stimulants affect the neurotransmitters within *Daphnia*. Stimulants, such as caffeine, affect excitatory neurotransmitters. Using *Daphnia* as a model organism, determine how certain chemicals have an impact on the neurotransmitters' ability to send signals to the heart by measuring cardiac activity.

Getty Images Plus/E+/ranplett

Figure 4.17 Maasai people from East Africa tend to be slender with long arms and legs.

Structural and behavioural adaptations

» The shape and size of the human body can aid heat loss. A larger surface area exposed to the environment will allow more heat to be lost from the body. Humans living in warm environments, such as much of Africa, tend to have a different body shape from humans living in subarctic regions. For example, Maasai people living in hot parts of East Africa tend to be tall with slender bodies and long limbs (Figure 4.17). This body shape assists in the loss of body heat because of their relatively large surface area to body mass ratio.

» Humans can increase heat loss by changing their behaviour. Removal of clothing, moving into the shade, having a cold bath, standing in front of a fan, drinking a cold drink or eating cold food are some of the behaviours that would aid heat loss.

» Heat gain can be reduced by decreasing physical activity and therefore cell metabolism. Sitting quietly in a chair or having a rest in the hottest part of the day helps to reduce heat gain because heat is a by-product of aerobic cellular respiration.

KEY CONCEPTS

» Thermoregulation is essential for an organism's survival. Heat energy can be lost or gained in the following four ways: conduction, convection, evaporation and radiation.

» Physiological mechanisms in the human body to reduce body temperature include vasodilation, sweating and lowering metabolic activity.

» Structural and behavioural adaptations to keep cool include larger surface area compared to body mass in shape and size, removal of clothing and moving out of the heat.

» The hypothalamus detects internal body temperature and initiates appropriate responses.

Concept questions 4.3a

1 Explain the four ways in which heat energy can be transferred from humans to their surroundings, and give examples of each.

2 Which part of the human body detects if the body is too hot or too cold? Where is this part located?

3 Explain how heat balance is achieved in the human body.

4 What is vasodilation? Explain how it helps to maintain internal temperature.

5 List three behavioural adaptations of humans that assist in heat loss.

HOT Challenge

6 How does heat exchange work on the skin to contribute to cooling the body down?

Keeping warm

If a person is exposed to cold conditions, their body may respond by reducing heat loss or by increasing heat gain. These responses may be physiological or behavioural; in addition, the body may have structural adaptations to living in a cold environment.

Mechanisms to reduce heat loss

» In many mammals, arrector pili muscles contract, raising hair into a more vertical position, trapping air in the spaces between the hairs. Because air is a poor conductor of heat, the trapped air serves as an insulating layer. In humans, however, the body hair is much reduced. The arrector pili muscles still contract, resulting in 'goose bumps', but no insulating air layer results. Clothing serves a similar insulating purpose especially if it is thick and fluffy or loosely woven.

» Arterioles in the skin constrict (**vasoconstriction**), reducing blood flow to the skin surface, thereby decreasing heat loss from the blood to the surroundings. This results in a paler appearance of the skin.

» Metabolic rate increases due to the release of the hormones adrenaline and **thyroxine** ,which are produced in larger amounts in cold conditions. The liver and muscles respond to these hormones, resulting in an increase in cellular metabolic activity, and also by spasmodic contractions of the muscles resulting in shivering. Larger meals eaten in colder conditions are used to fuel increased cellular respiration to generate more heat energy.

Structural and behavioural adaptations

» Body size and shape can play a role in reducing heat loss. The Inuit peoples of the far north in Canada, Alaska and Greenland typically have stocky bodies with short arms and legs (Figure 4.18). They have relatively less surface area compared to their body mass, which results in reduced heat loss. They eat large quantities of high-kilojoule fatty foods to fuel their higher metabolic rate, producing extra body heat.

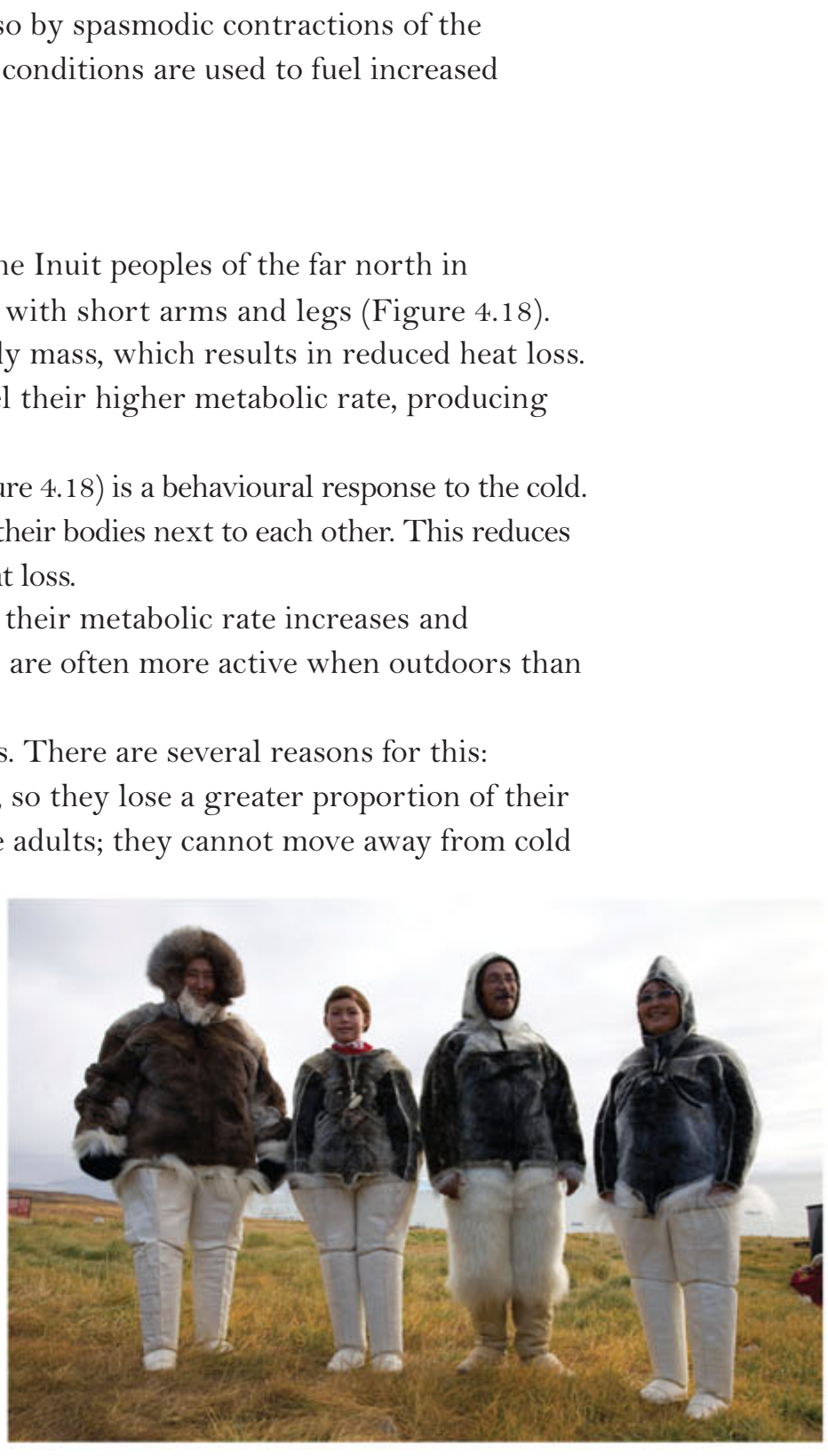
» The heavy clothing traditionally worn by the Inuit people (Figure 4.18) is a behavioural response to the cold. People in such cold regions traditionally slept in a huddle with their bodies next to each other. This reduces the group's overall surface-area-to-volume ratio, decreasing heat loss.

» Increasing heat gain will result if people are more active, as their metabolic rate increases and generates more heat energy. People living in cold conditions are often more active when outdoors than are people in warmer climates.

Newborn infants are more susceptible to cold than are adults. There are several reasons for this: newborns have a larger surface-area-to-volume ratio than adults, so they lose a greater proportion of their metabolic heat energy through their skin; they cannot shiver like adults; they cannot move away from cold areas or put on more clothes. A structural adaptation to aid in maintaining their body temperature is the presence of **brown fat**, in which heat production is more rapid. Although brown fat is also found in adults, there is a much higher proportion in newborn infants.

Temperature regulation in other animals

Animals other than humans also regulate their body temperature with physiological mechanisms and changes in their behaviour. Most animals can carry out thermoregulation to keep their body within a range around the optimal temperature for their cell functioning. There are different ways of achieving thermoregulation.



Alamy St

Figure 4.18 **Inuit people from the far north of Canada, Alaska and Greenland tend to be stocky with short arms and legs.**

WB
4.3.3 TEMPERATURE REGULATION IN OTHER ANIMALS PAGE 109

Losing heat

» Evaporation: Many animals will lose heat by evaporation of sweat from sweat glands. Animals that are covered in fur, however, have a limited ability to sweat through the skin and so they often pant to increase heat loss through evaporation from their mouth lining, tongue and lung surfaces. This can be observed in most dogs, cats, pigs and even bears.

» Radiation and convection: Birds such as cormorants, pelicans and owls can be seen flapping or fluttering their wings close to their throat. This increases the amount of heat radiated from their bodies in this area and helps to increase convection to blow hot air away, helping to maintain a heat gradient from their bodies.

Retaining heat

» Insulation: Thick skin and layers of blubber, as seen in seals, polar bears and walruses, act as insulating barriers to retain heat. Birds and other mammals fluff up their fur or feathers to trap air, a poor conductor of heat, and therefore provide an insulating barrier. During winter, the fur coat of mammals or feathers of birds become denser and sometimes darker in colour, to provide a more effective insulating layer that will absorb more heat.

» Hibernation and torpor: If body temperature is closer to the environmental temperature, the temperature gradient will be less, resulting in less heat loss. Mountain pygmy possums, bears and squirrels hibernate in winter so their body temperature drops to a minimum. To a lesser extent, when it is cold rats and mice will go into a state of torpor overnight to reduce heat loss.

» Counter-current blood flow to retain heat: To reduce heat loss at the extremities, some animals such as penguins, husky dogs and tuna fish have a circulatory system in which arteries with warm blood flowing to the extremities pass close by veins with cooler blood flowing back to the body. Heat is conducted from the warm arterial blood into the cooler venous blood and taken back to the core of the body, thereby retaining more heat.

» Blood chemicals to reduce freezing: Some fish species living in very cold waters, such as in Antarctica or the Arctic, have antifreeze blood proteins that stop the water in the blood and body fluids freezing.

Behavioural mechanisms

Many animals will act in ways that help them decrease heat production and lose more heat if their body temperature is too high, or increase heat production and reduce heat loss if their body temperature is too low (Figure 4.19). Reptiles cannot produce or store heat in their bodies, so animals such as lizards and snakes move in and out of the sun. They will bask on hot rocks, often with their bodies flattened down against the surface, to aid in maintaining a more constant body temperature. Some animals will huddle together in a group to share body heat, such as emperor penguins and bats. Burrowing, hiding under rocks or among vegetation, building nests or shelters, bathing in or drinking cool water, or just increasing or decreasing movement at different times of the day or night, can all be beneficial in thermoregulation.

a

Shutterstock.com/Markus J

b

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c

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Figure 4.19 Some of the ways that animals regulate their body heat: **a** a dog will pant to lose excess heat by evaporation from the mouth; **b** a bird will fluff up its feathers to trap an insulating layer of air in its feathers; **c** a lizard will absorb heat from a warm rock and the Sun to increase its body temperature.

Stress-tested by Southern Biological

INVESTIGATION 4.2

Modelling heat loss in mammals

Mammal body temperature varies little. What are some of the adaptations that help mammals maintain a relatively constant body temperature?

Aim

To model and investigate heat loss from an exposed surface

Materials

- 7 test tubes
- 4 thermometers
- 4 beakers
- Funnel
- Measuring cylinders
- Cotton wool (or some other insulating material)
- Cardboard cylinder (such as from a paper towel roll)
- Timer
- Fan
- Spray bottle of warm water
- Water
- Marker pen

What are the risks in doing this investigation?	How can you manage these risks to stay safe?
Hot water can burn.	Use a funnel and fill test tubes carefully.

Method

Part A: Effect of insulation on heat loss

1. Take three test tubes and label them 'A', 'B' and 'C'.
2. Surround test tube A with cotton wool or some other insulating material.
3. Place test tube B in a cardboard cylinder and wrap the outside of the cylinder with the same amount of insulating material as you used for tube A (this means that there is a layer of air between the test tube and the insulation).
4. Leave test tube C with no insulating material around it.
5. Fill each of the three test tubes with 20 mL water at 80°C (Figure 4.20). Place each test tube in its own beaker.
6. Insert a thermometer in each test tube and record the temperature as soon as possible after the water is added. In a table in your logbook, record the temperature every minute for 30 minutes.
7. Graph your results.

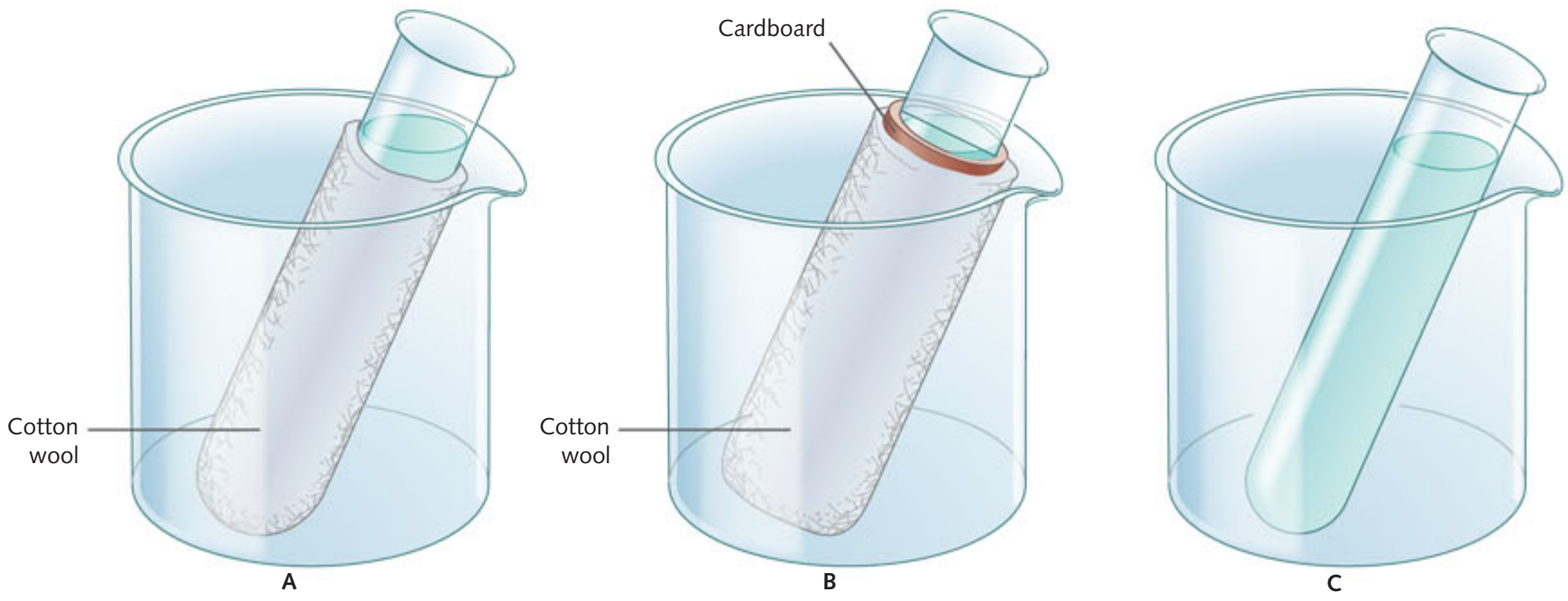

Figure 4.20 Experimental set-up to investigate the effect of insulation on heat loss

Part B: Effect of moisture on heat loss

1 Take four test tubes that have been wrapped in cotton wool and label them '1', '2', '3' and '4'.
2 Spray the outside of test tubes 1 and 3 with warm water. Place each of the four test tubes in a separate beaker.
3 Place test tubes 1 and 2 in front of a fan, as shown in Figure 4.21, and test tubes 3 and 4 in an area without air movement.
4 Fill each of the four test tubes with 20 mL water at 80°C.
5 Insert a thermometer in each test tube and record the temperature as soon as possible after the water is added. In a table in your logbook, record the temperature every minute for 30 minutes.
6 Graph your results.

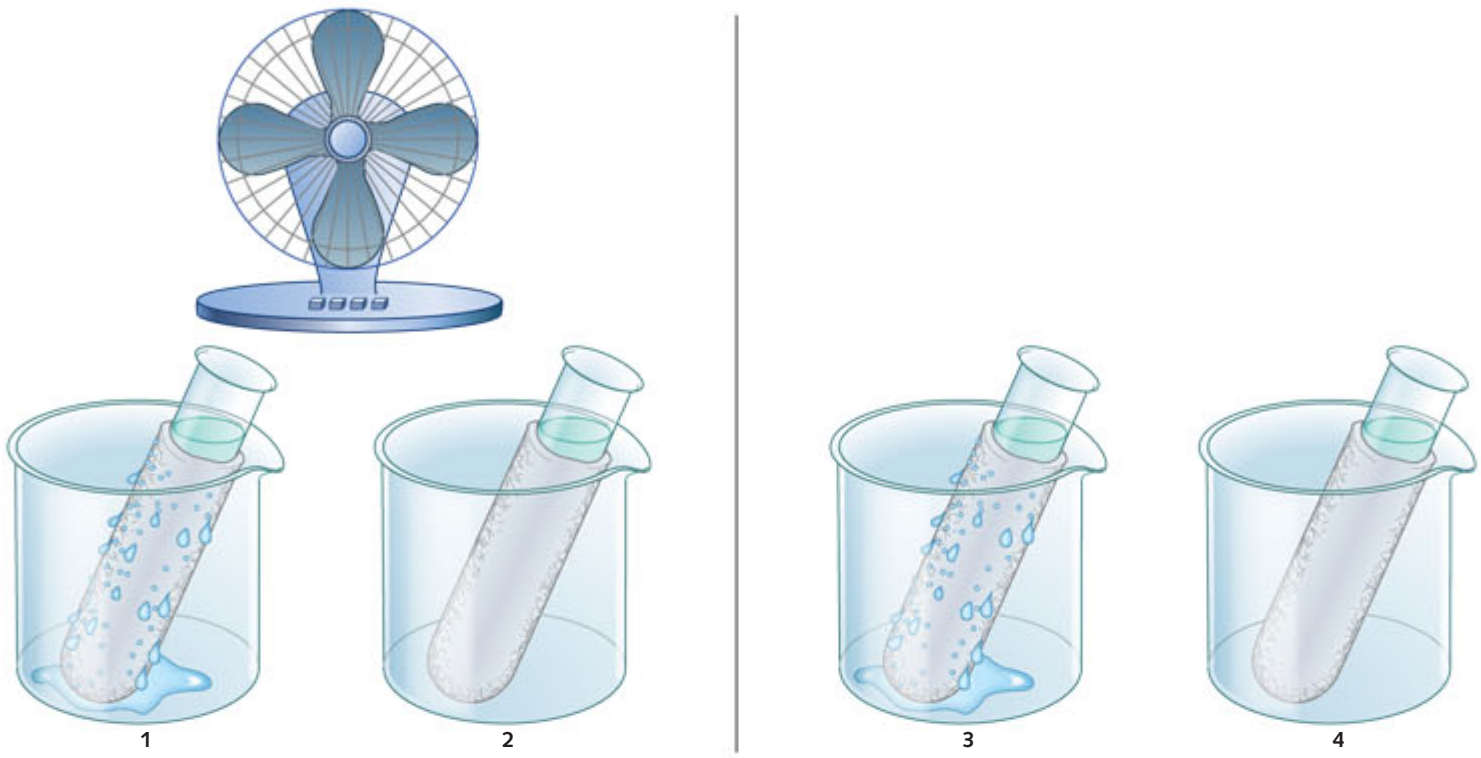

Figure 4.21 Experimental set-up to investigate the effect of moisture on heat loss

Results

Observations are to be recorded in tables and then graphed in your logbook.

Analysis of results

1 Which set-up in Part A was the most effective at reducing heat loss? Suggest what makes this set-up most effective at reducing heat loss.
2 Which set-up in Part B was the most effective at increasing heat loss? Suggest why.

Discussion

1 What structural feature of mammals is the cotton wool simulating?
2 How can an insulating layer of air be achieved in mammals?
3 How can the results from test tube B be used to explain the observation that a cat looks fatter on colder days?
4 Based on the results, suggest why a person feels cooler on a warm windy day compared with a warm still day.
5 Using the observations collected in this investigation, explain why panting in dogs is an effective way of losing body heat.
6 Why are animals like frogs at greater risk of perishing on a hot windy day? Use the results of your investigation to support your answer.

Taking it further

1 Which part of the investigation modelled the role of perspiration or sweating in maintaining body temperature?
2 Were any controls used in Part A and Part B of this experiment? If so, explain what these were and discuss their importance.
3 When the body temperature in mammals starts to drop, a number of things happen. Describe some of these physiological and behavioural responses. Are any of these responses being modelled in this investigation set-up? Explain.
4 When the body temperature in mammals starts to increase, different physiological and behavioural responses occur. Describe these responses. Are any of these responses being modelled in this investigation set-up? Explain.
5 Devise a method to test the effects of shivering on heat regulation. Use a method similar to the one in this investigation.

If a person's body temperature starts to increase beyond the limits of the human tolerance range, they may suffer heat stress. This can result in serious problems, such as heat exhaustion and heat stroke. Symptoms of heat stroke include dizziness, weakness, nausea, thirst and headache. **Hypothermia** is a dangerous condition that usually occurs due to a prolonged exposure to low temperatures and when the body loses more heat than it produces. It is the opposite of **hyperthermia** , which is the result of body temperature elevated above the tolerance range due to over production or absorption of heat, such as in the case of Mark Dorrity (Figure 4.4). In both cases, negative feedback mechanisms cannot restore temperature balance and so homeostasis is not achieved.

KEY CONCEPTS

- Physiological mechanisms humans have to keep warm include vasoconstriction, shivering and increasing metabolic activity.
- Structural and behavioural adaptations to keep warm include brown fat, body shape and size, adding clothing and moving out of the cold.
- Animals other than humans also regulate their body temperature with physiological mechanisms and changes in their behaviour.
- Hypothermia results after prolonged exposure to low temperatures and hyperthermia results after a prolonged period of elevated body temperature.

Concept questions 4.3b

1 Describe one structural and one behavioural adaptation of humans for retaining heat in cold environments.
2 Copy and complete Table 4.3 to relate a person's physiological response to temperature.
3 Describe two behavioural adaptations of animals other than humans that assist in keeping that animal warm on cold days.
4 Why would a small mammal shiver more than a large mammal on a cold day?
5 A small mammal was found to eat more than its body weight in food in a 24-hour period. In contrast, a larger mammal ate less than its body weight in food in the same time period. Suggest a reason why.

HOT Challenge

6 How does counter-current blood flow contribute to heat regulation in some animals?

Table 4.3 Mechanisms involved in thermoregulation and their effects in different animals

Stimulus	Physiological response	Effect
Increase in temperature		More heat lost through radiation
	Hairs flatten on skin, trapping less air	
Decrease in temperature	Constriction of blood vessels beneath the skin	
		Less heat loss through conduction
	Shivering	

4.4 Regulation of blood glucose levels

Glucose is the main source of chemical energy for all living organisms, including humans. When the glucose is broken down in cellular respiration, the energy stored in its chemical bonds is released to make the energy-carrying molecule ATP, which can be used by the cells to carry out their functions and activities.

A constant supply of glucose is necessary for the human body, and the glucose levels in the internal environment must be kept relatively constant to supply the cell needs. The normal range of glucose in human blood is about 3.0–7.7 mmol L^{-1}. Even after a meal or drink high in glucose, the level rarely rises above 8 mmol L^{-1}. If it does go higher, excess glucose is stored in body tissues. Maintenance of a relatively constant level of blood glucose in the internal environment is essential for the effective functioning of cells and, therefore, of the individual. Movement of materials in and out of cells is affected by the difference in osmotic concentration on either side of membranes and glucose also plays a role in this.

The concentration of glucose in the blood and tissue fluids at any time is determined by the balance between glucose input from food and stored compounds, and output due to glucose breakdown or storage.

Factors increasing glucose levels in the blood and tissue fluids include the following.

» Glucose is ingested in food either directly or in the form of complex carbohydrates, such as starch, which is then digested into glucose and absorbed into the bloodstream.
» Complex sugars such as sucrose, maltose and lactose are also taken into the body and digested into simple sugars such as fructose and galactose, as well as glucose.
» Fructose is ingested in soft drinks, which is converted into glucose in the small intestine and liver and absorbed into the bloodstream.
» Excess glucose that was converted into glycogen or fat stores can be broken back down into glucose and can pass into the blood.

Factors that cause a decrease in glucose levels include the following.

» Glucose is broken down in cellular respiration.
» Excess glucose is converted into glycogen, which is stored in the liver and muscles, or converted into fat.

WB 4.4.1 HOMEOSTASIS FOR THE REGULATION OF BLOOD GLUCOSE PAGE 111

Glucose homeostasis and the role of the pancreas

The homeostasis of blood glucose is maintained by the opposing action of two hormones: **insulin** and **glucagon** . These hormones are secreted into the bloodstream by special groups of cells in the pancreas, called the islets of Langerhans (Figure 4.22).

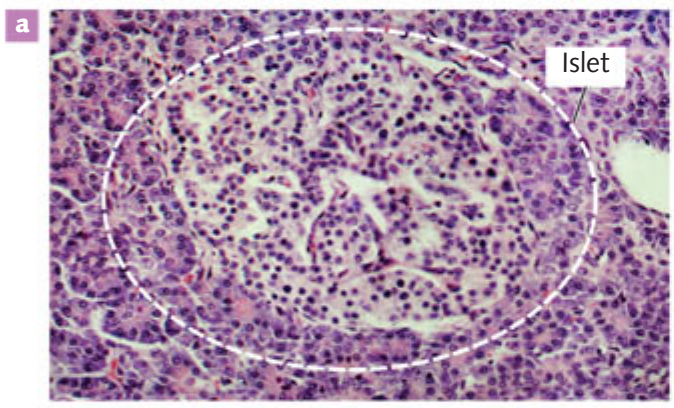

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Figure 4.22a Photomicrograph of part of the pancreas, showing one of the islets of Langerhans that secrete insulin and glucagon (magnification ×500) b Generalised diagram of the structure of one islet of Langerhans

Regulation of blood glucose levels is an example of homeostasis involving negative feedback mechanisms. When blood glucose levels rise above the optimum, such as after digesting and absorbing glucose from a meal of carbohydrates, this is the stimulus for the hormone insulin to be secreted by the beta cells in the islets of Langerhans. The insulin travels in the bloodstream to most cells of the body, causing them to increase their uptake of glucose from the blood. The cells that absorb the glucose are described as effector cells. Some of these target cells for insulin are the cells of the liver and muscles, which absorb excess glucose and convert it into the storage carbohydrate glycogen and also into fat. These responses lower the level of blood glucose back towards the optimum. When this happens, the pancreatic cells secrete less insulin so that the blood glucose level does not drop too far.

The reduction in blood glucose may overshoot and decrease the level below the set point. This will stimulate the alpha cells of the islets of Langerhans to secrete the hormone glucagon. Glucagon has an opposite effect to insulin. It causes the cells of the liver to convert stored glycogen into glucose; stored fats are also converted back into glucose. Once this glucose enters the blood, there is an increase in blood glucose back towards the optimum. When this happens, the alpha cells reduce their secretion of the glucagon.

In a healthy person, these negative feedback mechanisms will result in regular adjustment and balance of blood glucose levels that fluctuate around the optimum, as depicted in Figure 4.23.

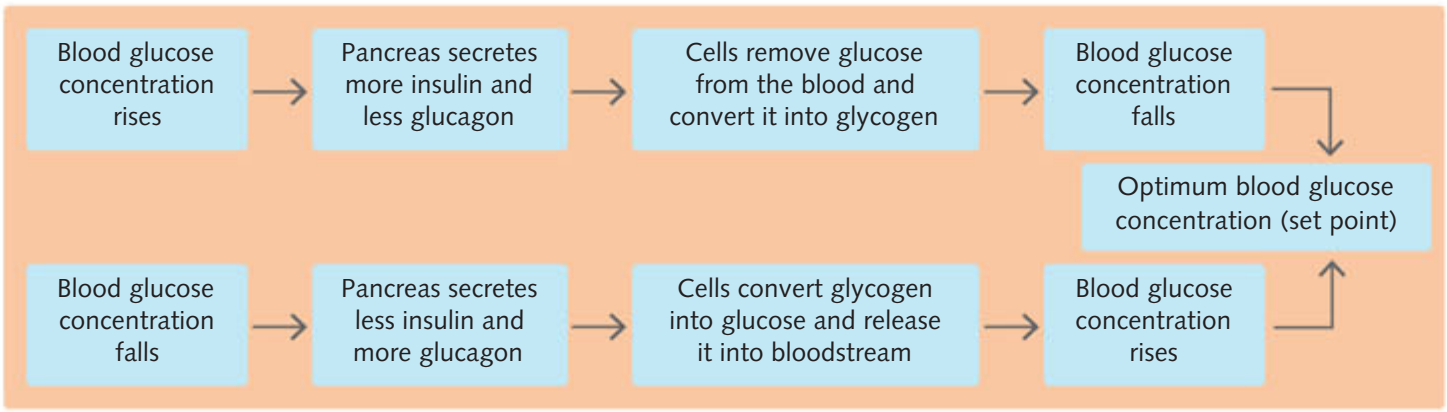

Figure 4.23 The action of two opposing hormones, insulin and glucagon, in maintaining blood glucose levels by a negative feedback mechanism

When the glucose homeostasis system malfunctions: type 1 diabetes

WB 4.4.2 WHEN THE GLUCOSE HOMEOSTASIS SYSTEM MALFUNCTIONS PAGE 114

Diabetes is a condition in which the body is unable to automatically regulate blood glucose levels, resulting in too much glucose in the blood. Type 1 diabetes results from a failure of the pancreas to produce enough insulin. In this condition, glucose is not absorbed by the body cells and they lack adequate glucose to produce enough energy. The body recognises the problem and as a substitute burns its fats. Extensive fat burning can release by-products which are dangerous in high amounts.

Over time, high blood glucose levels may damage blood vessels and nerves. If the blood glucose concentration remains above optimum levels (**hyperglycaemia**), glucose is excreted in the urine. The person produces large amounts of urine and drinks large amounts of water to compensate. Complications of persistent hyperglycaemia include damage to the eyes, nerves and kidneys and an increase in the risk of heart attack, stroke, sexual impotence and circulatory problems. Much of this damage can happen before a person is aware that they have diabetes.

Note:

In type 2 diabetes, the high blood glucose arises when cells do not respond appropriately to insulin. It affects mainly adults.

The exact cause of type 1 diabetes is not known, but there seems to be a strong family link. It is thought that an environmental factor, such as a virus, may cause the immune system to attack the insulin-producing cells of the pancreas in people with a genetic family history of diabetes. This attack on the person's own pancreatic cells by their immune system means that type 1 diabetes is classified as an autoimmune disease.

Type 1 diabetes can occur at any age but tends to develop in childhood. Currently, nothing can be done to prevent or cure type 1 diabetes; however, it can be successfully managed. People with type 1 diabetes monitor their blood glucose levels regularly (Figure 4.24) to ensure that they are maintained in the normal range. If the level of glucose is too high, they inject a measured amount of insulin.

If the level of glucose in the blood of a person with type 1 diabetes is too low (**hypoglycaemia**), as can happen when the person skips a meal, exercises vigorously or injects too much insulin, they need to boost their blood glucose quickly. If the hypoglycaemia is untreated, the diabetic person may go into a coma and can die. Blood glucose is boosted by eating sugar-rich foods that can be digested rapidly, such as jelly beans or barley sugar.

People with diabetes can live a completely normal lifestyle provided they keep to their routine and manage their blood glucose levels carefully.

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Figure 4.24 Monitoring of blood glucose and injection of insulin are part of the daily routine of a person with type 1 diabetes.

KEY CONCEPTS

- Blood glucose regulation is an example of homeostasis involving negative feedback mechanisms to maintain a relatively constant blood glucose level within narrow limits.
- A rise in blood glucose level stimulates the secretion of insulin from beta cells in the islets of Langerhans in the pancreas. Insulin causes a reduction in blood glucose levels.
- A drop in blood glucose levels stimulates alpha cells in the islets of Langerhans to secrete glucagon. The effect of glucagon is a rise in blood glucose levels.
- Type 1 diabetes results from the inability of beta cells in the pancreas to produce enough insulin.
- There is no known cause or cure for type 1 diabetes.
- Treatment of type 1 diabetes includes monitoring of blood glucose levels and insulin injections.

Concept questions 4.4

1 Name the cells in the pancreas that produce:
- **a** insulin
- **b** glucagon.

2 Describe the effects of insulin on the plasma membrane and glucose uptake of the target cells.

3 Draw a flow diagram to illustrate the sequence of events that occurs when blood glucose levels rise after eating a chocolate bar.

4 Study Figure 4.23, then analyse Figure 4.25.

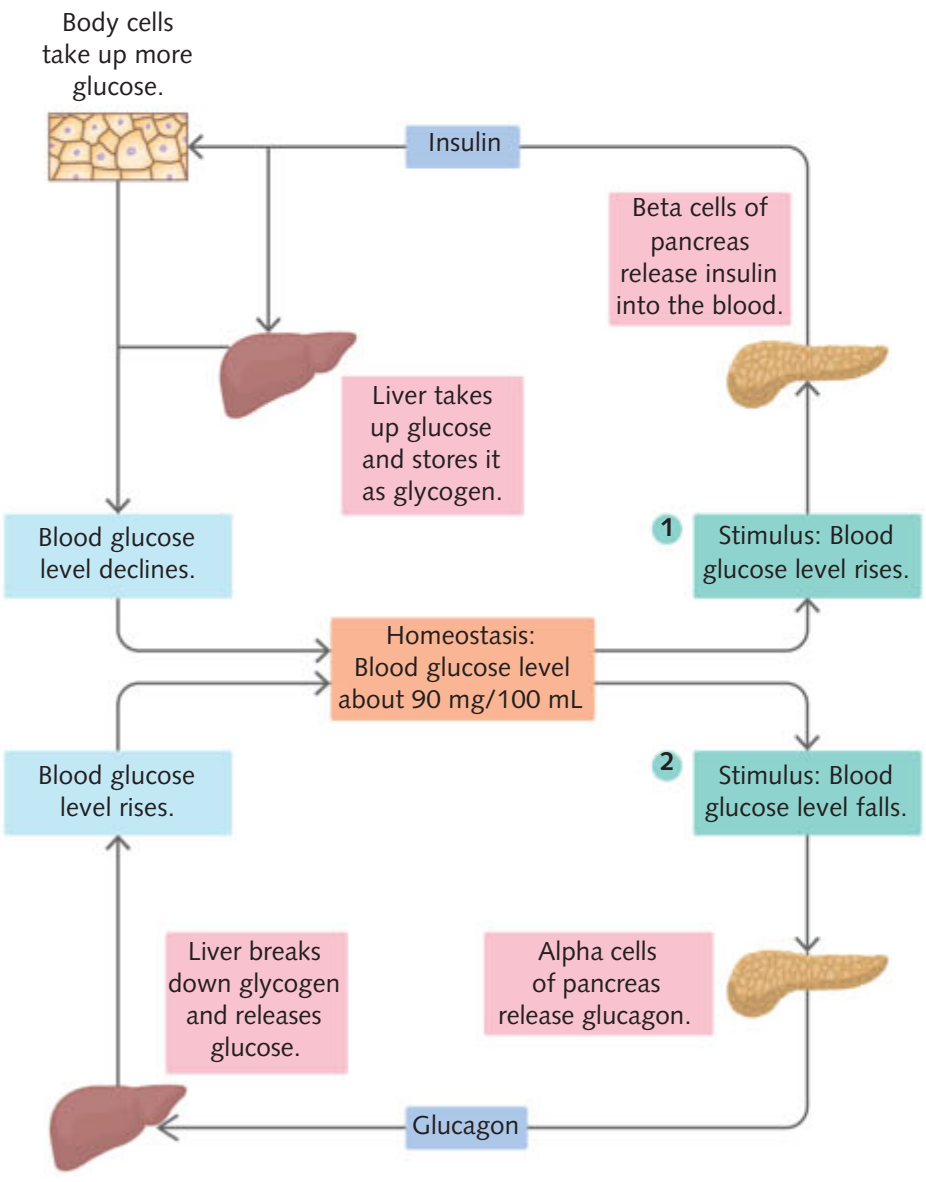


Figure 4.25 Homeostatic regulation of blood glucose in humans

Identify the following if the blood glucose increases.
- **a** Stimulus
- **b** Receptor
- **c** Messenger
- **d** Effector
- **e** Response

5
- **a** Explain the effect of type 1 diabetes on blood glucose levels.
- **b** List three possible complications of type 1 diabetes.

6 Distinguish between hypoglycaemia and hyperglycaemia.

7 Blood glucose concentration is one of the factors that affects human survival. List the tolerance and optimum range for blood glucose in humans.

HOT Challenge

8 You are a doctor. You find a person on the ground who you diagnose, by testing their blood, as hypoglycaemic. Hypoglycaemia can result in a coma and death if not treated promptly. The person is currently conscious. What would be one of the first things you, as a doctor, would do to treat the patient for this condition? Explain why you would do this?

4.5 Water balance regulation

Water makes up about 60–65% of human body mass. The percentage of water in infants is much higher, typically around 75–78%. Cell contents, blood and tissue fluid contain a variety of solutes dissolved in water. Water is the medium in which nutrients and wastes are transported and in which digestive enzymes are active. Water is lost continually from the body in urine, faeces, sweat and tears; by evaporation from mucous membranes lining the mouth and nose; and in air exhaled from the lungs. If input of water to the body does not equal output, the balance between solute and solvent concentrations in the tissue fluids and blood cannot be regulated and many bodily functions are affected. Blood pressure can drop with loss in volume of blood; toxic wastes cannot be excreted effectively; the osmotic balance of cells is upset; and enzyme activity cannot occur efficiently. Severe dehydration can result in death.

Osmoregulation in humans

The kidneys are the main organs of excretion, together with the lungs and skin. Ammonia is a nitrogenous (nitrogen-containing) waste product formed from the breakdown of protein molecules. Ammonia is toxic to cells, and a build-up of ammonia can affect pH markedly. Humans must quickly convert ammonia to the less toxic substance urea, so that waste nitrogen can be safely transported to the kidneys and then excreted. The structure and function of the kidneys is illustrated diagrammatically in Figure 4.26.

Urea and excess salts leave the body in the watery fluid called urine. By controlling how much water leaves in the urine, the water balance in the fluids of the body can be maintained. This control of water balance is called **osmoregulation** , and is a homeostatic mechanism under hormonal feedback control that involves negative feedback mechanisms.

CONNECT

Refer back to Chapter 3 and Figure 3.23 for an introduction to kidney structure and functioning.

WB

4.5.1 OSMOREGULATION IN HUMANS PAGE 115

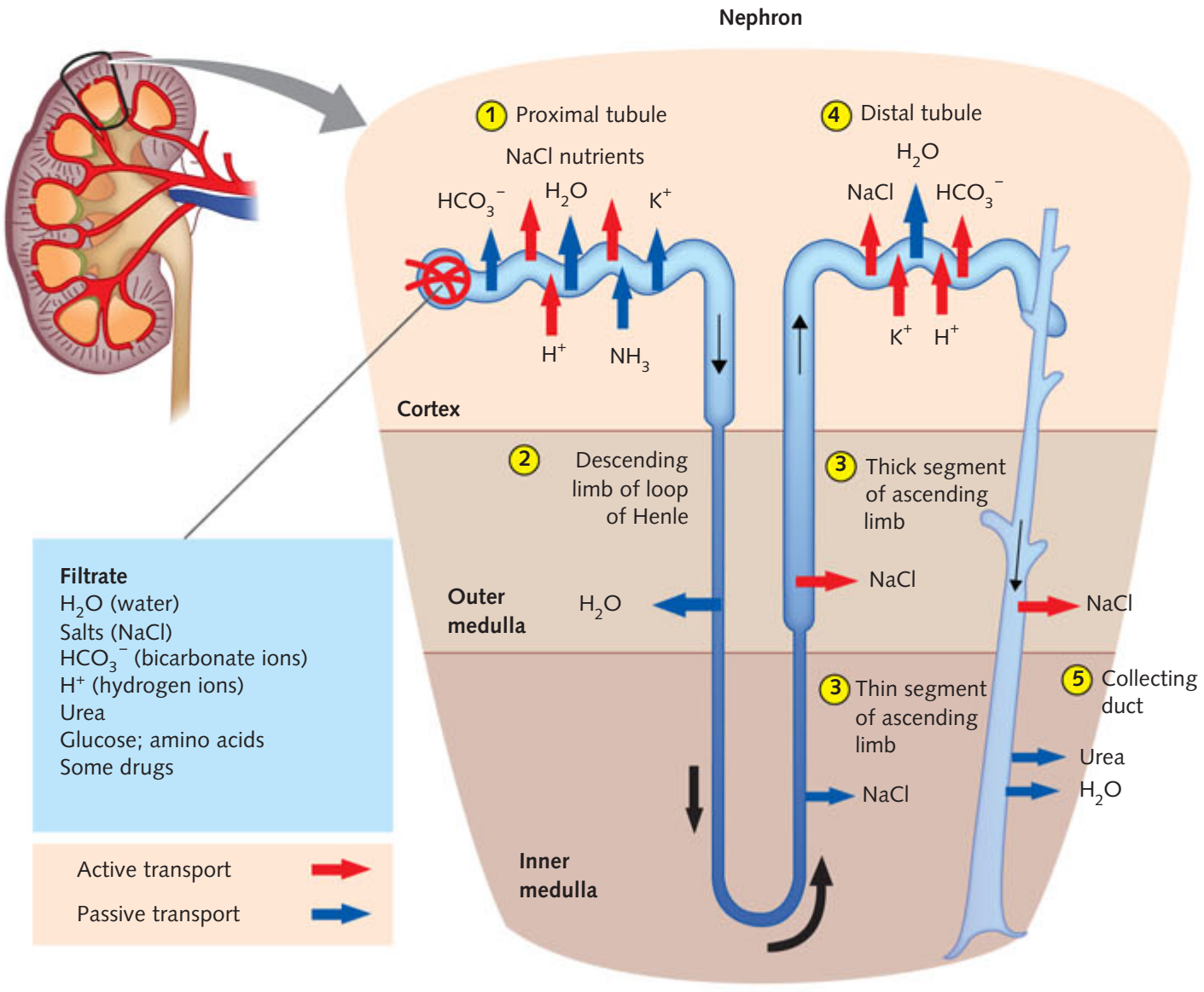


Figure 4.26 Schematic diagram of a mammalian kidney, showing the movement of water and salts in the nephron. Water is retained in the body when it is reabsorbed back into the blood in the descending portion of the loop of Henle and the collecting tubule of blood vessels and kidney tubules.

When the blood is first filtered in the kidney, water containing glucose, amino acids, salts and urea passes through from the glomerulus into the cavity of the Bowman's capsule. As this filtrate then passes along the tubules, all the glucose and amino acids are reabsorbed back into the blood because they are essential substances needed by the body. The amount of water and salts reabsorbed back into the blood is determined by the needs of the body to keep the concentration of the body fluids relatively constant. The concentration of the blood affects its osmotic pressure, which in turn determines how much water is reabsorbed. If there is a high loss of water (as on a hot day or due to intense exercise) or an increased salt intake, the water concentration of the blood will be lower and the solute concentration higher, resulting in a higher osmotic pressure. More water will be reabsorbed from the glomerular filtrate back into the blood and a smaller volume of more concentrated urine will be excreted. If there is a large intake of fluids, such as from drinking excess water, the blood will be less concentrated, resulting in lower osmotic pressure. Less water will be reabsorbed into the blood and a larger volume of dilute urine will be excreted. The differences in the volume and concentration of urine excreted will aid in keeping the concentration of the body fluids within a narrow tolerance range and closer to the optimum for maximum body functioning.

The mechanism of osmoregulation

WB 4.5.2 THE MECHANISM OF OSMOREGULATION PAGE 116

Video Osmoregulation

The change in osmotic pressure of the blood is the stimulus that will determine the amount of reabsorption that occurs, the response (Figure 4.27).

If a person loses a lot of water through sweating, or takes in an excessive amount of salt, or has not drunk any water for a while, **osmoreceptors** in the hypothalamus of the brain detect the rise in osmotic pressure of the blood. **Antidiuretic hormone (ADH)**, also known as **vasopressin** , is produced in the hypothalamus. When the osmoreceptors are stimulated, the hypothalamus sends ADH packaged in secretory vesicles through its neurons to the posterior pituitary gland, which is situated below the hypothalamus. The posterior pituitary gland releases the antidiuretic (urine-reducing) hormone into the bloodstream. The hormone is carried to the kidney, where it increases the permeability of cells lining the tubules. More water will be reabsorbed from the tubules into the blood and a smaller volume of more concentrated urine will be produced.

Urine production continues but at a reduced rate. To return the osmotic pressure of the blood to normal, more water must be taken in. A response to increased osmotic pressure is the person feeling thirsty and drinking.

Drinking a large volume of water results in the osmotic pressure of the blood falling below its optimum value. The osmoreceptors in the hypothalamus will be not be stimulated as much, so less ADH will be released from the hypothalamus, transported to the posterior pituitary gland and secreted into the bloodstream to travel to the kidneys. The response will be less water reabsorbed from the kidney tubules into the blood and a larger volume of dilute urine will be produced and excreted.

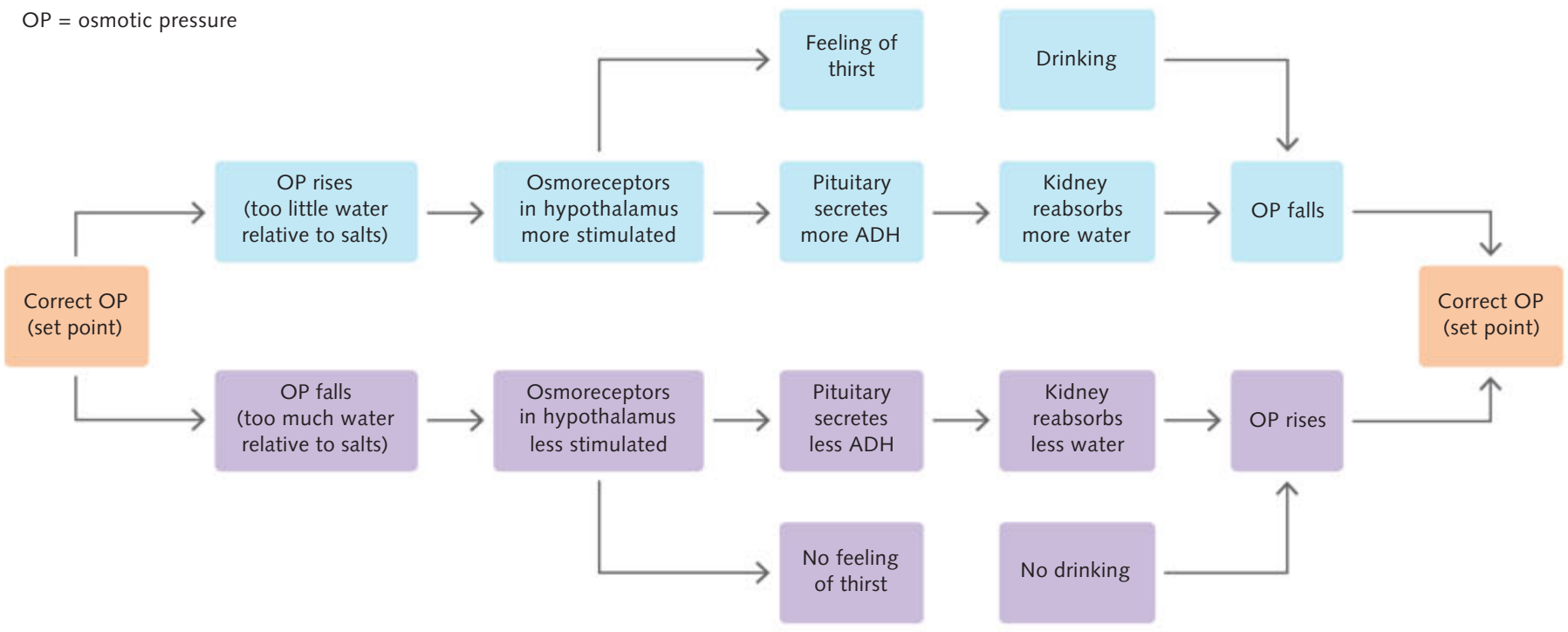


Figure 4.27 **A flow diagram summarising osmoregulation in humans**

ACTIVITY 4.1

Water balance in humans

Aim

To study water regulation in humans

What to do

Read the information in the paragraph below and Table 4.4 and answer the questions that follow.

> Antidiuretic hormone (ADH, also known as vasopressin) is a protein whose primary function is to aid retention of water in the bodies of humans. Osmoreceptors in the hypothalamus detect the variations in the concentration of blood solutes. The hypothalamus, which produced ADH and stored it, releases it for transport along its neurons to the posterior pituitary gland. The ADH is then secreted from the posterior pituitary gland into the blood and it is carried to target tissues: the distal tubules and collecting ducts of the kidneys, the sweat glands and the smooth muscles of small blood vessels, in which it causes blood vessel constriction.

Table 4.4 Factors that affect concentration of ADH

Concentration of ADH (pg mL^{-1})	Output of urine (litres per day)	Sweat gland activity	Blood pressure
0.5	15.0	High levels of sweat	Decreased
3.6	1.5	Moderate amounts of sweat	No change
4.7	0.5	Very little sweat	Increased

Questions

1. Various factors affect the secretion of ADH. Vomiting, diarrhoea, stress and cigarette smoking all cause an increase in the levels of ADH.
   - **a** What effects on urine output, sweating and blood pressure would you expect during these times?
   - **b** Describe another everyday situation that would cause the same effects.
2. What effects would high alcohol consumption have on levels of ADH and consequent body functions?
3. Relate changes in blood pressure to the action of ADH, which contracts the smooth muscle in small blood vessels.
4. Describe what happens to the ADH levels when the osmotic concentration of extracellular fluid is:
   - **a** high
   - **b** low.
5. Explain why water balance in humans is described as a negative feedback mechanism.
6. Draw a diagram of a stimulus–response model to demonstrate water balance in humans. Include the stimulus, receptor, control centre, transmission of message, effectors and response.

Water balance in other animals

WB
4.5.3
WATER BALANCE IN OTHER ANIMALS
PAGE 118

Osmoregulation is important in many other animals, both aquatic and terrestrial. There are two main groups in terms of osmoregulation: osmoconformers and osmoregulators. Osmoconformers are animals that maintain the same osmotic pressure inside their bodies as outside, either passively or actively. This includes most of the marine invertebrates, such as starfish, jellyfish and lobsters. Osmoregulators are animals that actively regulate their osmotic pressure to values different to their surrounding environment. This includes many vertebrates, including humans, other mammals, birds and marine and freshwater fish.

In freshwater fish, the concentration of their blood is higher than the surrounding water. These fish absorb a lot of water through their mouth and gills. They then produce a large volume of urine, but in so doing, they lose a lot of salt. To overcome this, they actively pump salt back into their blood through the

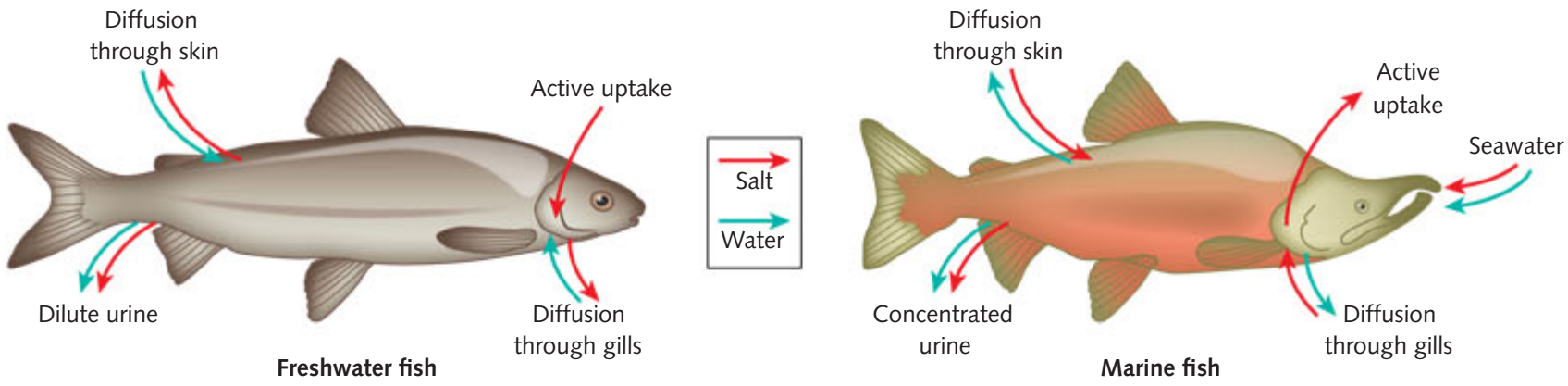


Figure 4.28 Osmoregulation in freshwater and marine fish

gills. Marine fish have the opposite problem, losing water and absorbing salt. To overcome this problem, they drink large amounts of water, urinate little and actively pump salt out of their gills (Figure 4.28).

Mammals conserve water by producing urine that is more concentrated than blood plasma. Reptiles and birds conserve water by converting ammonia to uric acid, which needs less water for excretion than urea. Insects and land snails also excrete uric acid. It is eliminated as a thick, white paste or in the form of pellets, rather than as a liquid, so that the animal retains as much water as possible.

Terrestrial animals use a variety of different methods to reduce water loss and gain water when living in air. Some live in moist or humid environments, such as bats in caves and wombats and rabbits in burrows; others have thick impermeable body coverings, such as the skin of an elephant or a rhinoceros, to reduce water loss. Desert animals must have well developed mechanisms for gaining water and reducing water loss. They not only gain water by drinking limited intermittent rain, they may lick dew off plants in the early morning, or use water produced in metabolic breakdown reactions, such as aerobic cellular respiration. To help in retaining water, they are often nocturnal or active only early in the morning or late at night when it is cooler. Other structural, physiological and behavioural adaptations that aid in water balance in animals are discussed in Chapter 9.

KEY CONCEPTS

- Osmoregulation is the process by which the osmotic pressure of the blood and tissue fluid is kept relatively constant within narrow limits.
- The kidney plays a major role in maintaining water balance by producing a large volume of dilute urine when concentration of the body fluids is lower (lower osmotic pressure). The kidney produces a smaller volume of more concentrated urine when body fluids are more concentrated (higher osmotic pressure).
- Osmoreceptors in the hypothalamus detect osmotic pressure.
- Reabsorption of water is under the control of antidiuretic hormone, which is produced in the hypothalamus. It travels in the neurons of the hypothalamus to the posterior pituitary gland, where it is secreted into the bloodstream.
- Osmoregulation also occurs in many other animals, both aquatic and terrestrial. There are two main groups in terms of osmoregulation: osmoconformers and osmoregulators.

Concept questions 4.5

1. Explain why maintaining a constant water concentration in the body is important.
2. Identify the nitrogenous waste produced in humans and explain how it is eliminated.
3. Describe the homeostatic response to high osmotic pressure in the blood.
4. Describe the homeostatic response to low osmotic pressure in the blood.
5. Humans are osmoregulators. Jellyfish are osmoconformers. What is it about their respective habitats that might go some way to explain these adaptations?

HOT Challenge

6. It's a hot day. You notice your urine is darker in colour than the day before, when the external temperature outside your house was 25°C. What is happening?

4.6 Regulation and control of basal metabolic rate and growth by thyroid hormones

WB
4.6.1 UNPACKING A SCIENCE JOURNAL ARTICLE PAGE 119

CONNECT

The thyroid gland and the hormones that it produces were discussed in the endocrine system in Chapter 3.

Thyroid hormones, often called 'thyroxines', are secreted by the thyroid gland, a butterfly-shaped organ situated in the neck close to the larynx, or voice box. Thyroxine is derived from the amino acid tyrosine and the element iodine. It affects three main physiological processes – cellular differentiation, growth and metabolism. Thyroxine has different effects in different cells and at different stages of development.

For example, thyroxine:

» increases the metabolic activities within most tissues – it is one of the main regulators of the body's basal metabolic rate
» is known to be critical for the development of the brain in foetuses and newborn babies
» has direct effects on muscle growth and bone development
» has significant effects on the cardiovascular, reproductive and central nervous systems.

As thyroxine has such far-reaching and fundamentally important effects on cells, it is important that its production is tightly regulated. It must be secreted at a constant rate so that its levels in the bloodstream are sufficient to maintain basal metabolic rates. However, there also needs to be a mechanism for the level of thyroxine to vary at certain times as the needs of the body change. This is achieved by a tightly controlled negative feedback system involving three different glands, the hypothalamus, the pituitary and the thryroid glands. This is summarised in Figure 4.29.

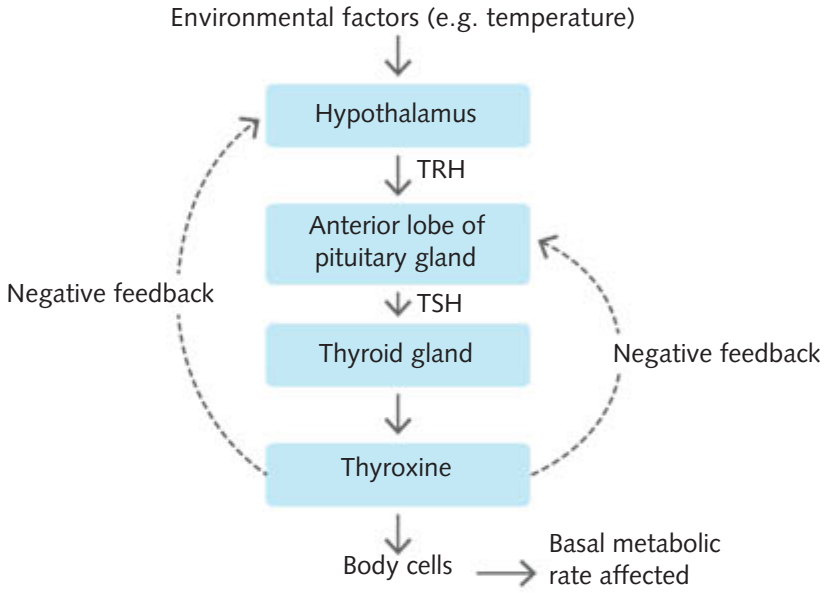


Figure 4.29 Thyroxine production is controlled through two negative feedback loops. Thyroxine inhibits the secretion of thyroid-stimulating hormone (TSH) from the pituitary gland and also the secretion of thyrotrophin-releasing hormone (TRH) from the hypothalamus.

Thyroxine synthesis and secretion is triggered by a hormone called **thyroid-stimulating hormone (TSH)** that is produced by the pituitary gland. The production of TSH is, in turn, regulated by the action of thyroxine. When there is a slight excess of thyroxine in the blood, the pituitary responds by secreting less TSH. This, in turn, signals the thyroid gland to produce less thyroxine, thus lowering the level in the blood. In response, the pituitary gland secretes more TSH and the cycle continues.

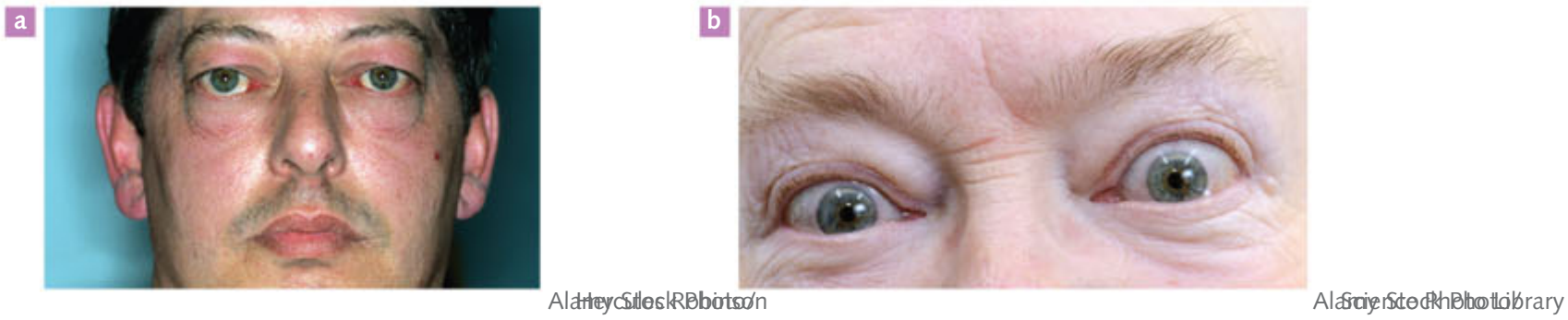
To accommodate the changing needs of the body, the secretion of TSH by the pituitary gland is regulated by the action of the hypothalamus, which is part of the brain. It secretes another hormone, **thyrotrophin-releasing hormone (TRH)**, which stimulates the production of TSH by the pituitary gland. Once thyroxine levels have reached the level required, higher levels inhibit TRH secretion, which leads to a reduction in the secretion of TSH, which then signals the thyroid to produce less thyroxine and so on.

The hypothalamus is sensitive to a number of different stimuli, such as temperature. In cold seasons it releases more TRH, signalling the pituitary to secrete more TSH, thus leading to higher levels of thyroxine and a higher metabolic rate, which helps the body to maintain a constant temperature. Similarly, its responsiveness to temperature helps in gearing growth and reproduction in animals that reproduce seasonally.

Malfunctions in the thyroid gland

Too little production and secretion of thyroxine is called **hypothyroidism** . The resulting reduced metabolism impairs physical and mental development, and in the foetus it leads to a condition called cretinism. The damage to the growing body and brain is permanent. In adults, because growth is complete, the effects of insufficient thyroxine can be reversed. Symptoms include fatigue, increased sensitivity to cold, dry skin, weight gain, puffy face (Figure 4.30a), muscle weakness and slowed mental functioning. A deficiency in thyroxine may be caused by either the thyroid gland failing to

function properly or a deficiency of iodine in the diet. In certain iodine-poor areas in the world, such as Switzerland and the Great Lakes region in the USA, iodine is added to the water or to the diet in iodised salt. If the symptoms are caused by the thyroid gland failing, the person is given daily oral tablets of synthetic thyroid hormones. Hypothyroidism is extremely common, with millions of people affected worldwide.



Alamy Stock Photo/Phanie
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Figure 4.30a **People suffering from too little thyroxine (hypothyroidism) often show puffiness around the eyes and coarsening of the skin. b Protrusion of the eyeballs (exophthalmia) is a symptom of hyperthyroidism, when the thyroid gland produces too much thyroxine.**

Alamy Stock Photo/domonabikebali

Figure 4.31 **Reduced or impaired production of thyroxine by the thyroid gland can cause it to enlarge to form a goitre.**

Production and release of too much thyroxine is called **hyperthyroidism** , resulting in a condition called exophthalmia in which the eyeballs protrude (see Figure 4.30b). More serious symptoms include greatly increased metabolic rate, leading to weight loss and accelerated, sometimes irregular, heart rate. Medication can be given to make the thyroid gland less responsive to TSH. If this is not an option, careful and precise surgery may be used to remove excess thyroid tissue or injections of radioactive iodine are given, which is taken up by the thyroid cells and kills off some of the overactive cells.

Both hypothyroidism and hyperthyroidism can cause the thyroid gland to enlarge (Figure 4.31), a condition called goitre. In hypothyroidism, if the thyroid gland cannot respond appropriately to TSH signals from the pituitary gland, the pituitary will secrete more TSH to stimulate the thyroid gland further. Eventually the thyroid gland may respond by producing more cells to try to increase thyroxine production, leading to an enlarged gland. In some forms of hyperthyroidism, there may be overgrowth of the cells that produce thyroxine. In both these scenarios, the enlarged thyroid gland can lead to problems with breathing and swallowing.

KEY CONCEPTS

- Thyroxine is produced in the thyroid gland in the neck.
- Thyroxine affects cellular differentiation, growth and metabolism.
- Levels of thyroxine in the blood are maintained at a relatively constant level through a negative feedback system.
- Too little production of thyroxine is called hypothyroidism and causes a slowing of physical and mental functioning.
- Production of too much thyroxine is called hyperthyroidism and causes accelerated metabolism.

Concept questions 4.6

1 What is meant by the basal metabolic rate?
2 Which hormone regulates the basal metabolic rate? Where is this hormone produced?
3 Thyroxine production is regulated by two feedback loops. Make separate lists of the steps in each loop.
4 Thyroid function is a good example of the pituitary gland acting as a master gland and the hypothalamus acting as its master switchboard. Explain what this means.
5 How is iodine in your diet an important input to this homeostatic regulation?

HOT Challenge

6 Some people presenting to doctors' clinics exhibiting a weight increase blame this on an 'underfunctioning thyroid' caused by a low iodine diet. Explore whether their contention could be true.

BRANCHING OUT

How many kidneys do you need to survive?

There are some interesting stories about kidneys. For example, when one person had unrelated surgery, the surgeon discovered he had three kidneys …. all functional. When another was having his appendix removed, they discovered he only had one kidney. He was 47 years old and had lived a physically active life, participating in long-distance triathalons and marathons, without being aware of his condition. Someone else was suffering from severe kidney disease and eventually had to go onto dialysis because his kidneys failed completely. The haemodialysis required four hours, three times a week, in a hospital clinic, together with some diet and fluid restrictions. This time commitment makes leading a 'normal' life impossible. Although dialysis is life-saving, doctors favour a transplant as people with transplants usually live longer than those on dialysis. The sister of this man, being closely related and a close tissue match, decided to donate one of her kidneys to him (Figure 4.32). With one functional kidney each, they have both continued to live healthy happy lives and, after 40 years, both are still alive and well.

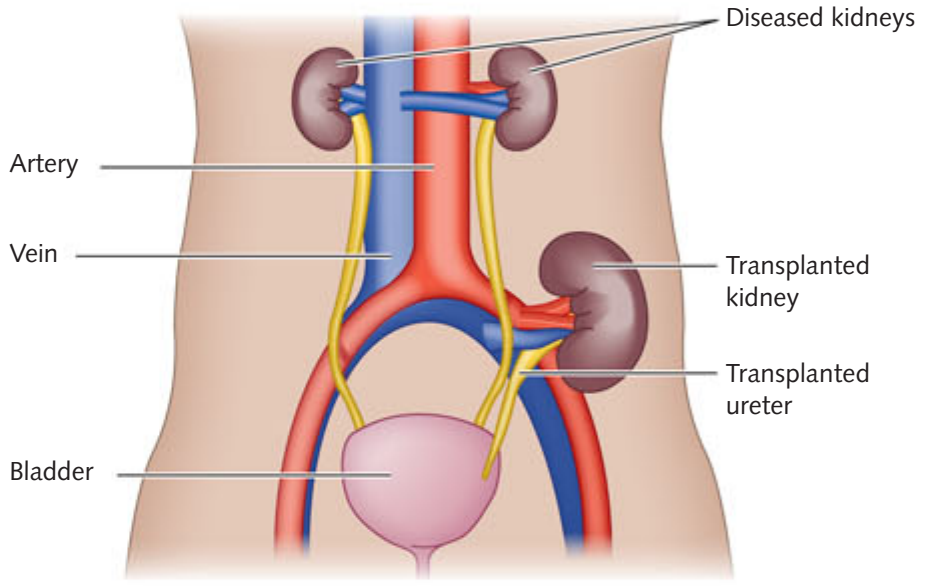

Figure 4.32 How a transplanted kidney is placed in the lower abdomen, with the joining of an artery, vein and ureter. To avoid unnecessary surgery, the diseased or malfunctioning kidneys are left in the body whenever possible.

So, how many kidneys do you need to stay alive? Obviously, one is enough. About one in every 750 people is born with a single kidney. This condition is called renal agenesis and is more common in males, with the left kidney more likely to be missing. Sometimes a kidney must be removed if there is a tumour, a blockage that cannot be cleared, or the kidney is damaged in an accident; the surgical procedure is called a nephrectomy. People who have a kidney transplant or are live donors will also only have one functional kidney.

Questions

1 Where in the body are the kidneys located?
2 What percentage of blood passes through them each time the blood circulates?
3 Why are they vitally important organs in the human body?

When there is only one functioning kidney, it gets larger and heavier and works harder, providing up to 75% of normal kidney function. Some people experience a slight drop in kidney functioning later in life if born with one kidney. Most people who have one kidney removed have no adverse effects and can live a complete life span.

Regular testing by a doctor should be carried out on a person with one kidney. There are three major tests.

- Blood test for glomerular filtration rate (eGFR)
- Urine test for protein in the urine
- Blood pressure (Figure 4.33)

The kidneys help to control blood pressure because they help to regulate blood solute concentration. If changes are detected, medication or lifestyle changes can slow any decrease in kidney function.

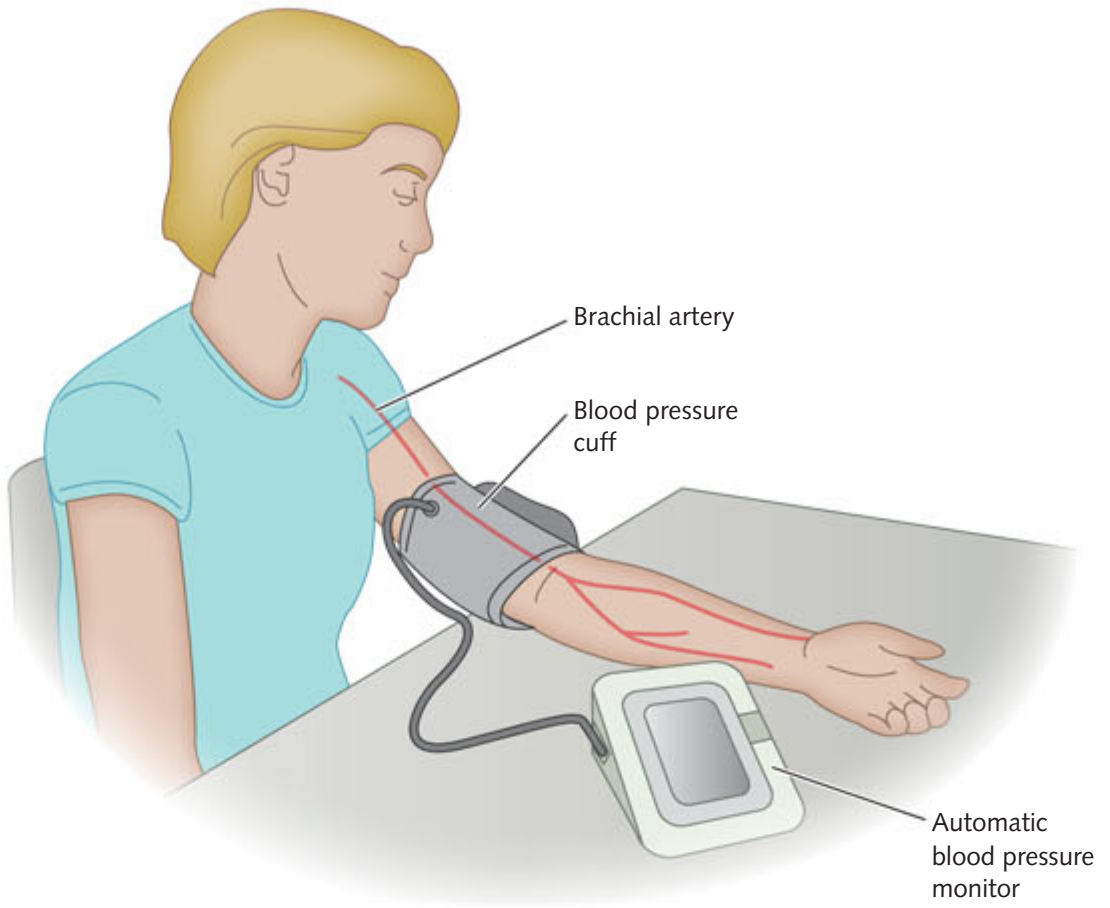

Figure 4.33 **Measuring blood pressure of a kidney recipient regularly is important because uncontrolled high blood pressure can damage the arteries around the kidney, reducing the volume of blood delivered to the kidney and thereby affecting its efficiency. Blood pressure is measured using an inflatable cuff around the upper arm attached to an electronic blood pressure monitor.**

Questions

4 **a** Identify the specific location where glomerular filtration occurs.

b What would the blood test results indicate about the amount of wastes, such as urea, in the blood?

c Predict what the eGFR of a person with one kidney would be like compared with a person with two kidneys.

5 **a** Why is it necessary to test for protein in the urine?

b What should the result be for a person with one kidney, if it is operating efficiently?

6 Suggest how each of the following lifestyle factors could be modified for it to be a healthy choice for a person with one kidney.

a Salt intake

b Physical exercise

c Lifestyle stress

d Body weight

e Alcohol consumption

Kidney transplants from living donors now make up around three out of every ten kidney transplants in Australia each year.

Living donors can be:

- related: a relative (parent, brother, sister or adult children), related by blood to the recipient
- unrelated but known to the recipient: partner, non-blood relative or friend of the recipient
- non-directed kidney donation or altruistic: someone anonymously donates a kidney to a recipient on the transplant waiting list. In this situation the living donor has no say in who receives their kidney.

Although age is not usually considered when matching kidney donors with recipients, research has demonstrated that matching donors and recipients by age would optimise the potential lifetime of a transplanted kidney. Matching young kidneys to young recipients could extend the life of the person by two and a half years. With the demand for donor kidneys in excess of supply, this would avoid giving optimal young kidneys to recipients who die long before the kidney would stop functioning.

There are certain requirements that a kidney donor must meet. Not everyone is able to be a living kidney donor. Conditions that may prevent a person from being a donor include:

- diabetes, or an increased risk of developing diabetes in the future
- high blood pressure
- heart, stroke or breathing problems
- being overweight or underweight
- smoking
- other conditions such as cancer, AIDS, hepatitis and psychological issues.

Question

7 Identify the three sources of living kidney donors and discuss the limitations of transplants from each group.

The Australian and New Zealand Paired Kidney Exchange Program

This scheme, also known as the ANZKX Program, is a joint initiative of the Australian Government's Organ and Tissue Authority and its New Zealand counterpart to increase the options for living kidney donation. The program helps people seeking a kidney transplant whose potential living donor is unsuitable due to blood group and/or tissue incompatibility.

A computer program is used to search the database of registered recipient/donor pairs and look for combinations where the donor in an incompatible pair can be matched to a recipient in another pair. If a compatible match is established, by exchanging donors two or more simultaneous transplants can occur. This option is known as paired kidney exchange, or paired kidney donation.

Issues for kidney transplant recipients and living donors

Even though most living kidney donor candidates appear in good mental health and show few concerns, little is known concerning the influence of the type of donor–recipient relationship on donor candidates' specific concerns regarding kidney donation. A study at Virgen del Rocío University Hospital of Seville asked 136 donor candidates to fill in a questionnaire on the concerns regarding living kidney donation; the mental health and quality of life of 105 donor candidates and their corresponding recipients were further evaluated. As had been hypothesised, recipients of kidneys scored higher on depression and lower on quality of life. Donor candidates intending to donate to their children were significantly less concerned about risks of donation for themselves than were donor candidates donating to siblings. These findings highlighted the importance of the type of donor–recipient relationship to understand the concerns of potential donors and make sure that they are supported both psychologically and socially after the donation. Parents' lack of concern about their own well-being after donating a kidney to one of their children can be considered from an evolutionary perspective – they are giving up their own health to increase their offspring's chance at survival.

Questions

8 Identify the issues regarding both the donor's and recipient's concerns, mental health and quality of life, for the living donor groups in which they were they were related, unrelated or parent–child.

9 Discuss issues that may arise when anonymous living donors donate a kidney to an unknown person on a waiting list.

Sources

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Pérez-San-Gregorio, M. A., Martin-Rodríguez, A., Luque-Budia, A. & Conrad, R. (2017). Concerns, mental health, and quality of life in living kidney donation–parent donor candidates worry less about themselves. *Frontiers in Psychology*, 11 April. https://www.frontiersin.org/articles/10.3389/fpsyg.2017.00564/full. https://doi.org/10.3389/fpsyg.2017.00564

Online Key Concepts
Chapter 4 summary of key concepts

4 Summary of key concepts

4.1 Regulation of water balance in vascular plants

KEY CONCEPTS

p. 135

- Water balance in vascular plants involves water uptake through the root system and water loss through the stems and, mainly, the leaves of the shoot system.
- For their cells to function efficiently, vascular plants have features that help them to obtain water, retain adequate water, and reduce water loss if necessary.
- If a plant loses more water through transpiration than it takes up through its roots, it wilts and is said to suffer from water stress.
- Movement of water by osmosis into and out of the guard cells, controls the opening and closing of the stomata.

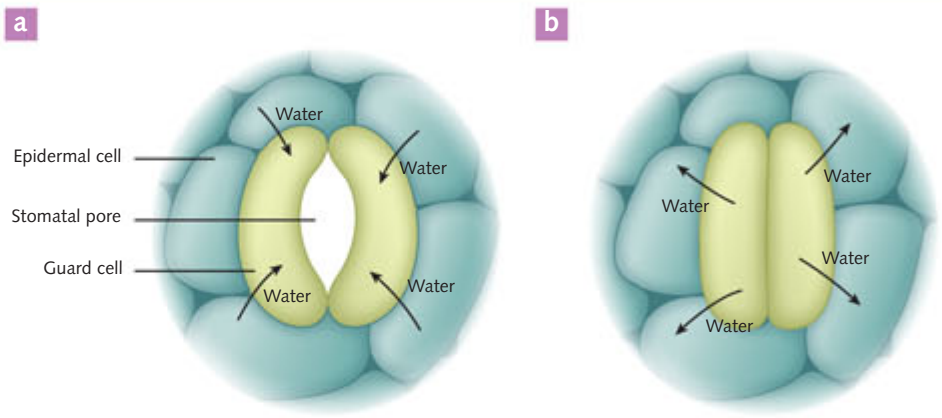


Figure 4.3 Guard cells control the opening and closing of the stomata, in turn controlling water loss from a plant. **a** Open stoma with turgid guard cells **b** Closed stoma with flaccid guard cells

4.2 Human survival in a range of environments

KEY CONCEPTS

p. 137

- The bodies of organisms must regulate their internal environments within narrow limits for survival. These are known as tolerance limits.
- Each organism has an optimum range in which it functions best; outside this range is the zone of physiological stress.
- The stimulus–response model involves a stimulus detected by a receptor, then transmission of the message via nerves or hormones, to an effector that carries out a response.
- Organisms detect signals through interoceptors (internal signals) and exteroceptors (external signals).
- Homeostasis is the maintenance of a relatively constant internal environment within narrow limits, despite changes in the external and internal environments.
- A negative feedback mechanism is a system of control in which, when a change is detected in a variable, a response occurs to counteract or reverse the stimulus; that is, an action occurs to produce a change the opposite direction, thereby maintaining a relatively constant internal environment.

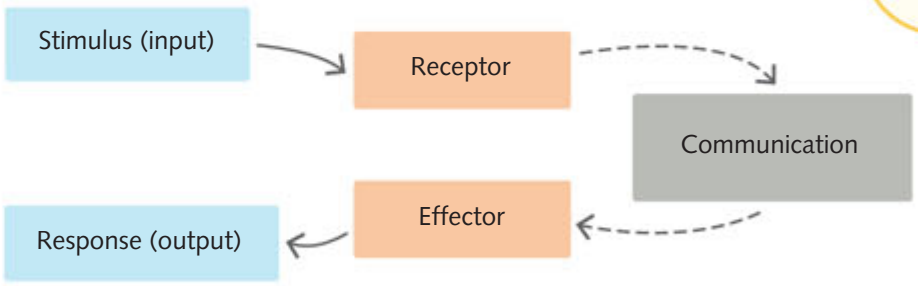


Figure 4.7 The stimulus–response model relies on the transfer of information between the receptor and effector.

4.3 Temperature regulation in the human body

KEY CONCEPTS

p. 144

- Thermoregulation is essential for an organism's survival. Heat energy can be lost or gained in the following four ways: conduction, convection, evaporation and radiation.
- Physiological mechanisms in the human body to reduce body temperature include vasodilation, sweating and lowering metabolic activity.
- Structural and behavioural adaptions to keep cool include larger surface area compared to body mass in shape and size, removal of clothing and moving out of the heat.
- The hypothalamus detects internal body temperature and initiates appropriate responses.
- Physiological mechanisms humans have to keep warm include vasoconstriction, shivering and increasing metabolic activity.
- Structural and behavioural adaptions to keep warm include brown fat, body shape and size, adding clothing and moving out of the cold.
- Animals other than humans also regulate their body temperature with physiological mechanisms and changes in their behaviour.
- Hypothermia results after prolonged exposure to low temperatures and hyperthermia results after a prolonged period of elevated body temperature.

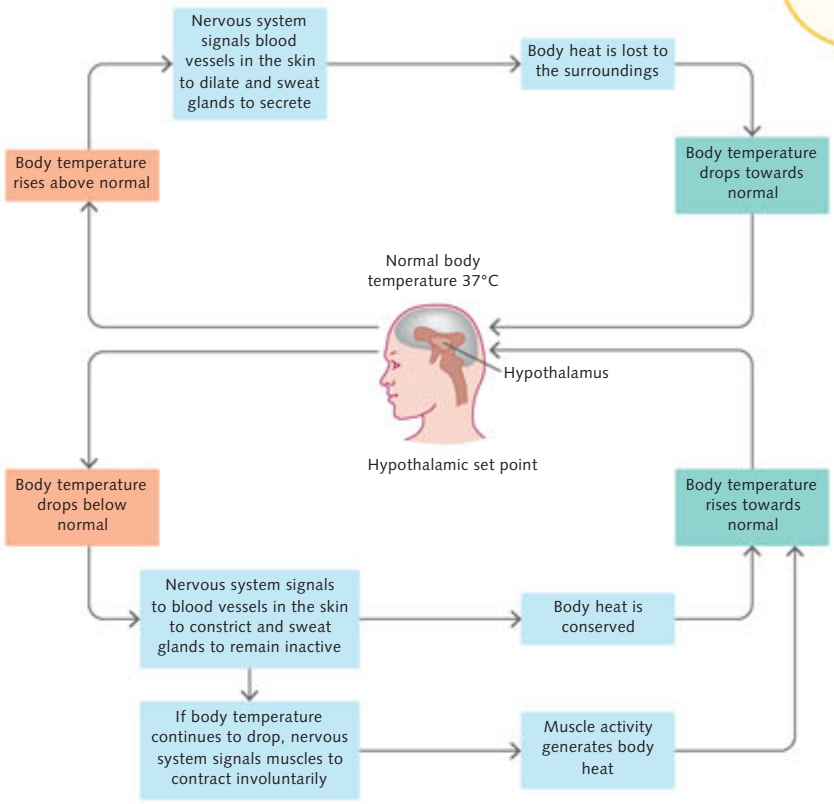


Figure 4.14 Homeostasis and temperature control

4.4 Regulation of blood glucose levels

KEY CONCEPTS

p. 155

- Blood glucose regulation is an example of homeostasis involving negative feedback mechanisms to maintain a relatively constant blood glucose level within narrow limits.
- A rise in blood glucose level stimulates the secretion of insulin from beta cells in the islets of Langerhans in the pancreas. Insulin causes a reduction in blood glucose levels.
- A drop in blood glucose levels stimulates alpha cells in the islets of Langerhans to secrete glucagon. The effect of glucagon is a rise in blood glucose levels.
- Type 1 diabetes results from the inability of beta cells in the pancreas to produce enough insulin.
- There is no known cause or cure for type 1 diabetes.
- Treatment of type 1 diabetes includes monitoring of blood glucose levels and insulin injections.

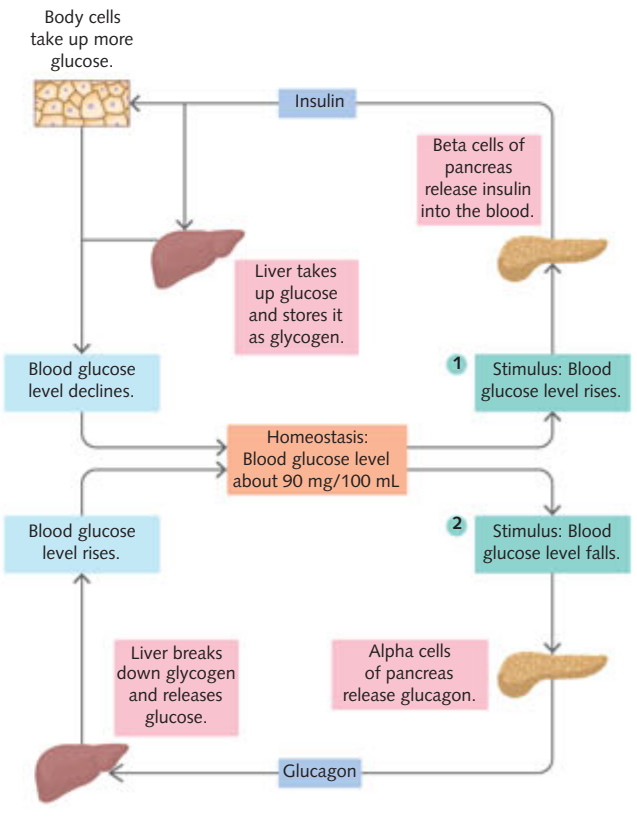


Figure 4.25 Homeostatic regulation of blood glucose in humans

4.5 Water balance regulation

KEY CONCEPTS

p. 159

- Osmoregulation is the process by which the osmotic pressure of the blood and tissue fluid is kept relatively constant within narrow limits.
- The kidney plays a major role in maintaining water balance by producing a large volume of dilute urine when concentration of the body fluids is lower (lower osmotic pressure). The kidney produces a smaller volume of more concentrated urine when body fluids are more concentrated (higher osmotic pressure).
- Osmoreceptors in the hypothalamus detect osmotic pressure.
- Reabsorption of water is under the control of antidiuretic hormone, which is produced in the hypothalamus. It travels in the neurons of the hypothalamus to the posterior pituitary gland, where it is secreted into the bloodstream.
- Osmoregulation also occurs in many other animals, both aquatic and terrestrial. There are two main groups in terms of osmoregulation: osmoconformers and osmoregulators.

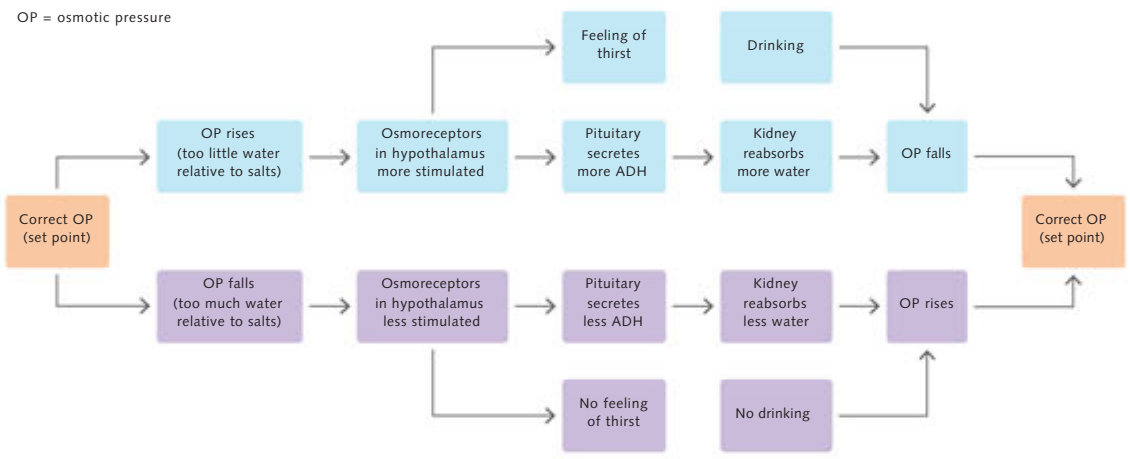


Figure 4.27 A flow diagram summarising osmoregulation in humans

4.6 Regulation and control of basal metabolic rate and growth by thyroid hormones

KEY CONCEPTS

p. 163

- Thyroxine is produced in the thyroid gland in the neck.
- Thyroxine affects cellular differentiation, growth and metabolism.
- Levels of thyroxine in the blood are maintained at a relatively constant level through a negative feedback system.
- Too little production of thyroxine is called hypothyroidism and causes a slowing of physical and mental functioning.
- Production of too much thyroxine is called hyperthyroidism and causes accelerated metabolism.

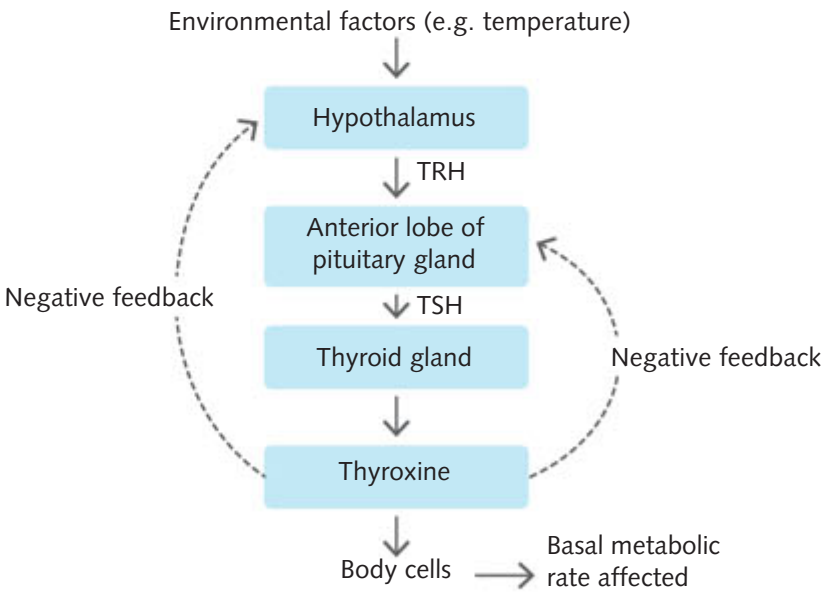


Figure 4.29 Thyroxine production is controlled through two negative feedback loops. Thyroxine inhibits the secretion of thyroid-stimulating hormone (TSH) from the pituitary gland and also the secretion of thyrotrophin-releasing hormone (TRH) from the hypothalamus.

4.7.1
KEY TERMS
PAGE 121

4 Chapter glossary

antidiuretic hormone (ADH) a hormone that regulates water reabsorption in the collecting tubules in the kidneys

arrector pili muscle a small muscle attached to a hair follicle that contracts to raise the hair

brown fat a type of fat involved in the rapid production of heat, especially in babies

conduction the transfer of heat energy from a relatively hot object to a relatively cool object by direct contact

convection the transfer of heat by means of rising currents of warm air or liquid

effector an organ, tissue or cell that acts in response to a stimulus

endothermic describes an organism that maintains a relatively constant internal temperature

evaporation the process in which liquid water changes to water vapour by gaining heat

exteroceptor a receptor that receives signals from the external environment

feedback mechanism a mechanism in which the output or response affects the input or stimulus

glucagon a hormone formed in the pancreas by the alpha cells in the islets of Langerhans that promotes the breakdown of stored glycogen to glucose in the liver and muscles

glycogen an energy-storing carbohydrate in animals, usually in the liver and muscles

heat balance a balance between heat gain and heat loss

homeostasis the maintenance of a relatively constant internal environment within narrow limits, despite changes in the external environment

hyperglycaemia a condition in which a person has elevated blood glucose levels above the set point

hyperthermia a state in which the internal temperature rises above the set point

hyperthyroidism a state in which there is an excess of thyroxine produced by the thyroid gland

hypoglycaemia a state in which the blood glucose level drops below the set point

hypothalamus a small region located at the base of the brain that plays a crucial role in releasing hormones, temperature control and water balance

hypothermia a state in which the internal temperature falls below the set point

hypothyroidism a state in which there is too little thyroxine in the body

insulin a hormone produced in the pancreas by the beta cells in the islets of Langerhans; it increases glucose absorption into cells from the blood

interoceptor a receptor that receives signals from the internal environment

interstitial fluid fluid that lies in the spaces between cells; also known as extracellular or tissue fluid

negative feedback a response to a stimulus that counteracts the stimulus and reverses the direction of the change

optimum range the narrow range within the tolerance range for a specific factor at which the organism functions best

osmoreceptor a receptor that responds to changes in the osmotic pressure of the blood

osmoregulation processes by which internal water and solute concentrations are maintained at relatively constant values, despite fluctuations in the external environment

physiological stress impact on physiological functioning caused when an organism experiences external and internal environmental conditions outside its tolerance range

radiation the transfer of heat from a hot object by infrared waves

response structural, behavioural or physiological action that results from a stimulus

set point optimal level

stimulus (plural: stimuli) a signal that causes a response

stimulus–response model a model that explains how the cells and organ systems of the human body respond to changes in the external and internal environments

thermoregulation temperature regulation

thyroid-stimulating hormone (TSH) a hormone produced by the pituitary gland that triggers thyroxine synthesis and secretion

thyrotrophin-releasing hormone (TRH) a hormone produced by the pituitary gland that stimulates the production of TSH

thyroxine a hormone produced in the thyroid gland in the neck, important in three main physiological processes – cellular differentiation, growth and metabolism

tolerance range the range of external and internal environmental conditions within which an organism can function efficiently

vasoconstriction a decrease in the diameter (narrowing) of blood vessels, particularly arterioles, to decrease blood flow near the skin surface to reduce heat loss

vasodilation the widening of blood vessels, particularly arterioles, to increase blood flow near the skin surface and allow increased heat loss

vasopressin a specific name for an antidiuretic hormone (ADH) responsible for increased permeability of the distal tubules of the kidney, increasing water reabsorption and reducing urine volume

water potential the capacity of water to do work based on the kinetic energy of its individual molecules; the work is done as water moves across selectively permeable membranes due to osmosis

WB
4.7.2
PRACTICE TEST
QUESTIONS
PAGE 122

4 Chapter review

Remembering

1 Draw a diagram of an animal cell. On it, label the intracellular fluid and the extracellular fluid.
2 What are the components of the internal environment? Why do scientists consider that the internal environment does not contain cells?
3 List six factors (variables) that can be measured from the internal environment of a human.
4 List three factors or variables that can be measured from the internal environment of a plant.
5 Name three organs of the body involved in homeostasis and briefly explain what they do.
6 Draw a flow chart demonstrating a stimulus–response mechanism.
7 Using an example, explain the principle of negative feedback.
8 Distinguish between hyperthyroidism and hypothyroidism.
9 Discuss the processes that a plant has to balance in order to maintain proper functioning while conserving water.
10 List the main functions of the hypothalamus that relate to homeostatic functioning.
11 Brown fat is a term given to tissue that is known to carry out large amounts of cellular respiration. It is found in higher concentrations in babies than in adults.
   a What is brown fat?
   b Why might babies have higher concentrations than adults?
   c What is the main energy molecule that would be synthesised in this type of tissue?

Understanding

12 Refer to Figure 4.27 (p. 156) and identify the stimuli, receptor, processing centre, messenger, effector and responses.
13 Homeostasis is the maintenance of a relatively stable internal environment necessary for survival. Name a factor that is under homeostatic control and explain why it must be regulated.
14 Draw a table to summarise examples of structural, physiological and behavioural adaptations to regulate temperature in a mammal.

Applying

15 Compare the stimulus–response model with the negative feedback model of regulation. Use annotated diagrams in your answer. Give one named example of each kind of regulation.
16 Explain how body shape aids thermoregulation.
17 Humans are able to survive and thrive in a range of extreme environments. Construct a table that compares structural, physiological and behavioural adaptations that humans exhibit to thermoregulate in extreme hot and extreme cold conditions.
18 Explain why we should not ignore the feeling of thirst.

19 Refer to the example of Mark Dorrity who became seriously ill after his homeostatic cooling mechanisms did not function adequately when he went for a run on a very hot day. Consider in more detail the mechanisms involved in heat regulation and water balance.
   a Describe and explain how Mark's body temperature would be regulated under normal conditions. Why was Mark's regulatory mechanism not able to cope with the extreme conditions experienced? Include labelled diagrams to support your answer.
   b Explain the causes of Mark's blood thickening. What would be the effects of this thickening?
   c Describe the mechanism by which water balance is normally maintained in humans. Include diagrams to support your answer.

Analysing

20 Imagine you are crossing a road while a car is travelling along it towards you. Draw a stimulus–response model to illustrate what happens. Decide whether this is an example of homeostasis, giving reasons for your decision.

21 Predict the effect on the quantity and composition of a person's urine of:
   a drinking a large amount of water
   b eating a very salty meal.

22 Explain the effect on the body's homeostatic processes of removing the pancreas.

Evaluating

23 Two men ate an identical meal and their blood glucose levels were recorded over a 5-hour period. The results are shown in Figure 4.34. Identify which individual's blood glucose was under homeostatic control. Justify your answer.

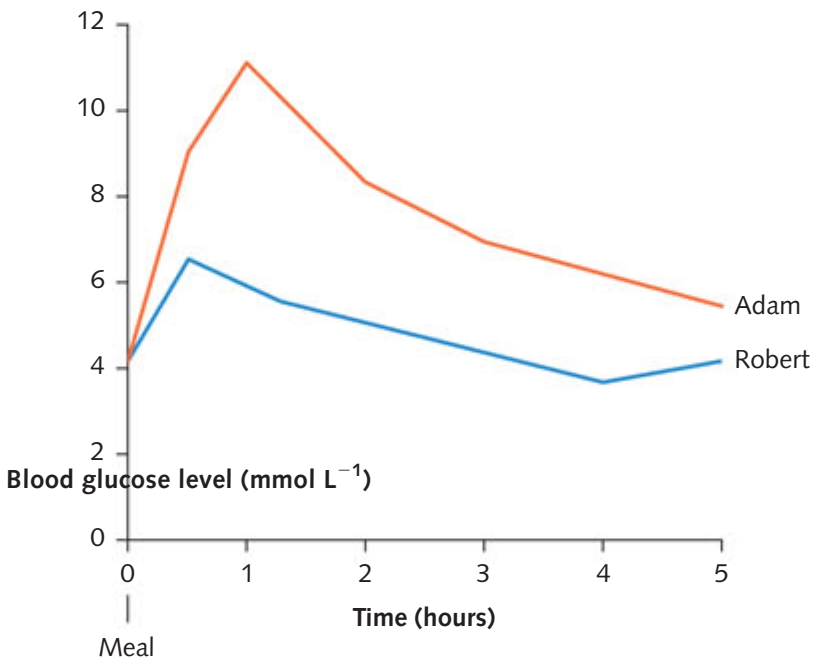


Figure 4.34 Blood glucose levels in the blood of two men over a 5-hour period

Creating

24 Humans must wear clothes in the depths of winter in order to survive, while other organisms do not. Propose some design modifications to the human body that would allow us to survive months of freezing temperatures without clothing.

Unit 1, Area of Study 2 review

Multiple choice

Question 1 In multicellular plants, an example of an organ is a:
- A leaf.
- B stomata cell.
- C tracheid.
- D shoot.

Question 2 Chemical digestion begins in the:
- A stomach.
- B small intestine.
- C mouth.
- D large intestine.

Question 3 Ringbarking a tree will kill it as a result of:
- A damage to the xylem preventing water reaching the leaves.
- B damage to the phloem preventing sugars reaching the roots.
- C damage to the bark making the tree vulnerable to dehydration.
- D mineral ions no longer being able to be transported through the tree.

Question 4 A person is dehydrated. What is the expected change in their urine?
- A More urine, dark in colour
- B Less urine, dark in colour
- C More urine, light in colour
- D Less urine, light in colour

Question 5 A plant is losing water from its tissues on a hot windy day. A response to prevent further water loss could be to:
- A stop photosynthesising.
- B increase water uptake from roots.
- C close its stomata.
- D open its stomata.

Question 6 Translocation:
- A is the movement of water in plants.
- B requires energy.
- C occurs in one direction only.
- D is driven by the evaporation of water from the leaves.

Question 7 Which one of the following is an example of chemical digestion?
- A Chewing food
- B Action of bile
- C Action of pepsin
- D Absorption of glucose

Question 8 Villi in the small intestine:
- A aid in the movement of food along the small intestine.
- B secrete digestive enzymes to assist in the digestion of protein.
- C increase the surface area available for absorption.
- D trap pathogens.

Question 9 During a dissection of an animal's kidney it was discovered to have a very long loop of Henle. Which one of the following could you conclude about this animal?
- A This animal produces lots of urine.
- B This animal probably lives in a wetlands environment.
- C This animal produces small volumes of very concentrated urine.
- D This animal produces small volumes of very dilute urine.

Question 10 ©VCAA 2004 E1 SEC. A Q20 ADAPTED MEDIUM

Cats that have not been fed for 2 to 3 days are able to maintain a constant blood glucose concentration. After 24 hours without food, glucose is still being released into the cat's blood. The molecule that is stimulating the release of glucose is:
- A glycogen.
- B insulin.
- C amylase.
- D glucagon.

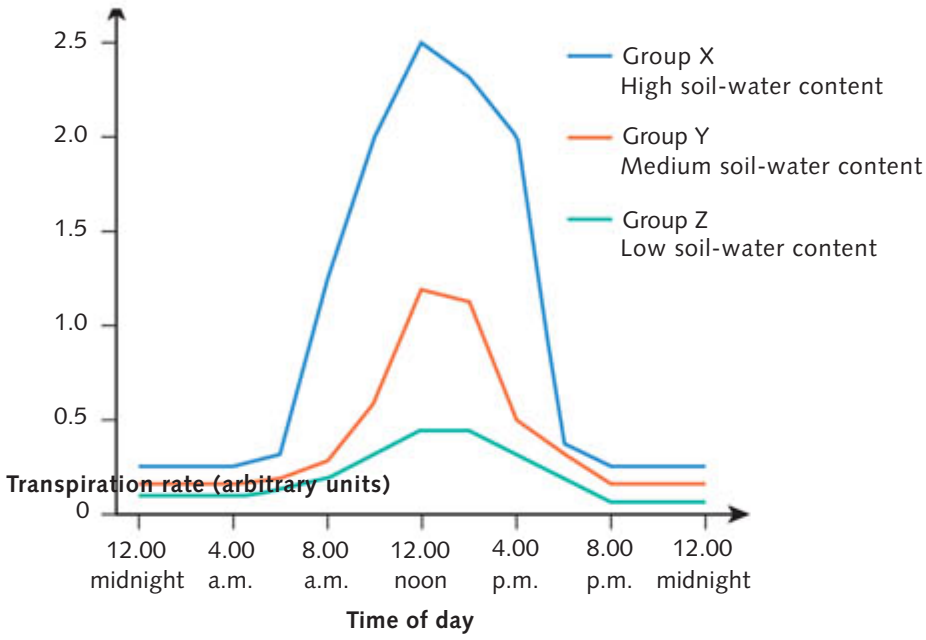
Question 11 ©VCAA 2011 E1 SEC. A Q1 ADAPTED EASY

Which one of the following is a homeostatic mechanism?
- A The Arctic hare changes coat colour from white in winter to brown in summer.
- B Your pupil dilates in low light.
- C The shoot of a oat seedling grows towards the light.
- D Shivering occurs after you have been swimming.

Question 12 ©VCAA 2004 E1 SEC. A Q12 ADAPTED **MEDIUM**

Transpiration rate was measured in the bean, *Phaseolus vulgaris*. Three identical groups were tested. In group X the soil moisture was high, in group Y it was medium and in group Z it was low.

The graph below shows the results of the experiment.



It is reasonable to conclude that:

A no photosynthesis was occurring between 8.00 a.m. and 4.00 p.m. in group Z.

B at 12.00 noon, water loss in group X was three times greater than water loss in group Y.

C no water was lost between 8.00 p.m. and 12.00 midnight in group Z.

D the rate of water loss through the stomata was least in group Z.

Question 13 Which one of these processes contributes to the movement of water through a plant due to the loss of water at the leaf surface?

A Evaporation

B Transpiration

C Translocation

D Respiration

Question 14 Name the structure through which the greatest amount of water is lost in most plants.

A Guard cells

B Epidermis

C Parenchyma

D Stomata

Question 15 When osmoreceptors in the hypothalamus detect a fall in osmotic pressure of the blood, the following response occurs.

A The posterior pituitary gland secretes more antidiuretic hormone.

B The permeability of the tubules in the kidneys is decreased.

C Small volumes of concentrated urine are produced.

D The person will feel thirsty.

Question 16 Which of the following is a behavioural adaptation employed by mammals to maintain constant body temperature?

A Shivering

B Sweating

C Sitting in the shade

D A fat layer under the skin

Short answer

Question 1

©VCAA 2010 E1 SEC. B Q1 ADAPTED

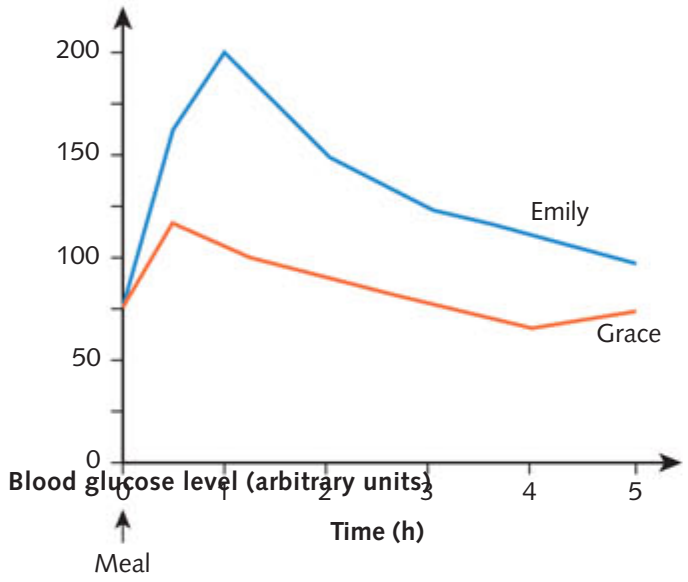
©VCAA 2012 E1 SEC. B Q6 ADAPTED

Blood glucose levels are controlled by a homeostatic mechanism.

a What is homeostasis?

2 marks

Two females of the same age and similar body structure were each given an identical meal. The following graph shows the level of blood glucose in each female for the 5-hour period after eating the meal.



b What causes the drop in blood glucose level for Grace from 30 minutes after the meal?

1 mark

c Explain the cause of differences between Emily's blood glucose levels and Grace's blood glucose levels.

2 marks

d In which graph is the action of glucagon evident? Use data from the graph to support your answer.

2 marks

e Many human regulating systems are based on negative feedback. Can the series of events occurring in Grace's body in relation to blood glucose levels be classified as a negative feedback system? Explain.

2 marks

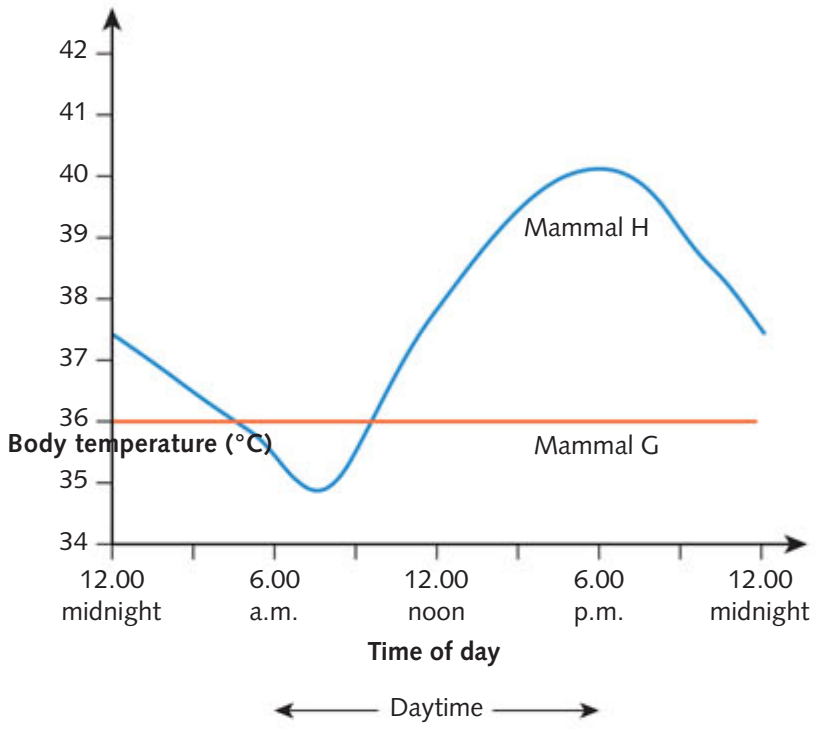
f State another variable other than blood glucose that is under homeostatic control in a mammal. Explain why the homeostatic control of this variable is essential for survival.

2 marks

Question 2

©VCAA 2005 E1 SEC. A Q23 ADAPTED

Over a 24-hour period, the average daytime temperature was 40°C and average night-time temperature was 20°C. The body temperatures of two different mammals were recorded over these 24 hours as shown in the graph below.



a Explain what could be causing the rise in body temperature of mammal H at 12.00 noon.

1 mark

b Describe a physiological process that is helping in maintaining mammal G's body temperature at 36°C even when the average daytime temperature is 40°C.

1 mark

c What advantage could there be for mammal H to have the body temperature pattern shown in the graph?

1 mark

Scientific investigations

5

By the end of this chapter you will have covered the following material.

Key knowledge

Investigation design

» biological science concepts specific to the selected scientific investigation and their significance, including the definition of key terms pp. 180–202

» scientific methodology relevant to the selected scientific investigation, selected from: classification and identification; controlled experiment; correlational study; fieldwork; modelling; product, process or system development; or simulation pp. 185–194

» techniques of primary qualitative and quantitative data generation relevant to the investigation pp. 194–195; 203

» accuracy, precision, reproducibility, repeatability and validity of measurements in relation to the investigation pp. 197–199

» health, safety and ethical guidelines relevant to the selected scientific investigation pp. 200–202

Scientific evidence

» the distinction between an aim, a hypothesis, a model, a theory and a law pp. 195–196

» observations and investigations that are consistent with, or challenge, current scientific models or theories pp. 92–93

» the characteristics of primary data pp. 196–198

» ways of organising, analysing, and evaluating generated primary data to identify patterns and relationships including sources of error pp. 198; 203–207

» use of a logbook to authenticate generated primary data p. 182

» the limitations of investigation methodologies and methods, and of data generation and/or analysis pp. 185–194; 203–207

Science communication

» the conventions of scientific report writing including scientific terminology and representations, standard abbreviations and units of measurement pp. 196–197; 208–211

» ways of presenting key findings and implications of the selected scientific investigation pp. 211–212

Online Chapter Map
Chapter 5 map

5 Scientific investigations

Unit 1 Outcome 3 invites you to work like a scientist. You are to undertake a student-adapted or student-designed investigation and present a report using a selected format. But you need to know how science works. Check the study design for full details on what you need to do.

5.1 Choosing your topic p. 181

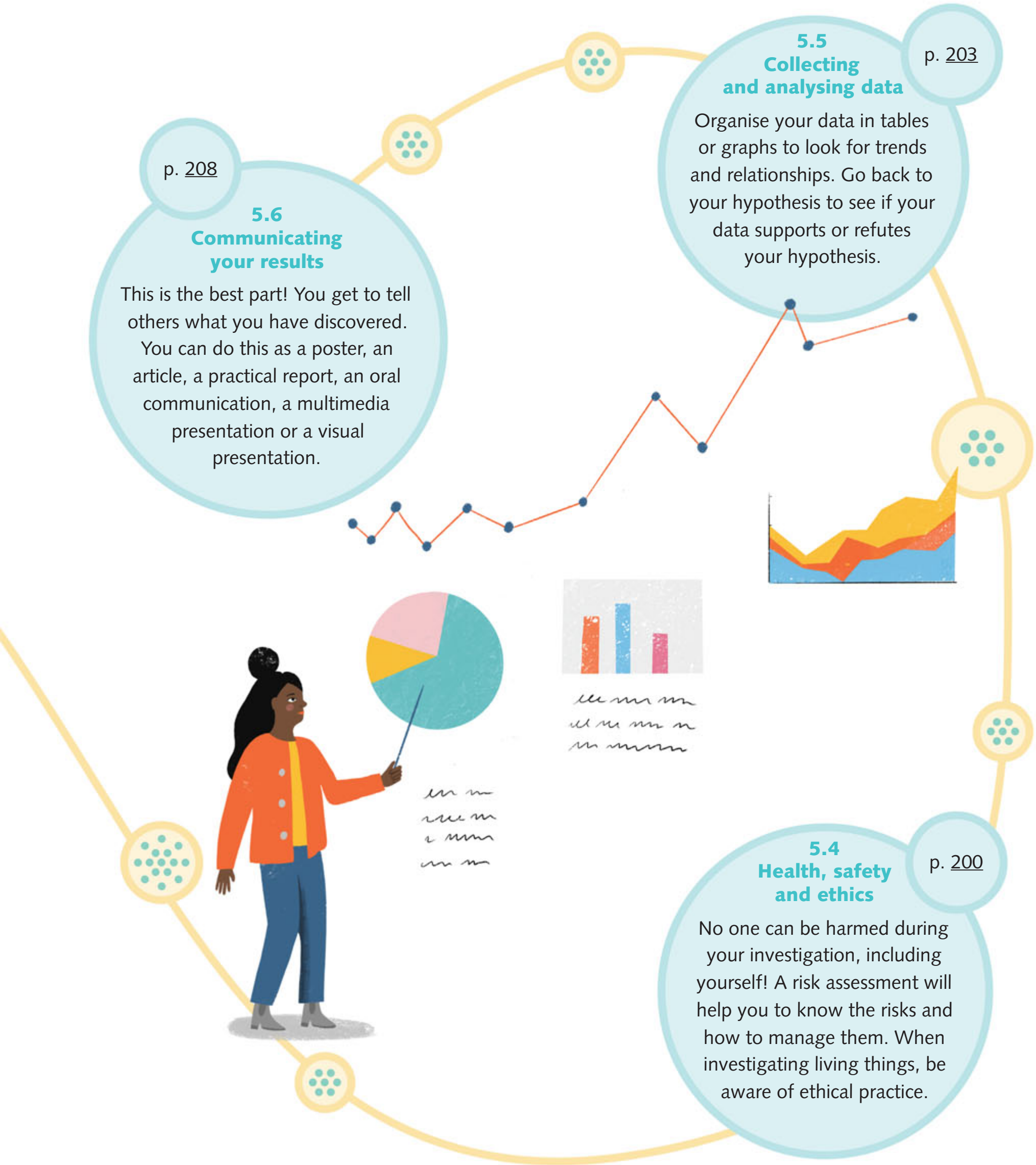
Choose a topic that you are interested in. Use a logbook to record all the details of your investigation. Work out a research question and do background reading to narrow down what to investigate.

5.2 Types of scientific methodology p. 185

Decide which type of scientific methodology would work best to answer your research question. There are lots to consider, so read each carefully before choosing.

5.3 Quantitative and qualitative data p. 194

What is your hypothesis? What data will you collect to test your hypothesis? How will you collect data? How will you avoid errors in your data? How will you record the data? How will you analyse the data? So many questions to answer!



5.5 Collecting and analysing data p. 203

Organise your data in tables or graphs to look for trends and relationships. Go back to your hypothesis to see if your data supports or refutes your hypothesis.

5.6 Communicating your results p. 208

This is the best part! You get to tell others what you have discovered. You can do this as a poster, an article, a practical report, an oral communication, a multimedia presentation or a visual presentation.

5.4 Health, safety and ethics p. 200

No one can be harmed during your investigation, including yourself! A risk assessment will help you to know the risks and how to manage them. When investigating living things, be aware of ethical practice.

Well done you for adding to the wealth of human knowledge by undertaking a scientific investigation!

To access resources below, visit www.nelsonnet.com.au

Online Chapter Map:
- Chapter 5 map (p. 178)

Online Key Terms:
- Chapter 5 flashcards (p. 180)

Weblinks:
- APA style guide (p. 183)
- Harvard system (p. 183)
- CSIRO (p. 184)
- Australia Academy of Science (p. 184)
- CRAAP test (p. 184)
- Sterile technique (p. 200)

Online Key Concepts:
- Chapter 5 summary of key concepts (p. 214)

Know your key terms

Online Key Terms
Chapter 5 flashcards

accurate
aim
authentication
autoclave
beneficence
bias
bibliography
bioethics
capture–mark–recapture
causation
control group
controlled variable
dependent variable
direct observation
ethics
extraneous variable
falsifiable
hypothesis
independent variable
integrity
International System of Units
justice
law
logbook
mean
method
methodology
model
non-maleficence
outlier
personal error
precise
primary data
primary source
quadrat
qualitative data
quantitative data
random error
reference
reliable
repeatable
replicate
reproducible
research question
respect
risk assessment
sample
secondary source
standard abbreviations
subjective
systematic error
theory
transect
true value
uncertainty
valid

Remember

This chapter will build on the following concepts that you will have already met. Take the time to refresh these concepts before you start this chapter.

REMEMBER PAGE 125

1. The scientific method is the process by which scientists can test a theory, or hypothesis.
2. Scientists perform experiments, take careful observations or use models and simulations to gain evidence to either support or to refute their hypothesis.
3. When designing a scientific investigation, ethical implications of the work must always be considered.
4. A well-designed scientific investigation includes relevant controls and clearly defines all variables.
5. A scientist keeps a carefully detailed record of their observations, their ideas and their data in a logbook.

Part A: investigation design

Performing scientific investigations is your chance to experience what *doing* science is really like. Science is about finding things out through observation and experimentation, which is what investigations are all about. This is why investigations are central to science.

Sometimes an important advance in science begins when an observant person with an inquiring mind notices something that might be scientifically interesting. For example, after hearing from milkmaids that people who contracted cowpox (a relatively innocuous disease picked up after working with cattle) were protected from deadly smallpox, the English physician Edward Jenner effectively kick-started the science of vaccination. Jenner used samples from open cowpox sores on a dairymaid's hands to inoculate a young boy and protect him against smallpox (Figure 5.1). However, it would be another 150 years and a lot of carefully planned research before scientists truly began to understand the biological basis of immunity. This sort of early observation may begin a new field of research, which then proceeds by carefully planned investigation.

Scientific investigations can take years to complete and may involve collaboration among many scientists. They may require access to special equipment in Australia or overseas. They may cost a lot of money, sometimes millions of dollars. Hence scientists invest time in *planning* investigations before they begin. When scientists apply for grants to carry out investigations, they need to show that they have carefully planned what they will do, how any money provided will be spent and what the implications of their research will be. Good planning is crucial to the success of the investigation.

Scientists then make careful *data measurements and observations* and record their *results*. They *keep records* of all their experiments in a logbook.

Once data are collected, they need to be *analysed*. This is done in various ways, but in the biological and biomedical sciences it typically involves constructing graphs and performing statistical tests to determine mathematical relationships within the data.

Finally, the results of the investigation must be *communicated*. This can involve publishing a scientific paper either in a journal or in conference proceedings or presenting the findings in talks or posters at conferences.

Wellcome Collection

Figure 5.1 Edward Jenner administers cowpox to James Phipps.

5.1 Choosing your topic

WB 5.1.1 GETTING STARTED: ORGANISATION PAGE 126

For VCE Biology Unit 1, Outcome 3 you will work like a biologist and submit

> *a report of a student-adapted or student-designed scientific investigation using a selected format such as a scientific poster, an article for a scientific publication, a practical report, an oral presentation, a multimedia presentation or a visual representation.*

The investigation topic that you choose must be

> *related to function and/or regulation of cells or systems, and draw a conclusion based on evidence from generated primary data.*

This chapter will assist you in the planning, implementation and communication for this outcome.

There are many things to consider when planning a scientific investigation. You need to think about how much time you will have inside and outside class. You also need to think about the space and equipment you will need, and where you will go if you want to make measurements or observations outside.

You may be working in a group or on your own. Most scientists work in groups. If you can choose who you work with, think about this carefully. It is not always best to work with friends. Think about working with people who have skill sets that are different from your own. If you do work in a group, each student will need to submit their own individual report for assessment.

Record keeping

Students studying VCE Biology are required to keep a record of their practical activities in a **logbook** . This is for recording, **authentication** and assessment purposes. You can keep your logbook either in hard copy form or soft copy form (electronic), although hard copy is the preferred form. It is a good idea to set up a section in your logbook for Unit 1 Outcome 3 now. Logbooks include details of investigations such as methods and results. They include comments and ideas, thoughts about the investigations, and analysis. They frequently include printouts of data, photocopies of relevant information, photos and other items.

You should talk to your teacher about what form of logbook records they require you to keep and any specific formatting requirements that the logbook needs to adhere to.

Make an entry in the logbook every time you work on your investigation, as illustrated in Figure 5.2. Each entry in your logbook needs to be dated. Write down what you do as you do it. It is easy to forget what you did if you do not write it down immediately. An accurate record is important if you need to repeat any measurements or if you get unexpected results. The more detail you include, the easier it will be to prepare your report or poster at the end. Include large, clear diagrams of any experimental set-up and include details of equipment used. You can also include photos of investigations.

Record the results of all measurements immediately and directly in your logbook. Never record data on bits of scrap paper instead of your logbook. Results must be recorded in indelible form using a pen. Never write your results in pencil. Never use whiteout or scribble over anything in your logbook. If you want to cross something out, just put a line through it. It is also a good idea to make a note explaining why it was crossed out.

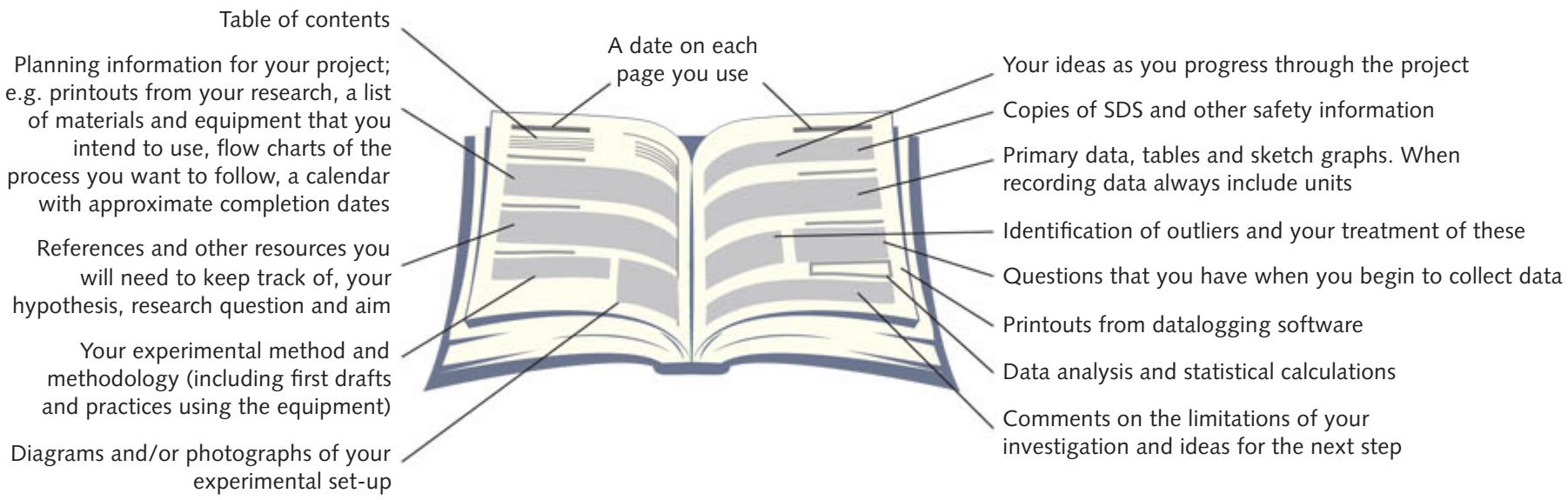


Figure 5.2 Features of an effective logbook

Research question

Any scientific investigation begins with a **research question** that you want to answer. An effective research question is a question that is specific and can be answered by performing your research or investigation with the resources and equipment that you have available to you.

A question that you may like to ask may be in the form 'What effect does a concentrated disinfectant have on bacterial growth?' The aim of your research is then to answer the question. It is important that you develop and frame the research question carefully.

Your research question needs to be specific enough that it guides the design of the investigation. Asking 'Does a concentrated disinfectant decrease bacterial growth more than a dilute disinfectant?' tells you what you will be varying – disinfectant concentration – and what you will be measuring – bacterial growth. It also gives a criterion for judging whether your results have answered the research question. If bacterial growth is less with the concentrated disinfectant compared to bacterial growth with the dilute disinfectant, then the results have answered your research question positively. If bacterial growth is not less with the concentrated disinfectant than the dilute disinfectant, then your results have answered your

research question negatively. It does not mean your results are wrong. It just means the results did not show less bacterial growth with the concentrated disinfectant.

Asking 'How can we make bacteria grow less?' is not a good question. This question does not say what will be varied, nor does it tell you when you have answered the question. 'Less' is too vague and too **subjective** a term.

Finally, a good research question should be feasible; that is, it should be answerable with the time and equipment available.

A good research question identifies the independent and dependent variables that will be investigated. It asks what effect your proposed independent variable will have upon your proposed dependent variable.

CONNECT

Independent and dependent variables are discussed on page 181.

Background research

Now that you have your research question, you need to undertake some background research on your topic and research question. This background research will inform you of what is already known about this topic and may even lead you to change or refine your research question. There are a number of places you can go to undertake this background research.

Primary sources

Primary sources contain original research, such as articles in scientific journals. The advantages of these are that they contain data from new investigations. They provide the background, method, results and discussion of the investigations. The disadvantage of these sources is that they tend to use a lot of highly specific technical language that can sometimes be difficult to understand.

Secondary sources

Secondary sources summarise, review or analyse primary sources. These include reviews of the work of other scientists, and some periodicals and even textbooks. In general, secondary sources are written in a more accessible way. They may also allow you to get an overview and an understanding of a whole field of study through the one article.

Professional scientists will consult both types of sources but prefer to read primary sources when planning their investigations. This helps them to develop a deep understanding of exactly what was done in the investigation, the **methodology** that was used and the **method** that was followed.

There are a variety of sources of information that a scientist can use when undertaking background research. These are listed in Table 5.1.

Table 5.1 Types of information sources

Primary sources	Secondary sources
Scientific journals or periodicals Research reports Sessions presented at scientific conferences Patents Masters and PhD theses	Review journals or periodicals that summarise recent research Reliable websites, such as Nature.com Scientific TV programs or news reports about a scientific discovery Textbooks

Weblink
APA style guide

Harvard system

Referencing source material

Keep a list in your logbook of all the primary and secondary sourced reference material that you use to investigate your research question. It is much better to do this as you go than to have to go back later on to try to find out where you sourced the material.

There are a number of ways to reference material, but the ones usually used in scientific research are the American Psychological Society (APA) style (see weblink) or the Harvard system (see weblink). Remember that **references** refer to sources that you actually cite in the write-up of your scientific

5.1.2 GETTING STARTED: ASSESSMENT PAGE 127

investigation. A **bibliography** is different in that it provides a list of sources that you may have consulted but that are not necessarily sources you cited in the write-up. Make sure you check with your teacher to determine the preferred style of referencing.

Evaluating source material

Be critical of what you read. Do not assume that everything you read online or even in books is true. Try to find **reliable** sources of information (Table 5.2). Textbooks, websites from universities and government research agencies are usually very reliable. Publications and web pages from professional organisations such as CSIRO, Australian Academy of Science and equivalent international organisations are also good sources.

Websites containing student research such as science fair projects are not always reliable, although they can be useful to give you ideas. Online sources that are trying to sell you something or push a particular point of view should be treated sceptically. If there is clear **bias** or a single perspective contained in the information, then it should be avoided.

Weblink
CSIRO
Australian Academy of Science
CRAAP test

Talk to your teacher or librarian about sources of information. Your library may also have access to databases containing scientific journal articles. They will be able to help you to assess whether a website is reliable and suggest sites they know are suitable. The CRAAP test will provide you with a list of questions to assist you in evaluating the resources that you are using. (See weblink.)

Table 5.2 Features of reliable and unreliable information sources

Reliable sources	Unreliable sources
Contain current information and seek to inform the reader	Are not from reputable sources
Contain information that is relevant to your project or inquiry	Present obvious bias
Are from a reputable source such as a university or scientific research institution	Do not contain references for their claims
Contain information that is likely to be accurate (such as a peer-reviewed journal article)	Provide links to unscientific references
Avoid bias	Have not been updated regularly
	Promote or advertise a large amount of unrelated content

KEY CONCEPTS

- VCE Biology Unit 1 Outcome 3 requires you to submit a student-adapted or student-designed investigation in a selected format.
- You need to set up a logbook at the beginning of your investigation for authentication and assessment.
- Write a research question that you want to answer with your investigation.
- Undertake background reading on your research question using reliable primary and/or secondary resources.
- Maintain a list of all your source material in your logbook.

Concept questions 5.1

1. Why does all legitimate scientific research start with a question?
2. What features make a good research question?
3. The logbook is used for authentication purposes in Outcome 3. What does authentication mean?
4. Specific referencing styles are used by scientists around the world. What are the referencing styles that are suggested to be used here?
5. What is the difference between primary and secondary sources?

HOT Challenge

6. Plagiarism is a consistent issue that educational and research institutions contend with. If plagiarism is engaged in, research can be ceased, funding of projects is risked, public humiliation can follow, and students of educational institutions can be expelled or, in the case of the VCE, have their mark cancelled. What is plagiarism and what can you do in your own work to avoid plagiarism?

5.2 Types of scientific methodology

There are many different methodologies to use when undertaking a scientific investigation. Methodology refers to the broader framework of the approach taken in the investigation to test your research question or hypothesis. The methodology you choose will depend upon your topic of research. The VCE Biology Study Design (p. 20) specifies which methodologies you can select from to complete your Outcome. These methodologies are shown in Figure 5.3 and each is explained in more detail below.

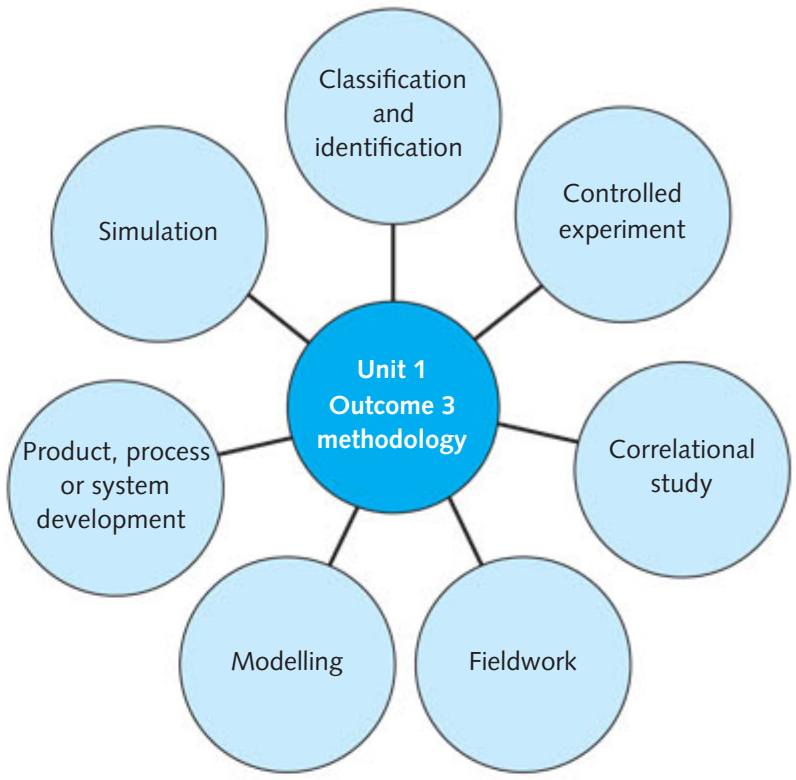


Figure 5.3 Choose one of these methodologies for your Unit 1 Outcome 3 report.

Classification and identification

Classification and identification methodology enables you to investigate a larger group of things (in biology this is usually living things) and to classify them by placing them into like groupings and identify them by naming them. All living things are classified into six Kingdoms based on their relatedness and the sharing of common characteristics. These Kingdoms are Animalia, Plantae, Fungi, Protista, Eubacteria and Archaebacteria. Each kingdom is further divided into the levels of phylum, class, order, family, genus and species. If you were to undertake a classification and identification methodology you would choose a research question that required you to classify a set of organisms using these levels and then identify them by name. For example, your research question might be: 'Are all the birds that visit my local park the same type?' To answer this research question, you would need to take photos of all the different types of birds that visited your local park. You would then consult printed field guides or online keys to use the characteristics of each bird to classify them and determine their scientific name. For example, the superb fairy wren in Figure 5.4 belongs to Kingdom Animalia, phylum Chordata and class Aves, as all birds do. In order to find out its scientific name you would need to classify it further into order, family, genus and species. Its scientific name is a combination of the genus name and species or specific name, such as *Malurus cyaneus*, where *Malurus* is the genus name and *cyaneus* is the specific name. Once you have identified all the birds that visit your local park in this way, you could then go back and answer your research question. You might like to present your results with the photo, the common name and the scientific name.

Getty Ima

Figure 5.4 The superb fairy wren has the scientific name *Malurus cyaneus*.

Controlled experiment

In a controlled experiment methodology, all factors that could affect the results of the experiment are kept constant except the one under investigation. This factor is called the independent variable.

Independent variable

The **independent variable** is the factor that you change or manipulate in your investigation. For example, if your research question was 'Does a concentrated disinfectant decrease bacterial growth more than a dilute disinfectant?' then your independent variable would be *concentration of disinfectant*. You would be using two or more different concentrations of disinfectant and measuring their effect on bacterial growth.

Dependent variable

The **dependent variable** is the factor that you measure during an investigation. For the above research question, the factor that you would be measuring is *bacterial growth*, so this is your dependent variable.

WB
5.2.1 IDENTIFYING THE DIFFERENT TYPES OF SCIENTIFIC METHODOLOGY PAGE 131

Another example is if a scientist is testing the effect of water temperature on germination in *Acacia* seeds. The research question would be 'Do different temperatures of water affect the germination of *Acacia* seeds?' The independent variable will be the temperature of the water poured onto the *Acacia* seeds and the dependent variable will be how many *Acacia* seeds germinate.

Usually your investigation will have one dependent variable and one independent variable. The investigator will change the independent variable and measure the influence on the dependent variable.

Controlled variables

Let's go back to the research question: 'Does a concentrated disinfectant decrease bacterial growth more than a dilute disinfectant?' You may already have realised that there are few things other than the concentration of disinfectant that can influence bacterial growth. Bacterial growth could also be influenced by the brand of disinfectant, temperature, humidity, type of agar nutrient and where the agar plates were exposed, just to name a few. These other things that could affect your results are called **extraneous variables** and they need to be controlled or kept constant. By controlling all other variables you are able to show that only your independent variable is influencing the results, not any other extraneous variable.

Shutterstock.com/pariwat pannium

Figure 5.5 Bacterial growth (yellow circles) on agar plates. Keeping conditions as consistent as possible helps to control the extraneous variables.

An extraneous variable must become a **controlled variable** by identifying it and keeping it constant during the investigation (Figure 5.5). If this is done then it does not impact upon the interpretation of the relationship between the dependent and independent variables. In the example of the bacterial growth investigation, controlled variables would include brand of disinfectant, temperature, humidity, type of agar nutrient and where the plates were exposed. These are all potential confounding factors that would need to be controlled; that is, kept constant. In this way, only the concentration of disinfectant (the independent variable) could be influencing the results (Figure 5.6).

Table 5.3 Types of variables

Type of variable	Definition
Independent variable	The variable changed or manipulated by the scientist and assumed to have an effect on the dependent variable
Dependent variable	The variable measured whose value depends upon the independent variable; that is, it responds to the independent variable
Extraneous variable	A variable that may affect the outcome of your investigation other than the independent variable; these variables need to be controlled (kept constant)
Controlled variable	A variable that is kept constant during the investigation in order to determine the relationship between the independent and dependent variable

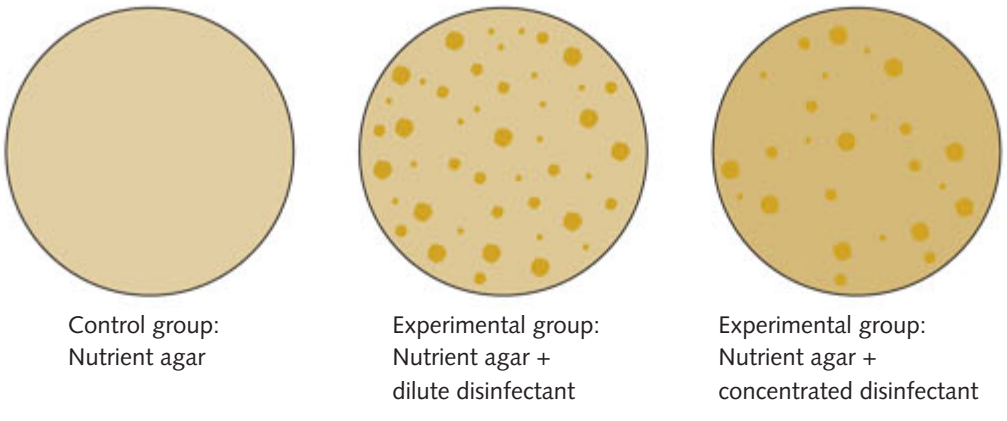


Figure 5.6 Controlling all the extraneous variables so that only the independent variable influences the dependent variable. All three agar plates were exposed in the same place for the same amount of time.

Correlational study

A correlational study methodology applies when two factors are studied to see if one affects the other. For example, a research question could be 'When the number of mice in an area increases, does the number of eagles also increase?' Factors are said to be positively correlated if they both increase together or if they both decrease together. They are said to be negatively correlated when one factor increases while the other decreases. Correlation is the statistical measure that indicates whether two or more factors fluctuate together (Figure 5.7).

Sometimes changes in one condition or event bring about or cause a change in another condition or event. This is known as **causation,** or cause and effect, where a factor (the cause) can change another factor (the effect). A valid experimental design is used to establish cause and effect claims. You need to be careful; however, just because two things correlate does not mean that one causes the other.

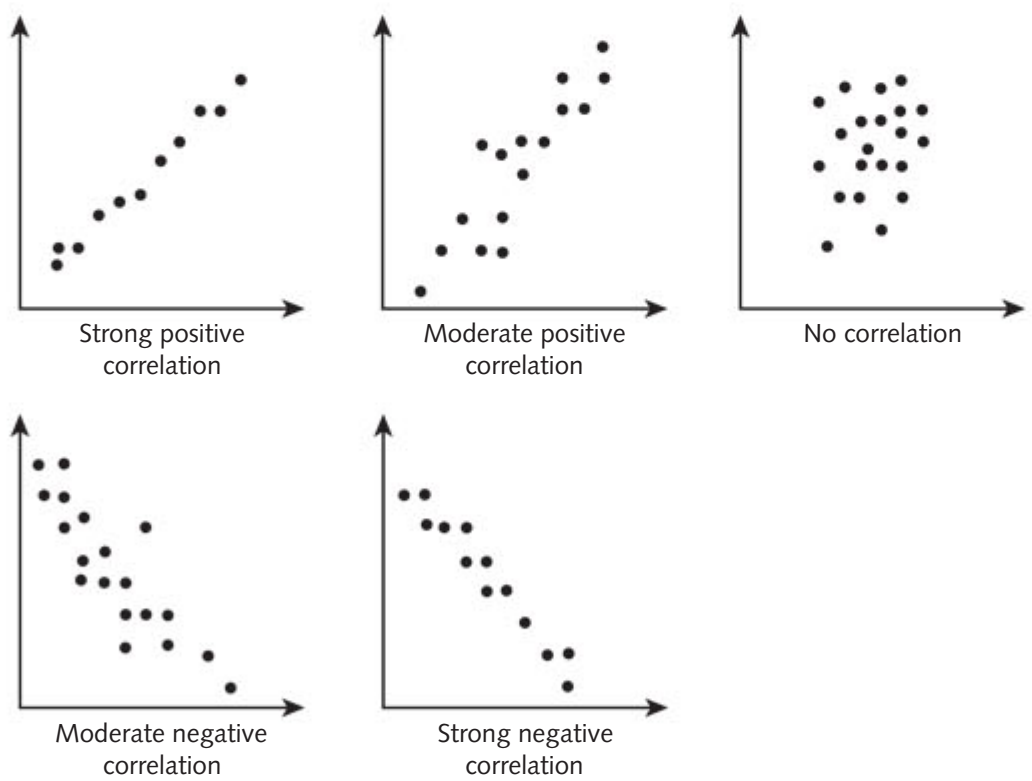


Figure 5.7 Graphs are useful when looking for correlation between factors.

Fieldwork

Fieldwork methodology is exactly as it says: scientific investigation that is undertaken outside the laboratory. Depending on the research question, the field could be a supermarket, paddock, local park, forest or rock platform along the coast. You could, for example, investigate the types of organisms that survive on a rock platform. To do this, you need to understand some of the common sampling techniques that are used by biologists.

Sampling populations

Taking accurate measurements in the field relies on measuring a large enough representative sample of the population. Various standardised techniques have been developed to sample populations and ecosystems accurately. Different techniques are suitable for different types of studies and the method of sampling a population is an important component of the experimental design.

Making **direct observations** and recording sightings at particular intervals might be possible, but it is time-consuming. It might even be dangerous, such as in the case of male fur seals in the breeding season on windswept shores. Satellite images have been used to determine percentage vegetation cover in relatively inaccessible regions. In aquatic ecosystems, plankton nets are used to 'sweep' or **sample** the organisms, and aircraft traverse areas to count kangaroos in Australia and other large mammals such as musk ox in the Arctic and antelope on African savannahs.

Even when it is possible to count all members of a given population, it may not be necessary. Various sampling techniques can provide estimates of a population. A sample is a small group of organisms selected from the total population in a given area or volume. This sample represents the whole population.

When determining population numbers of nocturnal species, slight variations need to be employed. In New Zealand, scientists have been using spotlights with a red filter to determine the number of fish in a measured and netted area of a river. The filter reduces the impact on the fish and counting can be carried out reliably.

Choosing a particular site because it is easy to get to or is more interesting, or selecting a very small number of sample specimens, reduces the reliability of the data obtained. It does not give a true picture of the whole population. To represent the population as a whole reliably, the samples must be collected in an unbiased way.

Alamy Stock Photo/ephotocorp

Figure 5.8 Quadrat sampling is often used to estimate plant population size.

Quadrats and transects

For organisms that are fixed or do not move very much, the **quadrat** method of sampling can be used to estimate distribution and abundance. A quadrat is a square, the size of which is determined according to the organism being studied, measured at ground level. It is most often used when measuring plant density, because plants are stationary, as shown in Figure 5.8. It is also a relevant method for recording sedentary marine species along shorelines that may be exposed as the tide varies. It can also be used to calculate density of a population.

If sufficient quadrats are chosen, and they are representative of the area under study, the results can be used to estimate total population size. For each quadrat:

- the number of individuals of each species is counted and recorded, *or*
- the relative numbers of each species is estimated using a scale from abundant (3) to absent (0), *or*
- percentage cover is estimated.

The totals of the quadrats are then averaged.

A simple mathematical calculation can give the total number or percentage cover for each species in the whole area. The density can also be calculated.

Estimating total population size of area under study

$$\text{Average density of members of species (estimated)} = \frac{\text{Total number of individuals counted}}{\text{Area of each quadrat}} \times \text{Number of quadrats}$$

A **transect** ('trans' = across, 'sect' = section) is a line drawn through a community and the information gathered along it is used to determine the distribution of species within that community. Again, this is a useful method when species are fixed in place, such as plants and fungi. In order to

improve the data collected, quadrats may also be placed at intervals along the transect line and thus data on density in specific locations may also be recorded.

When an area has been selected for study and the data needed have been nominated, the transect line is measured out. For example, it may be 10 metres long with regular segments (every metre), where information regarding changes in distribution is recorded as you move through a tidal zone towards land (Figure 5.9). It may also provide information on vertical features such as the canopy of the forest, as well as the species present. It may need to be a kilometre in length if studying changes in the distribution of organisms, because abiotic factors change with altitude along a mountainside.

The transect line method is best to use if environmental factors such as soil type, pH and salinity change along the distance to be sampled. Gradual changes like this are referred to as environmental gradients. Distribution of species can be correlated with changes in these abiotic factors. Vertical transects can show vertical distribution of species. Different conditions at different levels result in stratification – in forests, for example. Environmental factors change across a tidal mudflat or a marine rock platform. In these cases, a profile can be drawn Figure 5.9.

In order to gain a full picture of population distribution and specific abundance patterns in environments, a combination of methodologies is best. Data gathered using transects offer fairly accurate information regarding distribution of individuals and/or species, while quadrats offer a comprehensive picture of species abundance, but not its distribution.

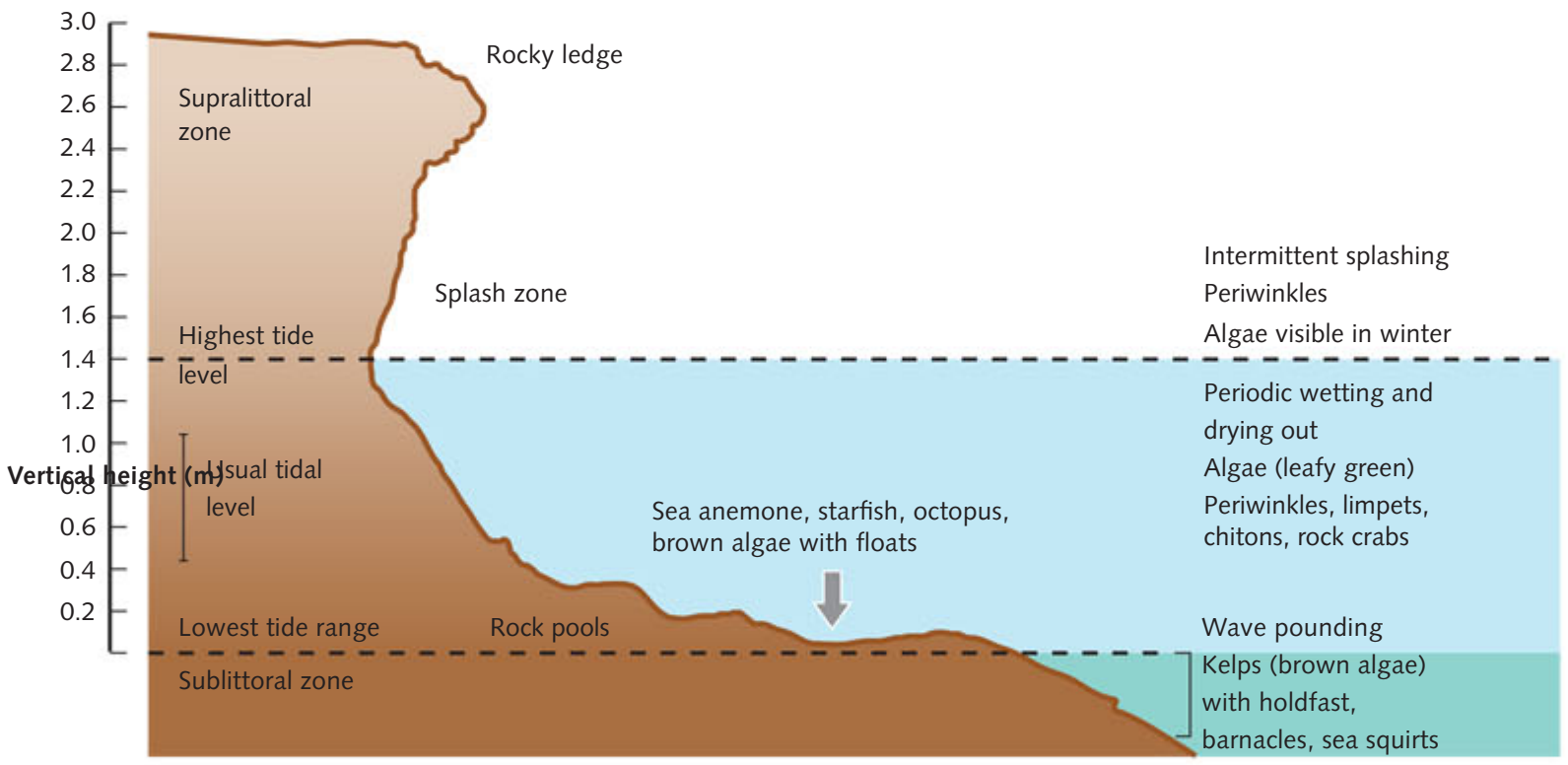


Figure 5.9 Transect profile of a marine rock platform

Capture–mark–recapture

The **capture–mark–recapture** method is commonly used to sample mobile species. A random sample of individuals of a species is taken and an overall estimation of the abundance of the species is made. The method comprises three steps.

1. Capture: Animals are caught randomly and in such a way that they are unhurt. Small animals are trapped in cages or pitfalls in the ground, birds are trapped in fine nets and some animals are caught easily when they 'freeze' in spotlights. Flying insects are attracted to light traps.
2. Mark and release: Each captured animal is marked so that the mark is not obvious to predators or harmful to the animal. Insects are usually marked with a blob of paint, while birds are tagged on the leg or wing. Figure 5.10 shows a turtle being tagged for study. The marked animals are returned to their habitat and left to mix with unmarked individuals.

Getty Images/Universal Images Group/Auscape

Figure 5.10 Tagging a turtle

3 Recapture. Later, a random sample is taken, and the number of marked individuals counted. The timing of recapture needs to be appropriate to again capture a random mixture of individuals, but without leaving it so long that many of the original marked individuals have died. From this information the total population can be estimated (Figure 5.11). The procedure has to be planned carefully so that the chances of each individual being caught are equal. Sometimes 'trap happy' individuals are sampled over and over.

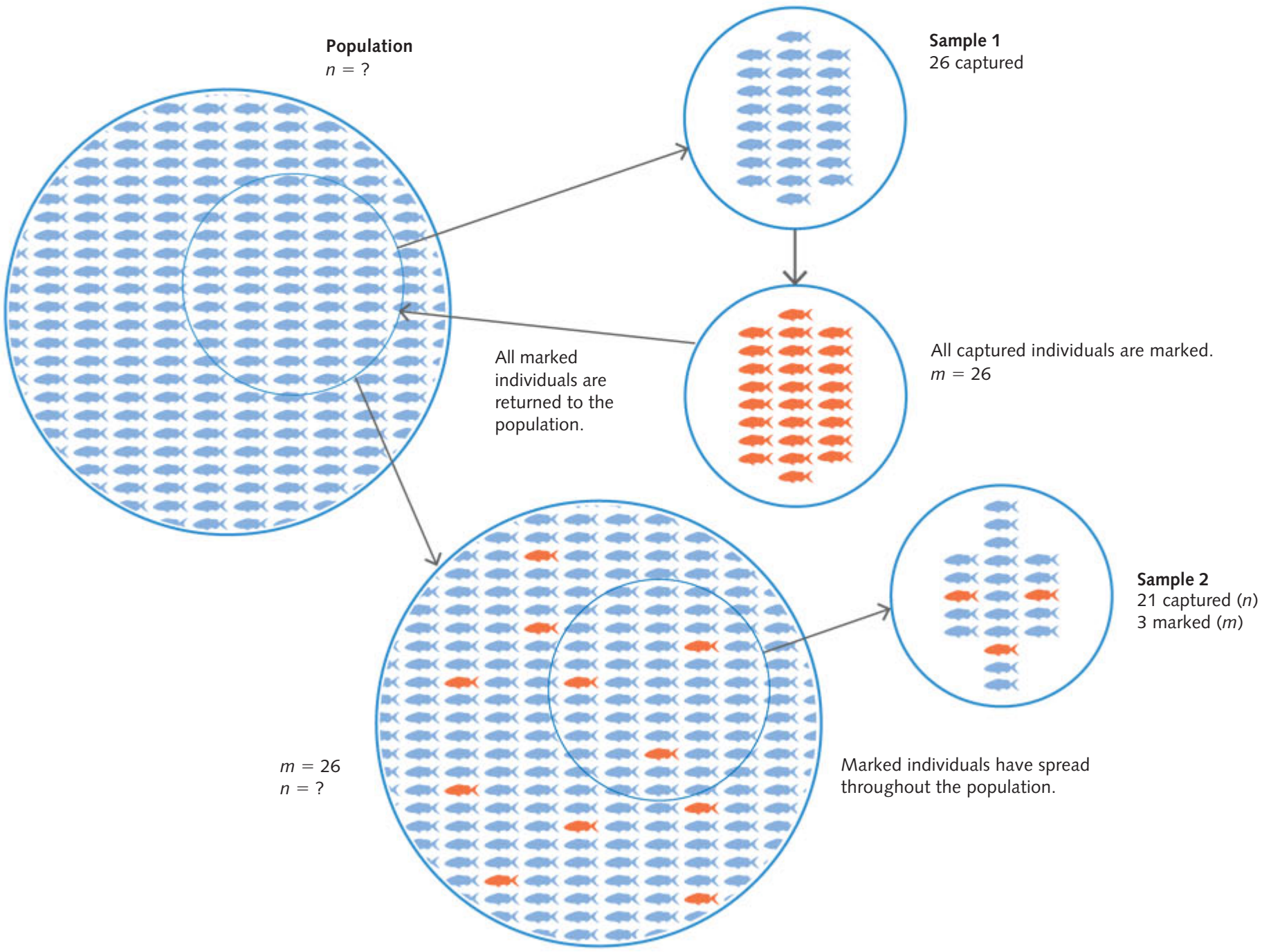


Figure 5.11 The capture–mark–recapture technique

Modelling

Modelling methodology can be used to test and explain theories, to describe the structure and function of a biological object, to describe biological concepts, to represent biological systems or to predict the impact of one factor on another.

We can view chromosomes using microscopes, but we have never actually seen the structure of DNA. Yet we can observe and manipulate physical models of DNA to help us understand how it functions as the genetic material of the cell. In 1953, James Watson and Francis Crick built a physical model to propose a theory for the molecular structure of DNA (Figure 5.12). How did they come up with this model? Upon viewing the results of a number of experiments, they had a conceptual model in their heads that explained these results. They built the physical model to test and subsequently present their theory, which was accepted by the scientific community.

Visualisation models can be used to link data with graphics, to help scientists construct theories, make predictions and explain phenomena. During the 1854 cholera outbreak in London, Dr John Snow recorded data on a map of London to track a cholera outbreak (Figure 5.13). This statistical map modelled the spread of the disease. He used it to convince authorities that cholera was transmitted through water. Three main observations supported his theory. First, there was a concentration of outbreaks around the Broad Street well. Second, workers from a nearby beer factory who drank beer instead of water did not get cholera. Third, a new outbreak started in a different part of town after a woman washed the nappy of an infected child in a well.

Alamy Stock Photo/ephotocorp

Figure 5.12 James Watson (left) and Francis Crick (right) built a physical model of DNA incorporating all that was known about DNA.

Mapping disease outbreaks today uses computational models. Computational models can deal with vast amounts of data at any one time, making them powerful predictive models. Some predictive models help us to forecast the future state of a system, which is useful in the debate of issues. They can forecast the spread of disease, the effects of climate change, and the impact of change on an ecosystem or the economy. They help us to understand how actions might affect the future. Data collected through observation and experimentation are added to computer programs. Mathematical computation identifies and generalises patterns, so the behaviour of systems can be simulated. Computer programs can be used to compare sequences of DNA, predict protein structures and make model viruses to help us investigate disease.

A map taken from a report by Dr. J

Figure 5.13 A reproduction of John Snow's map showing cases of cholera. The cluster of cholera cases around the Broad Street pump (map centre) strongly suggests a link between the water and the disease.

Critiquing and revising biological models

Models are often made for a specific reason. Revisions are made using new data when they are used for a different purpose or when new evidence arises that does not fit the model.

The first food pyramid was published in Sweden in 1974 (Figure 5.14a). It was a descriptive model advising on basic nutrition during a time when food was very expensive. It was triangular, so consumers could visualise suggested portions of each food type. It had three levels: basic foods at the base, including dairy and cereals; fruit and vegetables on the next level; and meat and fish at the top. The US Department of Agriculture released a new food pyramid in 1992 (Figure 5.14b). It was created to advise on eating habits based on knowledge gained from studying the relationship between diet and disease. It had six sections and recommended how many portions of each should be consumed. Critics of this model remark on two factors they believe were added due to pressure from lobby groups. First, dairy now had its own section, indicating that dairy is necessary in the diet. Many cultures and vegans live without dairy in their diet. Second, the recommended intake of cereals was 6–11 servings. The nutritionist designers who had recommended 3–4 serves believe this was increased due to pressure from the wheat and corn industry. Nutrition models continue to be revised in response to new experimental findings. The National Cancer Institute later used evidence to have the portion of fruit and vegetables raised from 2–3 to 5–7.

a

b

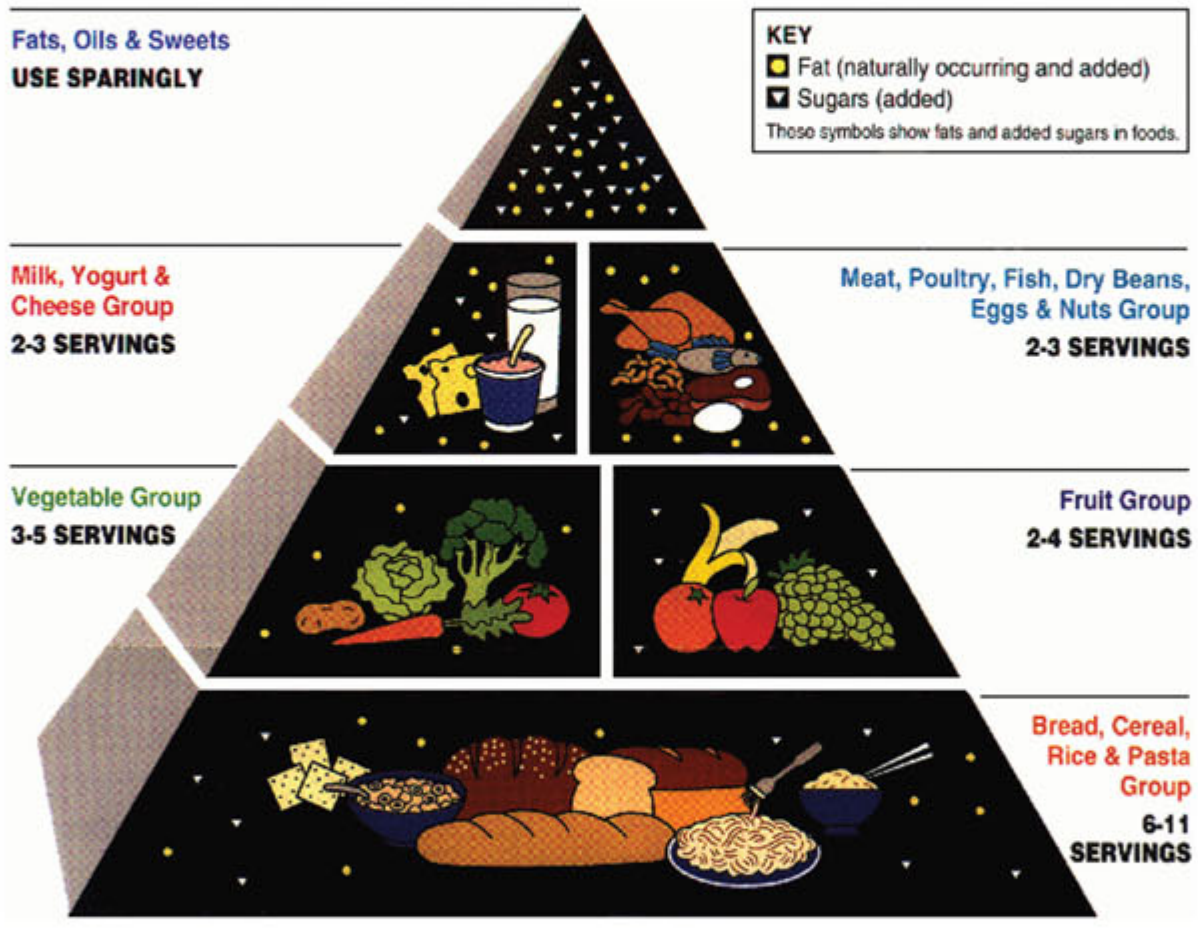


Figure 5.14 The food pyramid model has been modified over time. **a** The first food pyramid, published in Sweden in 1974 **b** Food pyramid released by the US Department of Agriculture in 1992, which critics claim was influenced by lobbyists in the dairy and wheat industries

Product, process or system development

Product, process or system development methodology is used to design an object or product, process or system that will assist a human in meeting their biological demands and requirements. The product, process or system could, for example, replace a damaged part of the body or enhance a part of the body to make it work better. Products that have been designed and manufactured for this purpose include the heart-lung machine, which takes over the role of the heart and lungs during open-heart surgery, and the pacemaker, which is inserted into the heart to control abnormal heart rhythms.

WB

5.2.2 DESIGNING A SCIENTIFIC INVESTIGATION PAGE 132

Simulation

Simulation methodology allows you to use a model to simulate real life or part or whole of a system to gain knowledge of its functioning. The model will enable you to alter certain variables so you can see how the system responds and therefore use this to predict future responses. The model could be physical or digital, such as a computer model that predicts nephron behaviour as the levels of water, minerals and salts are altered.

KEY CONCEPTS

- Methodology refers to the broader framework of approach taken in the investigation to test your research question or hypothesis.
- Classification and identification methodology enables you to investigate a larger group of things and to classify them by placing them into like groupings and identify them by naming them.
- A controlled experiment methodology is when all factors that could affect the results of the experiment are kept constant, except the one under investigation.
- A correlational study methodology studies two factors to see if one affects the other.
- Fieldwork methodology is scientific investigation that is undertaken outside the laboratory.
- Modelling methodology can be used to represent biological systems or to predict the impact of one factor on another.
- Product, process or system development methodology is used to design an object or product, process or system that will assist a human in meeting their biological demands and requirements.
- Simulation methodology allows you to use a model to simulate real life or part or whole of a system to gain knowledge of its functioning.

Concept questions 5.2

1 Classification and identification methodology requires an understanding of the principles of classifying things into groups. What is the main underlying principle of this methodology when applied to living things?

2 Controlled experiments require an understanding of variables. What are variables?

3 Cause and effect is a specific principle utilised in correlational methodologies. Define what this means, with an example.

4 Capture and recapture is a useful process in fieldwork. Observational and other counting techniques such as using quadrats also serve to give useful primary data. Prepare a mind map of the various techniques used in fieldwork.

5 It has been said that modelling is only as good as the assumptions on which it is based. Provide one example of modelling that was based on faulty assumptions.

6 How does designing a product, process or system to meet a need qualify as scientific research?

7 How can simulations help a scientist better understand a theory or model new concepts?

HOT Challenge

8 A student scientist is seeking to answer the question 'Does starch storage in leaves stay constant when a vascular plant is placed in different wavelengths of light?' The student decides to use a controlled experiment methodology to investigate this question.

a What is the independent variable and what is the dependent variable in this investigation?

b List three possible extraneous variables.

c How would you control these three extraneous variables?

5.3 Quantitative and qualitative data

Once you have decided upon a specific research question and methodology you can begin to plan and design your investigation. Having a plan ensures that you make the observations and measurements that you need. The longer the investigation, the more important it is that you have a clear plan. There are several things to consider.

- What is my hypothesis?
- What data will I need to collect?
- When and where will I collect the data?
- How will the data be analysed?
- What materials and equipment will I need?

» What are the independent and dependent variables?
» Have I identified all the variables that could influence my results? (See pages 185–6.)

Definition of key terms

It is important that you understand the differences between some related key terms so that you use them correctly during your investigation and when you write your report.

The **aim** of an investigation is the reason why you are undertaking the investigation. In the bacterial growth example described on page 182, the aim of the investigation is to find out if there is a relationship between the concentration of disinfectant and the growth of bacterial colonies. This aim could be turned into a research question: 'Does a concentrated disinfectant decrease bacterial growth more than a dilute disinfectant?'

Models are often used in science. Sometimes, objects are too small to be seen, such as an atom; too big, such as planet Earth; or too expensive and dangerous to use, such as a rocket. Therefore, in order to understand it, all the information that we know about the object can be represented by a model. A **model** is a visual, mathematical or computer-based representation of an idea that cannot be seen or experienced. Models are used to simulate the real object and to predict how the object would behave under certain circumstances. An example of a model in science is the plate tectonic model to explain how tectonic plates move across the surface of the planet. These are far too big to see, so computer models have been constructed to predict how the plates will behave.

A **theory** is a well-established explanation of scientific data. A theory is testable and enables predictions to be made. The theory of evolution by natural selection has a vast body of evidence to support it, and it can be used to make predictions on how survival of a species will occur under certain conditions.

A **law** is a general rule that explains repeated experimental observations and is usually in the form of a verbal statement or a mathematical statement. A law has to be applied under the same conditions and implies a cause and effect relationship. For example, Boyle's law in chemistry states that the volume of a given gas varies inversely with the pressure applied. This law only applies when the temperature and pressure are kept constant.

Hypothesis

You need to turn your research question into a hypothesis. A **hypothesis** is a tentative prediction, or a tentative explanation of an observation, based on an existing model or theory. A hypothesis should give you a prediction that you can test by performing an investigation. This means it should at least be **falsifiable**; that is, it should be able to be refuted. However, you will not generally be able to claim that you have proved your hypothesis. Rather, you may be able to say at the end of the study that your results support your hypothesis. Hence an aim for an investigation should not start 'To prove …' because it is not actually possible to prove a hypothesis, only to refute it. If your investigations agree with predictions based on your hypothesis, then you can claim that they support your hypothesis. This increases your confidence in your findings, but it does not prove that they are true.

In summary, a well-designed research question and hypothesis will guide your inquiry and help you to understand whether or not you have met the goals of your investigation (Table 5.4).

Table 5.4 Features of effective research questions and hypotheses

	Effective research questions	Effective hypotheses
Phrasing	Framed as a question Specific, and includes scientific terminology	Framed as a prediction based on your research Specific, and includes scientific terminology
Use of variables	Includes mention of the independent and dependent variables e.g. 'How does the independent variable affect the dependent variable?'	Includes mention of the independent and dependent variables e.g. 'If there is a change in the independent variable then this will result in a predicted trend in the dependent variable.'
Predicts results	No	Yes
Outcome	Can be answered by your investigation	Can be supported or refuted by an investigation

For example, using the research question 'Does a concentrated disinfectant decrease bacterial growth more than a dilute disinfectant?' the hypothesis could be: '*If* the more concentrated disinfectant is used rather than the dilute disinfectant *then* the number and size of bacterial colonies will decrease.' You will note that this hypothesis meets all the requirements set out in Table 5.4.

- It predicts what the result will be (bacterial growth will decrease)
- It is specific in that it states *if* … [the independent variable is changed] … *then* … [something will happen to the dependent variable] …
- It mentions the independent (disinfectant) and dependent (bacterial growth) variables.
- It states how the dependent variable will be measured (number and size of bacterial colonies).
- It can be supported or refuted by an investigation.

Primary data

WB 5.3.1 PRIMARY DATA PAGE 134

Unit 1 Outcome 3 specifies that your scientific investigation must generate primary data. **Primary data** is data that you collect yourself via an investigation. Generating primary data involves collecting either quantitative data and/or qualitative data. **Quantitative data** is data that is a *quantity* and is recorded numerically or in numbers. You measure the numerical value in the appropriate units. For example, you may measure height in centimetres or mass in grams.

In some investigations you may collect qualitative data. **Qualitative data** is non-numerical and can be directly observed; it is a *quality*. For example, you may observe that when you add Chemical X to Chemical Y a colour change of red to green occurs.

Sometimes you use a combination of qualitative and quantitative data. For example, you may describe the width of bacterial colonies in millimetres (quantitative) as well as the colour of the colony (qualitative).

As discussed earlier your hypothesis should specify your dependent variable; that is, what you are quantitatively measuring. In the case of the hypothesis '*If* the more concentrated disinfectant is used rather than the dilute disinfectant *then* the number and size of bacterial colonies will decrease' you will be measuring the number and size of bacterial colonies. You need to determine how you are going to measure this (Figure 5.15). The number of bacterial colonies is easy – you just need to count them – but how will you measure their size? Will you use a stereomicroscope with a measuring eyepiece, or will you measure the colony size using the naked eye and a ruler? Will you measure all the colonies or just the ones you can see with the naked eye? Will you count all the colonies or just the ones that are larger than a full stop? You need to make all these decisions before you carry out your investigation.

Shutterstock.com/Ebrahim Lotfi

Figure 5.15 Plan exactly what you will measure to collect your data.

When collecting your data and communicating your results to a scientific audience (including your classmates and teacher), ensure you use the correct scientific terminology and the key biological terms to describe your study and your findings. Be aware of any **standard abbreviations** that may be applicable (you might have come across these during your background reading in the planning phase of your study), and use only the **International System of Units** or Système International d'Unités (SI) of measurement or other units recognised for use with SI units.

Keep a record of all of your planning. This should go in your logbook. This is useful information as your investigation evolves and is needed for authentication purposes. Writing down what you plan to do and why will also help you to stay focused during the investigation.

Table 5.5 Some examples of SI units

SI unit	Measurement
kilogram (kg)	mass
metre (m)	length
second (s)	time
degree Celsius (°C)	temperature

Quality of primary data

You need to plan your investigation to generate the highest quality data. A well-designed investigation allows you to collect data that is accurate, precise, repeatable, reproducible and valid. This will allow you to rely on the data to draw conclusions, and to be confident that a difference between one measurement and another reflects a real change in what is being measured. A definition of each term is provided in Table 5.6 and illustrated in Figure 5.16.

WB 5.3.2 QUALITY OF PRIMARY DATA PAGE 135

Measurements are **valid** if they measure what is supposed to be measured. Validity of measurement is important because results in a well-designed investigation are affected only by a single independent variable. Only investigations where all the extraneous variables have been controlled will produce valid results (p. 186). If the results are similar each time, then your results are more likely to be both valid and reliable.

A measurement is **accurate** if it is close to the **true value** of the parameter being measured. You will also aim to collect **precise** measurements; that is, repeated measurements that are close to each other. For example, suppose you measured the length of the stem of a plant five times and recorded the measurements 15.2 cm, 15.1 cm, 15.1 cm, 15.0 cm and 15.1 cm. These five measurements are close to each other and therefore considered precise.

If a result is not repeatable by you or reproducible by others it is probably not a valid result. A result is **repeatable** if the same measurement (within the limits of experimental uncertainty) is made more than once by the same investigator using the same equipment under the same conditions.

A result is **reproducible** if another investigator, following your method, obtains data that leads them to the same conclusion as yours, even if there is some small variability between your results and theirs (for example due to the different equipment used to take the measurements). If a result is not repeatable or reproducible, then a variable other than the one you are controlling is affecting its value. If this is the case, you need to determine what this other variable is and control it if possible.

Table 5.6 Quality of data

Valid	Does it measure what it is supposed to measure?
Precise	How closely do individual measurements of the same thing agree with each other?
Accurate	Has the data been measured and recorded correctly?
Repeatable	Can the same investigator use the same method and equipment and get the same result?
Reproducible	Can another investigator use the same method and equipment and get a similar result?

Sometimes investigations simply do not work or cannot be done for some reason, such as equipment failure or unforeseen variables. For example, bacterial growth will be affected if someone knocks all your Petri dishes onto the floor during the investigation. Try to think of all the things that could go wrong. If possible, come up with backup plans. Allowing plenty of time helps with this, as does starting your investigations as early as possible.

Think about how you can minimise uncertainty. Experimental **uncertainty** is the doubt associated with the value derived from measuring a variable, usually affected by the equipment used to take that measurement. For example, are your scales working properly, or has your tape measure stretched?

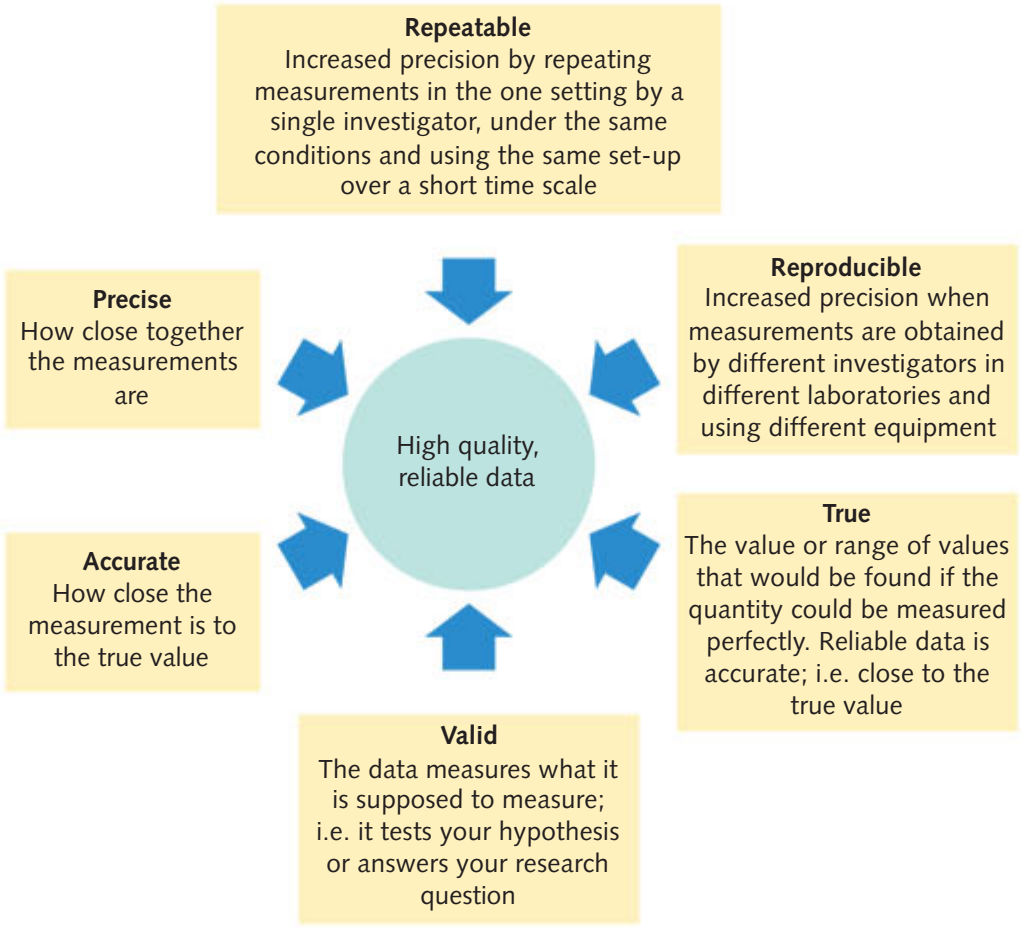


Figure 5.16 Features of data from a well-designed investigation

Make sure you have allowed time for analysis. Ideally, do as much analysis as you can while you collect results. If you plot graphs as you take measurements, then you will be able to identify outliers early. An **outlier** is a data point that does not fit the pattern of the rest of the data and may distort the data, acting as a source of error. If you identify an outlier while you still have access to equipment and space, you can check the measurement and make sure that you did not make a mistake or that the investigation has not been compromised by an extraneous variable.

With these things in mind, you may need to consider the number of **replicates** to include in your investigations. These are independent samples that allow you to take multiple measurements, thereby increasing the reliability of your data. In the bacterial growth example, having four petri dishes in each experimental condition allows you to calculate an average or **mean** value as well as the variation between values in your sample set. If the variation is small, it is likely that there is only one independent variable acting in your investigation and your results are probably reliable.

Minimising error

Errors occur when subjects are not randomly assigned to experimental groups or when there are faults or imperfections with the equipment being used. **Personal errors** arise as a result of mistakes or miscalculations on the part of the investigator; for example, counting the number of bacterial colonies incorrectly.

Systematic errors are predictable errors that arise through imperfections in the equipment used to take the measurements. To minimise systematic errors, you first need to ensure that all equipment you are using has been calibrated and tested. Calibration using known standards ensures that the equipment gives the correct readings. For example, scales can be calibrated by using known weights. The equipment should be calibrated at the top and the bottom of its range at least. Instructions for calibrating equipment correctly can be obtained from your teacher, laboratory technician or the user manual for the equipment.

Random assignment of subjects into experimental and **control groups** is an important part of the design of a study. For example, in a clinical trial of a new drug, patients are randomly assigned to be in the control group or the drug (experimental) group, with a fairly equal representation in both groups of age, gender, ethnicity and other variables. The control group acts as a baseline of what would occur without the action of the independent variable. Clinical trials are also designed as double-blinded studies in which neither the patient nor the nurse or doctor treating the patient knows which group they have been assigned to. These steps are essential for reducing bias.

Even in a well-planned investigation, **random errors** can occur. These are variations in the data and result in less precision of your measurements. These errors can be reduced by using multiple trials or samples (replicates) and/or ensuring that your investigation is repeatable.

When the person conducting the investigation and/or making the measurements has particular expectations about the results, this can introduce bias in the study. An example of bias in an investigation would be the investigator choosing the tallest or healthiest plants to treat with fertiliser, as these might give the biggest growth measurements at the end of the study. When an investigation is biased the results are not valid and no conclusions can be drawn from the investigation.

For every step of your investigation, try to identify possible sources of error, come up with ways of eliminating systematic, random and personal errors, and incorporate these into your investigation design. If you make a mistake during your investigation, then the investigation should be repeated. For example, ensuring that you have germinated sufficient seeds so that you have additional plants to carry out the investigation again, if need be, is good planning.

KEY CONCEPTS

- The aim of an investigation is the reason why you are undertaking the investigation.
- A model is a visual, mathematical or computer-based representation of an idea that cannot be seen or experienced.
- A theory is a well-established explanation of scientific data.
- A law is a general rule that explains repeated experimental observations and is usually in the form of a verbal or mathematical statement.
- A hypothesis is a tentative prediction or explanation of an observation based on an existing model or theory.
- Primary data is data that you collect yourself via an investigation.
- Quantitative data is data that is a quantity and is recorded numerically.
- Qualitative data is non-numerical and can be directly observed; it is a quality.
- A measurement is accurate if it is close to the true value of the parameter being measured.
- A precise measurement is when repeated measurements are close to each other.
- A result is repeatable if the same measurement is made more than once by the same investigator using the same equipment under the same conditions.
- A result is reproducible if another investigator, following your method, obtains data that leads them to the same conclusion as yours.
- A measurement is valid if it measures what is supposed to be measured.
- Experimental uncertainty is the doubt associated with the value derived from measuring a variable.
- An outlier is a data point that does not fit the pattern of the rest of the data, and so is acting as a source of error.
- Personal errors arise as a result of mistakes or miscalculations on the part of the investigator.
- Systematic errors are predictable errors that arise through imperfections in the equipment used to take the measurements.
- Random errors are variations in the data and result in less precision in your measurements.

Concept questions 5.3

1 List the main steps in conducting an investigation.

2 **a** How is an aim different from a hypothesis?
b Hypothesis testing is the basis of most scientific investigation. What does this mean?

3 Quantitative data usually includes measurements.
a What are the principal parts of a measurement in a scientific investigation?
b What are SI units and why are they used?

4 Fair testing is a basic premise of scientific methodology. What are the components of fair testing?

5 Differentiate between the following terms when discussing data: reliability, precision, reproducibility, uncertainty, accuracy, validity, outlier.

HOT Challenge

6 Scientific errors are an important component of all measurements. Errors are additive and increasingly large errors can compromise the data to the extent that the investigation 'falls over'.
a Classify the different types of scientific errors.
b What does the scientist do to limit scientific errors?

5.4 Health, safety and ethics

Health and safety considerations are paramount when planning a scientific investigation. You need to make sure that you stay safe, that others stay safe and that the environment stays safe.

Risk assessment

Risk assessment is the process of evaluating potential risks involved in an investigation. Even if this is not a requirement for your own investigation, you should consider the following.

- What are the possible risks to you, to other people, to the environment or to property?
- How likely is it that there will be an injury or damage?
- If there is an injury or damage to property or the environment, how serious are the consequences likely to be?

If you intend to use hazardous chemicals you will need to locate the accompanying safety data sheet (SDS). This provides information on how the chemical affects health and safety (Figure 5.17). It gives guidance on safe handling and storage procedures for the chemical, as well as emergency procedures for exposure and considerations for the correct disposal of the chemical. The SDS for a chemical can usually be found by an internet search or looking on the manufacturer's website. It is important to read the SDS when assessing the risk associated with the use of the chemical and the precautions you should take in your investigations.

Table 5.7 Matrix for assessing severity of risk

Likelihood	Consequences			
	Negligible	Marginal	Severe	Catastrophic
Rare	Low risk	Low risk	Moderate risk	High risk
Unlikely	Low risk	Low risk	High risk	Extreme risk
Possible	Low risk	Moderate risk	Extreme risk	Extreme risk
Likely	Moderate risk	High risk	Extreme risk	Extreme risk
Certain	Moderate risk	High risk	Extreme risk	Extreme risk

Once you have considered possible risks, you need to plan how to address them. What will you do to minimise them, and what will you do to deal with the consequences if something does happen? This may be as simple as using personal protective equipment such as 'always wear a lab coat, gloves and safety glasses'.

Table 5.8 Risk assessment table

What are the risks in doing this investigation?	How can you manage these risks to stay safe?
The fertiliser might be spilled on clothes or skin during application.	Wear a lab coat, gloves and safety glasses. Clean spills immediately.

Safe use and disposal of biological material

Weblink
Sterile technique

When dealing with many biological materials, it is important to be aware of safe handling and disposal. For example, when growing known or unknown microbes on agar plates it is important to use safe sterile techniques. These include taping the lid of the plates securely to the bases, not opening the plates once they are sealed and to wear lab coats, safety glasses, gloves and, if required, a face mask. Treat all microbes on agar plates as potentially pathogenic: you need to kill the bacteria by heating used plates in an **autoclave** before disposing of them. If you are uncertain about how to dispose of material used in your investigation, see your teacher or laboratory technician for assistance.

Rowe Scientific Hydrochloric Acid 25-37% w/w (7.7-12M HCl)

ROWE SCIENTIFIC

Chemwatch Hazard Alert Code: **3**

Chemwatch: **32-3051**
Version No: **6.1.1.1**
Safety Data Sheet according to WHS and ADG requirements

Issue Date: **24/04/2019**
Print Date: **24/04/2019**
S.GHS.AUS.EN

SECTION 1 IDENTIFICATION OF THE SUBSTANCE / MIXTURE AND OF THE COMPANY / UNDERTAKING

Product Identifier

Product name	Rowe Scientific Hydrochloric Acid 25-37% w/w (7.7-12M HCl)
Synonyms	CH1100; CH1150; CH1160; CH1175; CH1180; CH1181; CH1182; CH1183; CH1185; CH1190; CH1191; CH1192; CH1200; CH1201; CH1680; CH1707; CH1730; CH1740; CH0040
Proper shipping name	HYDROCHLORIC ACID
Other means of identification	Not Available

Relevant identified uses of the substance or mixture and uses advised against

Relevant identified uses	Laboratory chemical.

Details of the supplier of the safety data sheet

Registered company name	**ROWE SCIENTIFIC**
Address	11 Challenge Boulevard Wangara WA 6065 Australia
Telephone	+61 8 9302 1911
Fax	+61 8 9302 1905
Website	http://rowe.com.au/
Email	rowewa@rowe.com.au

Emergency telephone number

Association / Organisation	**Not Available**
Emergency telephone numbers	+61 8 9302 1911 (24 Hrs)
Other emergency telephone numbers	Not Available

SECTION 2 HAZARDS IDENTIFICATION

Classification of the substance or mixture

HAZARDOUS CHEMICAL. DANGEROUS GOODS. According to the WHS Regulations and the ADG Code.

Poisons Schedule	S6
Classification [1]	Metal Corrosion Category 1, Skin Corrosion/Irritation Category 1B, Serious Eye Damage Category 1
Legend:	*1. Classified by Chemwatch; 2. Classification drawn from HCIS; 3. Classification drawn from Regulation (EU) No 1272/2008 - Annex VI*

Label elements

Hazard pictogram(s)	
SIGNAL WORD	**DANGER**

Continued...

Figure 5.17 An example SDS for hydrochloric acid

Ethical guidelines

Ethics is a system of moral principles that considers what is good and bad for society. Put simply, it is what is right and wrong. **Bioethics** is ethics in the context of biological research. You need to consider ethical guidelines relevant to your selected investigation during the planning stages of your investigation.

WB 5.4.1 ETHICAL GUIDELINES PAGE 137

The following approaches can help guide you through ethical considerations relating to your investigation.

» Consequences-based: aims to maximise the positive effects (benefits) and minimise the negative effects (harms) of a particular action. The *end results* are key in this approach.
» Duty- and or rule-based: states that people have the duty to act in a certain way, and obey certain rules, regardless of the outcome. The *actions*, or *means*, are key in this approach.
» Virtues-based: The moral character or virtue of the person conducting the action is considered: are they seeking to exhibit 'good' characteristics and behaviours? In this approach, the *person conducting the action* is key.

There are several concepts relating to acting ethically in your research.

» **Integrity** is about being honest as a scientist. This means recording data accurately and not ignoring, hiding or changing any data that does not support your hypothesis. It means acknowledging and referencing sources of information, including books, websites, articles and people who have helped you. It means not using other people's ideas or data without their knowledge or permission. It also means allowing others to scrutinise your work fully to further public knowledge and understanding. Put simply, showing integrity is 'doing the right thing'. A good rule is that if you would not want someone to know what you were doing, you probably should not be doing it. It is no different from behaving ethically in any other area of your life.
» **Justice** is the moral obligation to consider competing claims, not place unfair burden on a particular group and to fairly distribute or allow access to the benefits of an action.
» **Respect** means giving intrinsic or instrumental value to living things, and being considerate of their welfare, freedom and autonomy, their beliefs, perceptions, customs and cultural heritage. It also means considering that living things can make their own decisions and, when they have diminished capacity to do so, they are empowered and protected.

When planning your research, you should also be guided by the ethical principles of:

» **beneficence**, which is a commitment to maximise the benefits and minimises the risks and harms involved in taking a particular course of action
» **non-maleficence**, which is the commitment to avoid causing harm, and ensuring that any harm caused is proportional to the benefit gained from taking that course of action.

Refer to the VCE Biology Study Design for further information about the ethical conduct of scientific investigations (p. 5) and ethical approaches and concepts (pp. 15–16).

KEY CONCEPTS

» Health and safety considerations are paramount when planning a scientific investigation.
» Risk assessment is the process of evaluating potential risks involved in an investigation and how to manage them.
» Ethics is a system of moral principles that considers what is good and bad for society.
» Bioethics is ethics in the context of biological research.

Concept questions 5.4

1 What components does a good risk assessment include?
2 Can you mitigate all risk?
3 Why is it necessary to perform a risk assessment for scientific investigations?
4 Distinguish between consequences-based, duty-based and virtue-based ethical approaches.
5 Safety Data Sheets are maintained by laboratory technicians and are monitored by risk departments at whatever institution is performing research. What is your responsibility in relation to safety data sheets?

HOT Challenge

6 Non-maleficence is a construct relating to ethics. How does it relate to science?

Part B: scientific evidence

5.5 Collecting and analysing data

As already stated, primary data is data that you have collected yourself. Collecting primary data can be time-consuming so it is important that, when you come to do it, you do it correctly and efficiently.

Collecting raw data

To determine a relationship between your variables, you need to have enough data points and the range of your data points should be as large as possible. A minimum of six data points (therefore six replicates) is generally considered adequate, but collect as many as you reasonably can, given the available time.

The raw data should always be recorded directly in the logbook unless it is recorded using data loggers connected to a computer. In this case a printout of the data should be attached to the logbook and the filename and location recorded. Make sure that you measure and record everything you will need for your analysis. For example, if you are investigating the effect of disinfectant on bacterial growth, you would record the concentration of disinfectant used, the time of day and the temperature. It is much better to measure something and then discover that you did not need to, than to start your analysis and realise that you did not measure something that you need.

Use appropriate units; for example, millimetres (mm) for length, width and height, degrees Celsius (°C) for temperature and grams (g) for mass. If you are going to be collecting multiple data points, it is a good idea to draw a table to record them. Label the columns in the table with the name and units of the variables. Do not put the units in the table cells. Note that the instruments you use will often restrict the accuracy of your measurements. For example, a ruler may only have markings down to 0.1 cm. Make a note of these restrictions because they may affect the accuracy of your final results, especially if the changes measured are small.

Analysing your data

5.5.1 ANALYSING YOUR DATA PAGE 139

Having gathered your data, there are usually a number of steps you need to take to analyse it. This allows you to draw meaningful conclusions from your investigation, leading you to either support or refute your hypothesis. Usually, you will use descriptive statistics to describe the data, such as calculating the mean, plot a graph of the data, and try to determine whether any trends or patterns emerge in the data.

If you are collecting a number of measurements from the same experimental condition then you might like to know the central value of the data, or the mean (also known as the average). The mean value is used when a set of data does not have outliers. Any outliers in the data will affect the mean by skewing it towards the lower or higher end. The mean value is useful for comparing sets of data.

$$\text{Mean} = \frac{\text{sum of all values}}{\text{number of values}}$$

Calculating percentage change is useful, particularly when you want to identify a trend but your starting values vary. For example, imagine you are studying the effect of salt concentration of osmosis in potato cores. When you create your potato cores, they are likely to have different starting masses. In order to make the trends in the data more apparent, you can use the formula below for percentage change.

$$\text{Percentage change (in mass)} = \frac{\text{final mass} - \text{initial mass}}{\text{initial mass}} \times 100$$

Record all your analyses in your logbook. If you do your analysis on a computer, then record the file name and location and attach a printout of the analysis to your logbook. Many scientists have logbooks that are bulging with printouts of their analysis.

Diagrams

You may find that it is important to include scientific diagrams in your results. You may want to include drawings of your experimental equipment and how it is set up when collecting data, drawings of structures under the microscope, or drawings of organisms that you are studying in your investigation. Like other kinds of data, diagrams require a figure number and a clear title. There are other important rules to follow when constructing scientific drawings (Figure 5.18).

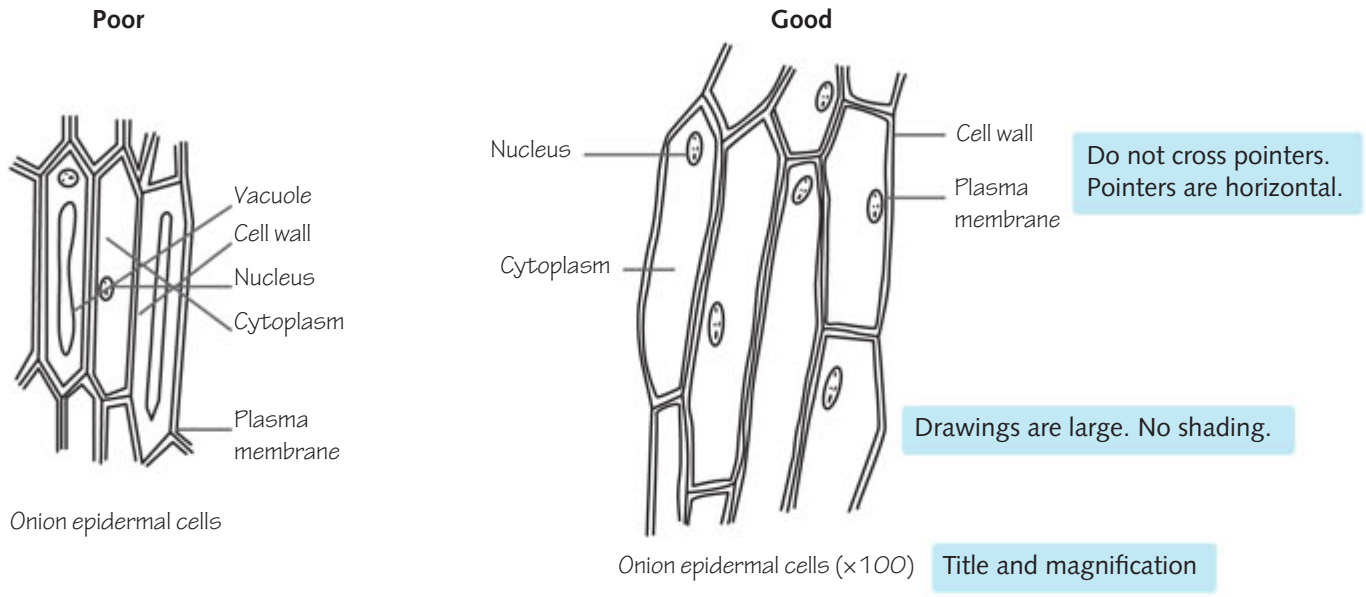


Figure 5.18 Features of effective scientific drawings

Tables

When recording data from your investigation, you will most likely write it down in a table. The advantage of this is that you can organise your data as you record it and begin to identify trends. A well-organised table saves you significant time later. Your table should have a clear title and be organised so that you can easily record and compare your independent and dependent variables. If you have completed any calculations on your data, you should record this information alongside your primary data. An example is shown in Figure 5.19.

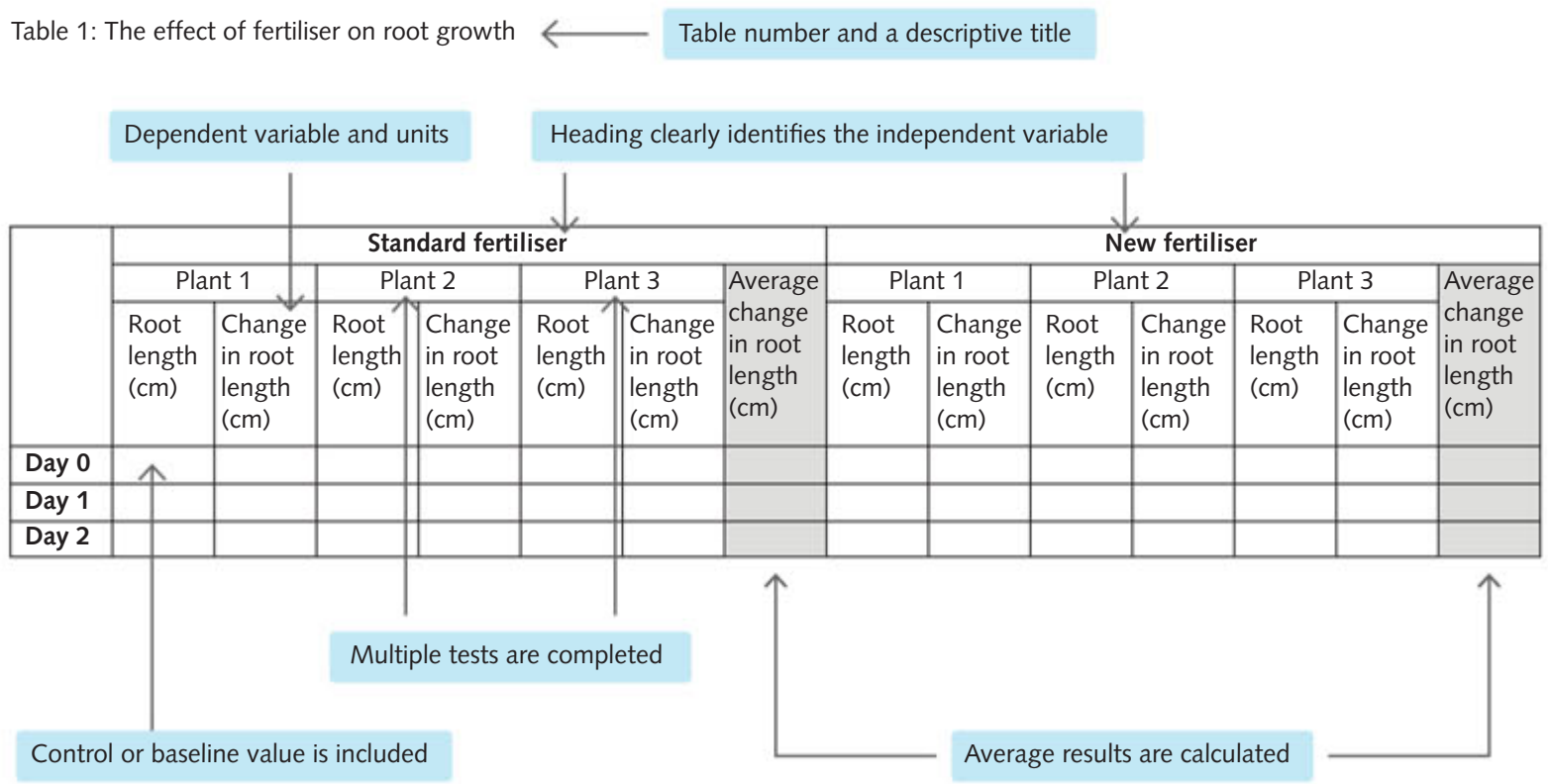


Figure 5.19 Features of an effective table to record primary data and simple statistics

Graphs

You may be able to see a pattern simply by looking at the list of numbers in your table. However, perhaps the easiest way to identify a pattern in data or a relationship between variables is to plot a graph. Figure 5.20 provides two examples of well-constructed graphs. A graph should be large and clear. The axes should be labelled with the names of the variables and their units. The variable that you are measuring (dependent) goes on the vertical axis and the variable that you are altering (independent) goes on the horizontal axis. Choose a scale so that your data takes up most of the plot area. The origin (0,0) does not always need to be shown in graphs, but by including it you will provide an honest representation of the data without any exaggeration.

Note:

The acronym DRY MIX can help you remember how to plot variables on a graph.
D = dependent variable
R = responding variable
Y = y-axis
M = manipulated variable
I = independent variable
X = x-axis
Plot the dependent (responding) variable on the y-axis. Plot the independent (manipulated) variable on the x-axis.

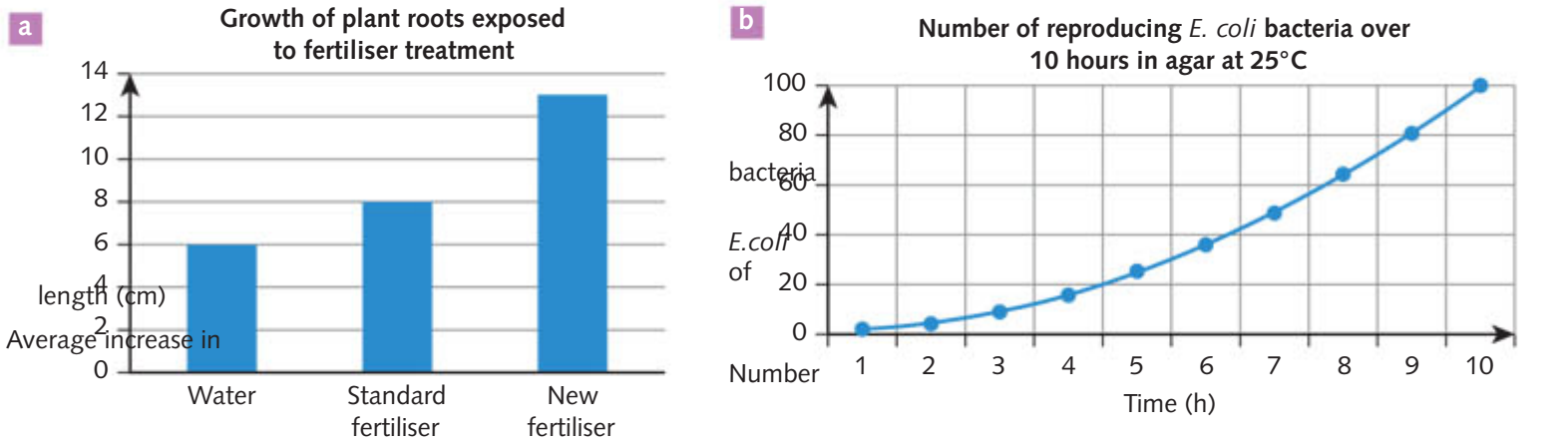


Figure 5.20 A correctly drawn a bar graph and b line graph

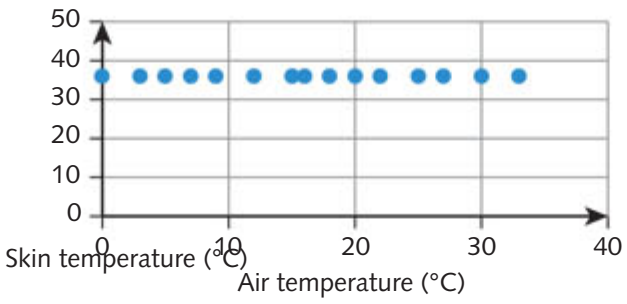
Interpreting your results

Once you have visualised your data by plotting it in a graph, you can begin to consider what trends, patterns or relationships the results are showing, and determine whether the trends are likely to reflect the true relationships between the factors in your study. You can then relate your findings to your research question and hypothesis.

Determining relationships

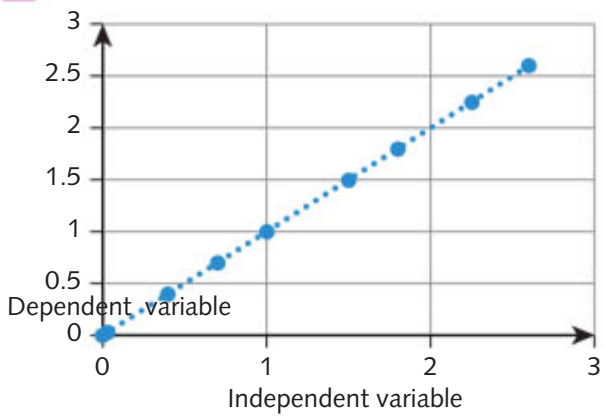
When you have created a graph of your data, provided you have carefully considered the scale of your graph and you have considered any outliers, you should be able to see any relationships evident in the data. When writing your results section in your report, you should describe any relationship that you notice between the independent and dependent variables, noting the gradient or slope of the graph. You should then try to interpret whether the relationship between the independent and dependent variable is a causative one (i.e. your data are a result of the treatments or test groups in your investigation). Your interpretation of the data, and what it means to the field of science that you are investigating, should be explained. Figure 5.21 explains the types of relationships that you may observe in your data.

a **No relationship**



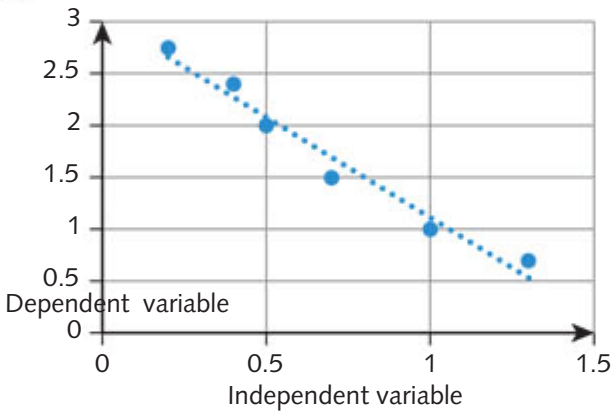
No relationship is evident between the two variables because the skin temperature remains constant.

b **Linear relationship**



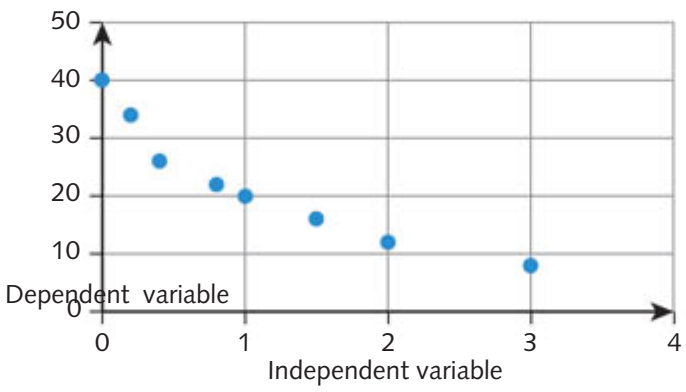
The dependent variable is directly proportional to the independent variable. There appears to be a correlation between the values.

c **Inverse relationship**



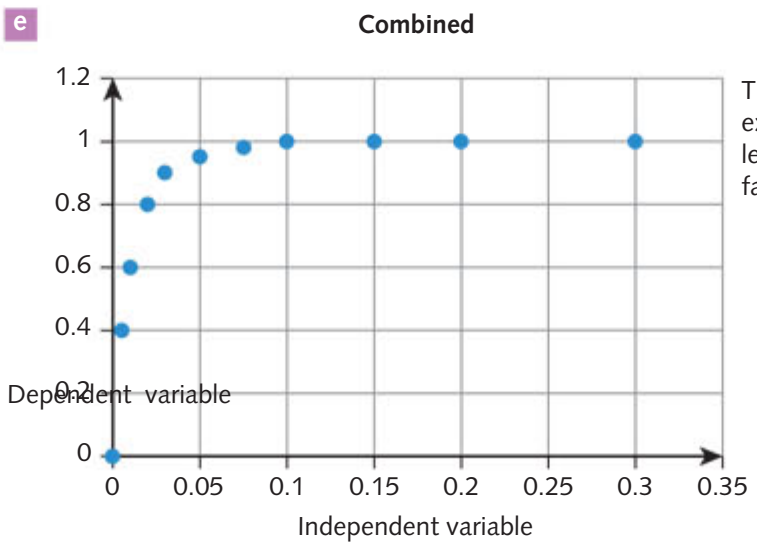
The dependent variable is indirectly proportional to the independent variable. There appears to be an inverse correlation between the values (the dependent variable increases when the independent variable decreases).

d **Exponential relationship**



There is an inverse exponential relationship. As the independent variable increases, the dependent variable decreases.

e **Combined**



The initial increase is positive and exponential. The graph then levels off, which indicates that the factor is no longer changing.

Figure 5.21 **Different types of relationship that may be evident in data. It is possible that there will be no mathematical relationship (panel a), there may be a clear linear relationship (panels b and c) or an exponential relationship (panels d and e).**

Relating your results to your hypothesis

Note:
$\overline{X}$ is a symbol for mean.

Once you have analysed your results you need to interpret them. This means being able either to answer your research question or to state whether your results support your hypothesis. If you have performed a statistical analysis, does this support your hypothesis?

For example:

- after 10 days, the mean number of bacterial colonies on the agar plates with the concentrated disinfectant: $\overline{X} = 16$ and diameter: $\overline{X} = 0.4$ mm
- after 10 days, the mean number of bacterial colonies on the agar plates with the dilute disinfectant: $\overline{X} = 52$ and diameter: $\overline{X} = 1.4$ mm.

With all other variables being equal, this would support the hypothesis that *If* the more concentrated disinfectant is used rather than the dilute disinfectant *then* the number and size of bacterial colonies will be less (Figure 5.22). If there was no difference between the two experimental set-ups, or if there were more bacterial colonies of a larger size on the agar plates with concentrated disinfectant, this would not support the hypothesis.

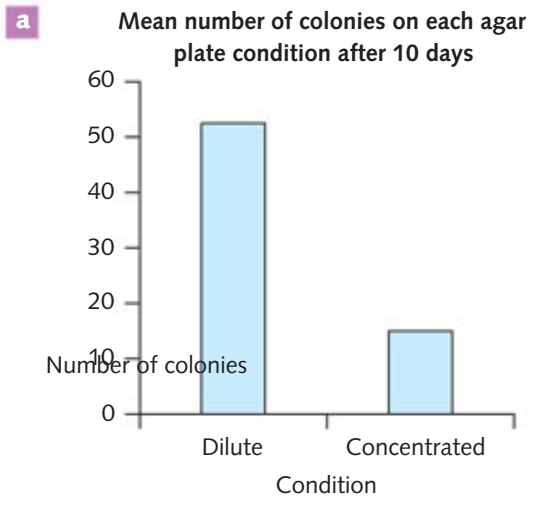


Figure 5.22 Bar graphs that show that there is a difference between the independent variable, which supports the hypothesis: **a** number of colonies; **b** width of colonies

If your hypothesis is not supported

If there is not a significant difference in your data, it may be that the hypothesis was not supported by the data. This may occur if the investigation was not able to show the effect posed by the hypothesis; for example, by not having enough replicates to reduce variability and produce a significant difference. Alternatively, the hypothesis may be wrong. However, it is not enough to simply say 'our hypothesis is wrong'. If the hypothesis is wrong, what is wrong with it?

You may have used a method that is too simple or did not take into account all of the other variables. For example, in the bacterial growth investigations, the disinfectant may work best at a particular temperature, or over a longer time, or in conjunction with other unknown conditions. Or maybe it does not work with the type of nutrient agar you chose to use. It may be that the investigation was simply too limited to test the hypothesis fully. You might conclude that further investigations are required to test these other variables.

Before you decide that the method is at fault, however, check carefully that you have not made mistakes or ignored any variables. Think carefully about factors that you did not take into account but which might have affected your investigation. Go through your method, results and analysis. Check that your equipment was correctly calibrated and that you were using it correctly. Check that your data are recorded in the correct units and that the units are correctly carried through all calculations during analysis. Check your analysis carefully. If you are working in a group, get another person to repeat the calculations.

If you are certain your investigation results are real, and they still refute your hypothesis, do not be disappointed. The process of scientific inquiry is often propelled forward when old hypotheses are tested and refuted, and new observations made that pave the way to discoveries that change our understanding of biological systems.

KEY CONCEPTS

- To determine a relationship between your variables, you need to have enough data points and the range of your data points should be as large as possible.
- Raw data is analysed and summarised as diagrams, tables or graphs.
- Determine any relationships or trends in your data.
- Relate your results to your hypothesis, which is either supported or refuted.

Concept questions 5.5

1 Differentiate between raw data, primary data and secondary data.
2 A good hypothesis relates to the independent variable and the dependent variable. What does this mean?
3 State two reasons why the data collected during an investigation may not support the hypothesis.
4 a Scientists look for trends in data. What does this mean?
b Scientists look for relationships in data. What does this mean?
5 How do you relate the data to the hypothesis?

HOT Challenge

6 If you do not like the look of some of your data, what do you do with it?

Part C: scientific communication

5.6 Communicating your results

If scientific research is not communicated to others, then no one else can learn from it. An investigation is not complete until this has happened. There are a number of ways to communicate the results of a scientific investigation. The VCE Biology Study Design (p. 21) specifies which methods you can select from to communicate your Outcome. These methods are shown in Figure 5.23 and each is explained in more detail below.

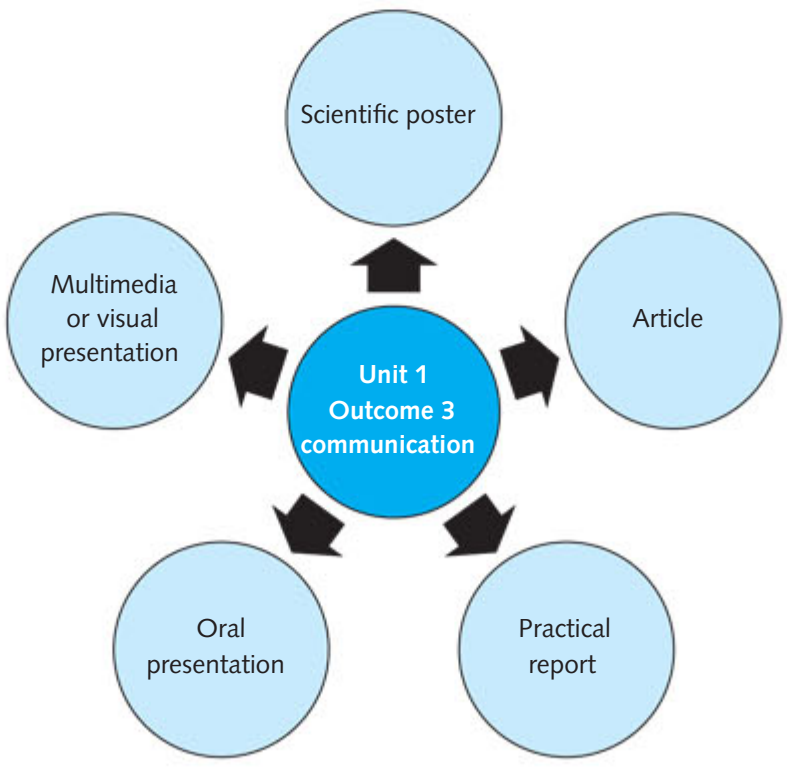


Figure 5.23 There are many different ways to present your findings.

Presenting your work as a scientific poster

Here are some things to consider if you decide to format your scientific investigation into a poster. The length and size of the poster will be determined by your teacher. As the word count may be limiting, you will need to think very carefully about what you put in each section of the poster (Table 5.9).

Title

The title for your poster is the research question that you are investigating.

Introduction

The introduction to your poster could also be called the background research that you undertook in the planning stages of your investigation. The introduction outlines the existing knowledge surrounding the research topic. This is the place to summarise any existing theories, models, concept and similar studies, all of which should be correctly referenced, as described in the section on referencing below.

The introduction contains a clear aim and a stated hypothesis for the investigation with (or without) a prediction of whether you think the hypothesis will be supported or refuted.

Methodology and methods

The methodology is the framework of the approach that you have adopted to investigate your hypothesis.

The method used in your investigation should be briefly but clearly described in sentences. In the case of presenting it for the poster, it is not necessary to have the complete sequence for someone else to follow. Instead it can be a series of explained photographs or diagrams that summarise what you did. You are not commanding anyone to do anything. You are telling people what you did. For example, you would write 'bacterial colony diameter was measured' not 'measure the diameter of the bacterial colony'.

If your study contains potential safety issues or ethical considerations, these should be identified in this section and the ways in which these issues were handled should be described briefly.

Table 5.9 Sections in a poster

Section	What it includes
Title	Question under investigation
Introduction	Brief explanation or reason for undertaking the investigation, including a clear aim, hypothesis and/or prediction and relevant background biological concepts
Methodology and methods	Brief outline of the selected methodology used to address the investigation question Summary of data generation method/s and data analysis method/s
Results	Presentation of generated data/evidence in appropriate format to illustrate trends, patterns and/or relationships
Discussion	Interpretation and evaluation of analysed primary data Identification of limitations in data and methods, and suggested improvements Cross-referencing of results to relevant biological concepts Linking of results to investigation question and to the aim to explain whether or not the investigation data and findings support the hypothesis Implications of the investigation and/or suggestions as to further investigations that may be undertaken
Conclusion	Conclusion that provides a response to the investigation question Identification of the extent to which the analysis has answered the investigation question, with no new information being introduced
References and acknowledgements	Referencing and acknowledgment of all quotations and sourced content relevant to the investigation

Results

The results section is a summary of your results together with schematic diagrams, flow charts, bar charts, tables or line graphs showing trends in the data (Figure 5.24). Do not interpret your results in this section. Make sure you always label your axes, including units. Choose an appropriate scale so that the data takes up most of the plot area. Do not include tables of raw data in your report or poster.

When stating the finding of your study in the main text of the results section, refer immediately afterwards to the figure in which the finding is shown, for example 'The bacterial growth in the diluted disinfectant condition was significantly greater after 6 days (Figure 1).'

Figures

There are several different types of figures that may be included in a scientific poster. The most informative figures are quantitative, such as graphs or tables, although it is often useful to include qualitative data such as cross sections or photographs. Regardless of the type of figure used, it should be chosen for its ability to communicate the findings of the study. Sometimes a figure will have multiple panels (labelled A, B etc); for example, a graph and a photograph showing the same pattern could be presented in two panels of the same figure.

Each diagram should have a figure number, and you should refer to it in the text of your poster. Position the diagram close to where it is referred to in the text. Figure captions are essential. They are usually below the figure and begin with the figure number followed by a brief description of the figure.

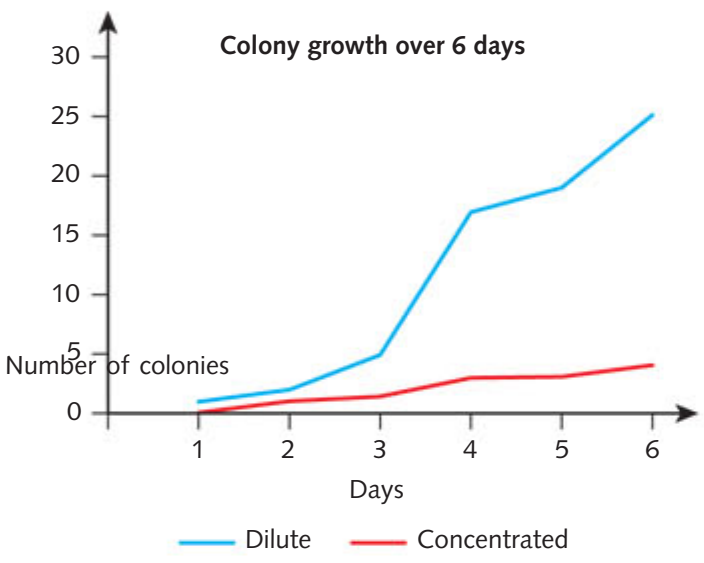


Figure 5.24 Line graph showing colony growth over time for the two conditions

Discussion

In the discussion section you need to use the evidence that you have produced from your investigation to construct a scientific argument about how well your investigation answered your research question and achieved the intended aim(s). This is probably the most difficult part of the report that you have to write.

Some questions you should consider when writing your discussion section are:

- What relationships did you observe in your data?
- Did your results support or refute your own hypothesis?
- How could you improve your investigation design to more accurately address your hypothesis?
- What do your results add to the current scientific knowledge of biological concepts?
- Do they agree with or contradict models or classification keys based on other published findings?
- What were the implications of your study, and how could you address these in hypothetical or real future studies?
- How might your findings impact the scientific community, industry, medical practice or the community at large?

It will be difficult to address all these questions in the limited space you have available. Start by writing all the key points down and then read through several times, cutting down unnecessary words each time. Do not remove your own connections or ideas. This type of critical thinking is often a significant part of what is assessed in scientific writing. Remember that concise, coherent writing is an important scientific skill to practice.

Conclusion

This short section allows you to draw conclusions based on the evidence you have gathered during your study. It is a very brief summary of the results and their implications. It should provide a response to your research question and directly address the hypothesis you proposed in your introduction. The conclusion should also state the extent to which the analysis answered the research question, without introducing new information. A conclusion should only be a few sentences long.

References

A reference list details all the sources of information that were actually used to write the text and figures for the poster. Wherever a piece of information or quotation is used in your poster it must be referenced at that point. This is typically done by placing a number in brackets at the point [2], or the author and the year of publication (Smith 2019), depending on which referencing style you use. The reference list is provided in a single, alphabetical, complete list at the bottom of the poster. Referencing must be done in a consistent style. Check with your teacher as to what style is preferred.

Acknowledgements

You should thank anyone who helped you in your investigation. This includes people who supplied equipment or funding, as well as people who gave you good ideas or helped you with the analysis.

Article

Presenting your investigation as an article requires you to organise your material into a sequence similar to that of a poster, but you do not include all the sections. As your audience may not necessarily have a science background your writing style must be clear, straightforward, logical and easy to follow. You want to use a writing style that will grab your reader's attention, take them along for the ride and convince them that you have investigated a real problem and made significant advances with your discoveries.

WB 5.6.1 PRESENTING YOUR WORK AS AN ARTICLE PAGE 141

You will organise your article into:

- Introduction – here you will explain the problem you are addressing and what other people have done to address this problem. Why are you addressing this problem again?
- Method – how did you address the problem? Was this design rigorous and appropriate?
- Results – what did your investigation find out?
- Discussion – what do your results mean in terms of the problem and what is the significance of this?
- Conclusion – draw the threads of your investigation into one or two well-thought-out sentences.

Practical report

At this stage of your schooling, you have undoubtedly submitted many reports to your science teacher following a practical exercise. You may have observed that the sub headings when completing a scientific poster are very like those you would have encountered when completing your earlier reports. Where the focus in the poster is on the discussion of your findings and the conclusions drawn, the primary purpose of the practical report is to add a detailed description of the methodology and method employed to complete your investigation. The discussion and conclusion are also important; however, your method needs to be able to stand up to scrutiny when others look at your findings. The method must be able to be replicated by others in order to reach the same conclusions you have.

Oral presentation

If using an oral presentation, you have a captive audience that you can take on a journey of discovery about your investigation. Ask yourself whether the mode of communication is addressing the planned need. You can interact with the audience to clarify their understanding and to answer questions. Always consider the journey for your audience. Retain your audience's attention by explaining scientific concepts and technologies clearly and succinctly. Build up your audience's knowledge in steps. If you begin with ideas and terminology that are too complex, your audience will be lost from the beginning and it will be difficult for you to reconnect with them. Use metaphors, diagrams, animations and models to help the audience understand the science. Always clearly label or describe all components and remove any unwanted components that could distract the audience. Allow your audience enough time to digest a piece of information before moving on to a new piece of information. Stop and recap to remind the audience of the journey and describe how this understanding led to the next logical step in the investigation.

Multimedia or visual presentation

Your multimedia presentation could be in the form of a video or could be presented using PowerPoint, Keynote or Prezi, for example. This gives you the opportunity to present your investigation in a visually exciting manner. Make sure that you cover all the key points including the methodology, method, results and discussion. You can include video or photographs to show the audience the experimental setup. You could either record the narration of your presentation or narrate it to the audience as it is shown. Either way, make sure you have a well-prepared script.

KEY CONCEPTS

- An investigation is not complete until the information gained from the investigation has been communicated to others.
- Your communication piece could take the form of a poster, an article, a practical report, an oral presentation, multimedia presentation or a visual representation.

Concept questions 5.6

1. In your earlier school years, you referred to writing up experiments as producing a practical report. What is the difference from what you did then to what you are starting to do now?
2. In your logbook, you need to make sure you have an easily accessible list of all the parts of a senior experimental report. List the components.
3. The final presentation in Outcome 3 is a scientific communication. When you complete your draft sections in your logbook, you may find the information you want to include is far too much for the word or time limit you have been given. How do you handle this?
4. One of the things you need to consider in science communication is the audience you are reporting to. Why?

5 Why do you have to communicate your findings to others in a report following a particular format?

HOT Challenge

6 **a** Figure 5.25 shows a student logbook. Tabulate the data from the logbook into a qualitative data table and a quantitative data table, then graph the quantitative data.

b Has this investigator employed fair testing? If not, what was missing?

c What SI units were used?

d The original hypothesis determined by the investigator was 'If a weed is planted in a terrarium and initially lightly watered, then it will grow in height over time'.

i What was the aim?

ii What was the independent variable?

iii What was the dependent variable?

iv List three controlled variables.

v Was a control employed? Did it need to be?

vi Was the hypothesis testable?

vii In a conclusion for this investigation, what might be the statement about the relationship of the variables?

Collected data: terrarium observations

Qualitative data	
Day 1	Weed (1) looks upright, very green, seems to have grown a little but there are foggy drops forming on side of plastic wall.
Day 2	Weed still growing. More moisture on the wall. White patches appearing on the soil.
Day 3	Weed stopped growing. More white patches on the soil. An ant is climbing on the plant.
Day 4	More of the soil has become white. Might be a fungus. Leaves are a little taller but one of the leaves has a black patch on it.
Day 5	Not as many water-drops on the bottle wall. The weed has stopped growing. Black patch on leaf is bigger.
Day 6	A little mushroom has appeared in soil. Plant is a little taller. Ant disappeared.

Figure 1 Diagram of set-up of terrarium, Day 1

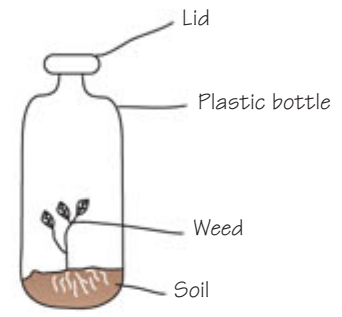
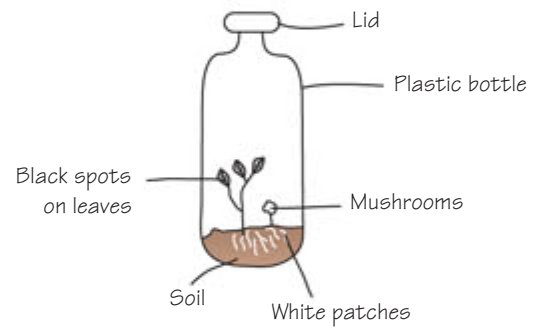


Figure 2 Diagram of terrarium, Day 6



Quantitative data	
	Height (cm)
Day 1	4.2
Day 2	4.7
Day 3	4.8
Day 4	5.0
Day 5	5.0
Day 6	5.0

Figure 5.25 Logbook raw data: height change in a weed growing in a terrarium over 6 days

Online Key Concepts
Chapter 5 summary of key concepts

5 Summary of key concepts

5.1 Choosing your topic

KEY CONCEPTS

p. 181

- VCE Biology Unit 1 Outcome 3 requires you to submit a student-adapted or student-designed investigation in a selected format.
- You need to set up a logbook at the beginning of your investigation for authentication and assessment.
- Write a research question that you want to answer with your investigation.

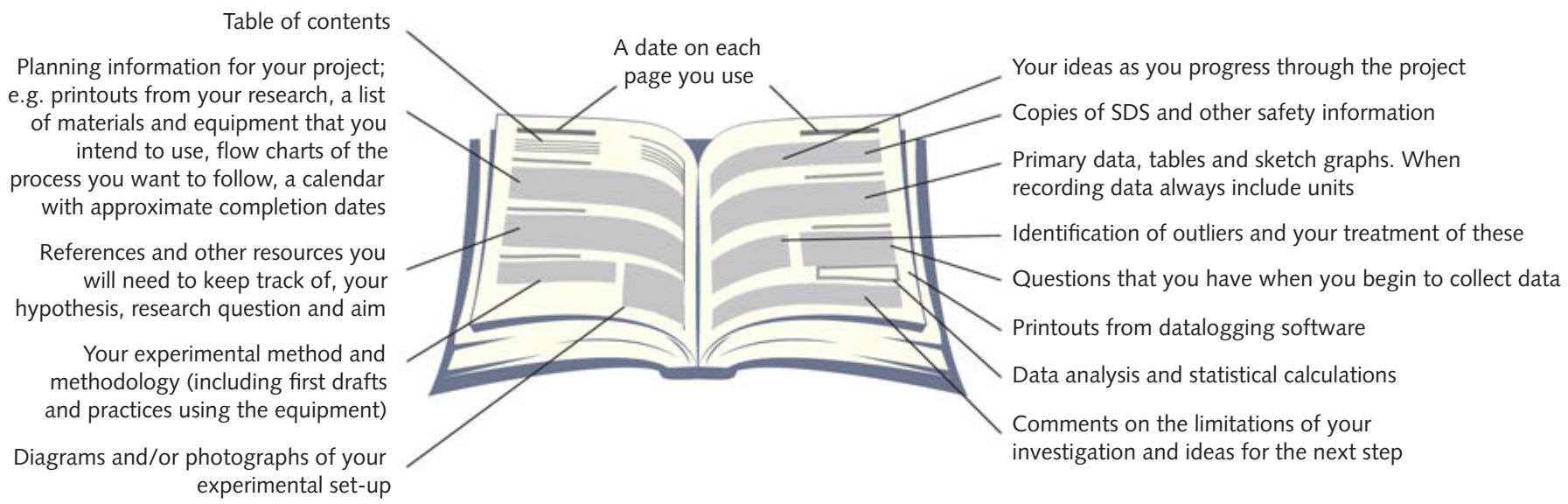


Figure 5.2 Features of an effective logbook

- Undertake background reading on your research question using reliable primary and/or secondary resources.
- Maintain a list of all your source material in your logbook.

Table 5.1 Types of information sources

Primary sources	Secondary sources
Scientific journals or periodicals Research reports Sessions presented at scientific conferences Patents Masters and PhD theses	Review journals or periodicals that summarise recent research Reliable websites, such as Nature.com Scientific TV programs or news reports about a scientific discovery Textbooks

Table 5.2 Features of reliable and unreliable information sources

Reliable sources	Unreliable sources
Contain current information and seek to inform the reader Contain information that is relevant to your project or inquiry Are from a reputable source such as a university or scientific research institution Contain information that is likely to be accurate (such as a peer-reviewed journal article) Avoid bias	Are not from reputable sources Present obvious bias Do not contain references for their claims Provide links to unscientific references Have not been updated regularly Promote or advertise a large amount of unrelated content

5.2 Types of scientific methodology

KEY CONCEPTS

p. 185

» Methodology refers to the broader framework of approach taken in the investigation to test your research question or hypothesis.

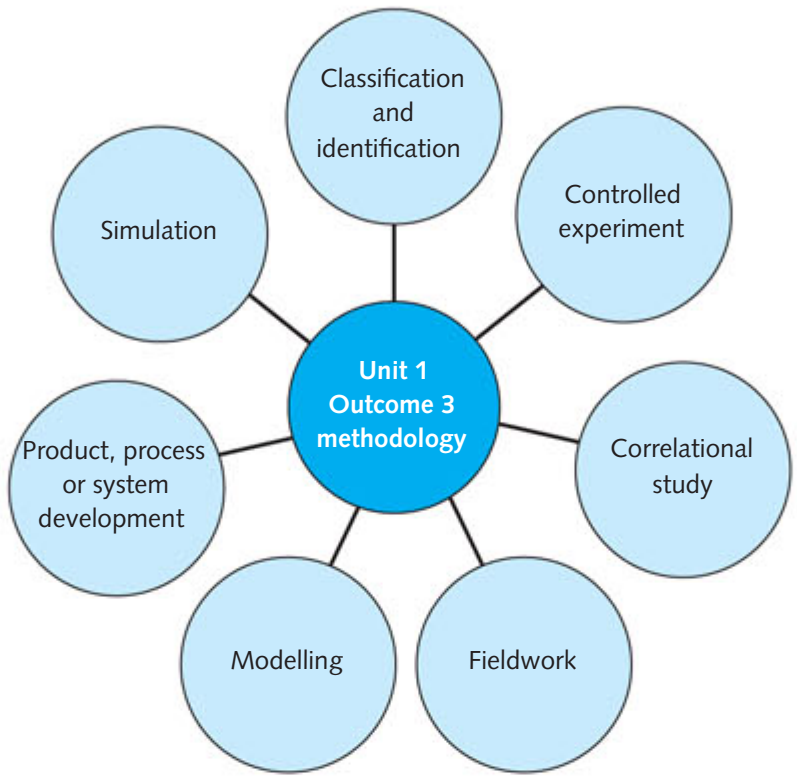


Figure 5.3 Choose one of these methodologies for your Unit 1 Outcome 3 report.

» Classification and identification methodology enables you to investigate a larger group of things and to classify them by placing them into like groupings and identify them by naming them.
» A controlled experiment methodology is when all factors that could affect the results of the experiment are kept constant, except the one under investigation.
» A correlational study methodology studies two factors to see if one affects the other.
» Fieldwork methodology is scientific investigation that is undertaken outside the laboratory.
» Modelling methodology can be used to represent biological systems or to predict the impact of one factor on another.
» Product, process or system development methodology is used to design an object or product, process or system that will assist a human in meeting their biological demands and requirements.
» Simulation and methodology allows you to use a model to simulate real life or part or whole of a system to gain knowledge of its functioning.

5.3 Quantitative and qualitative data

KEY CONCEPTS

p. 194

- The aim of an investigation is the reason why you are undertaking the investigation.
- A model is a visual, mathematical or computer-based representation of an idea that cannot be seen or experienced.
- A theory is a well-established explanation of scientific data.
- A law is a general rule that explains repeated experimental observations and is usually in the form of a verbal or mathematical statement.
- A hypothesis is a tentative prediction or explanation of an observation based on an existing model or theory.
- Primary data is data that you collect yourself via an investigation.
- Quantitative data is data that is a quantity and is recorded numerically.
- Qualitative data is non-numerical and can be directly observed; it is a quality.
- A measurement is accurate if it is close to the true value of the parameter being measured.
- A precise measurement is when repeated measurements are close to each other.
- A result is repeatable if the same measurement is made more than once by the same investigator using the same equipment under the same conditions.

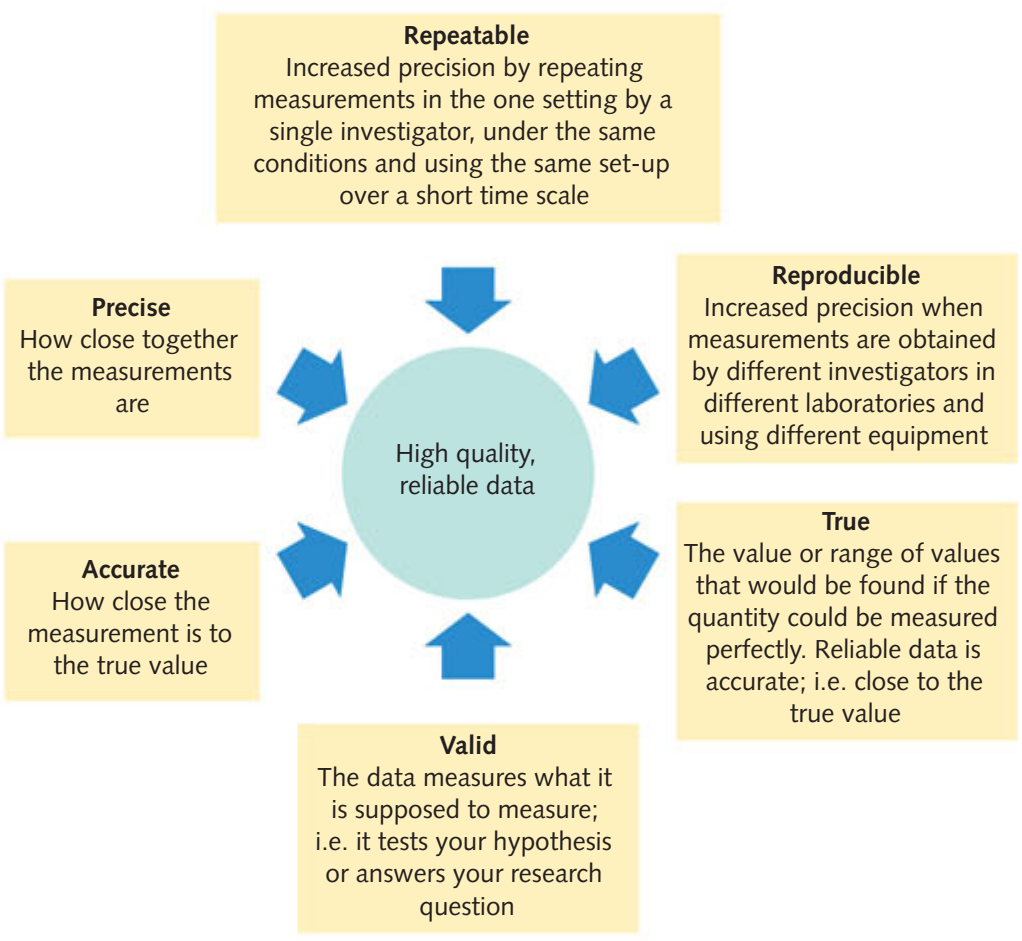


Figure 5.16 Features of data from a well-designed investigation

- A result is reproducible if another investigator, following your method, obtains data that leads them to the same conclusion as yours.
- A measurement is valid if it measures what is supposed to be measured.
- Experimental uncertainty is the doubt associated with the value derived from measuring a variable.
- An outlier is a data point that does not fit the pattern of the rest of the data, and so is acting as a source of error.
- Personal errors arise as a result of mistakes or miscalculations on the part of the investigator.
- Systematic errors are predictable errors that arise through imperfections in the equipment used to take the measurements.
- Random errors are variations in the data and result in less precision in your measurements.

5.4 Health, safety and ethics

KEY CONCEPTS

p. 200

- Health and safety considerations are paramount when planning a scientific investigation.
- Risk assessment is the process of evaluating potential risks involved in an investigation and how to manage them.
- Ethics is a system of moral principles that considers what is good and bad for society.
- Bioethics is ethics in the context of biological research.

5.5 Collecting and analysing data

KEY CONCEPTS

p. 203

- To determine a relationship between your variables, you need to have enough data points and the range of your data points should be as large as possible.
- Raw data is analysed and summarised as diagrams, tables or graphs.
- Determine any relationships or trends in your data.
- Relate your results to your hypothesis, which is either supported or refuted.

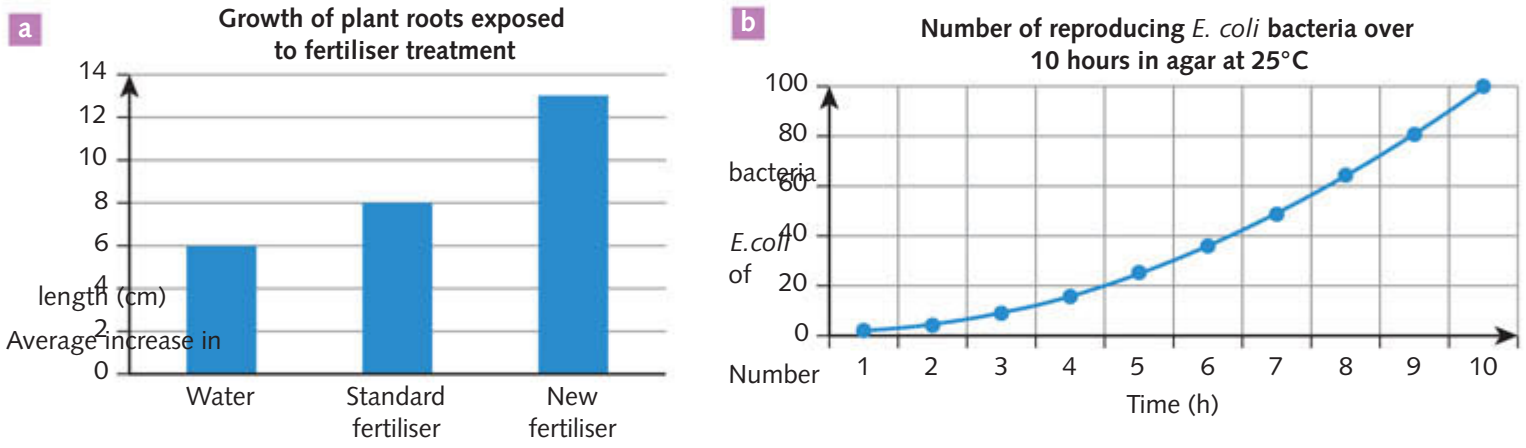


Figure 5.20 A correctly drawn **a** bar graph and **b** line graph

5.6 Communicating your results

KEY CONCEPTS

p. 208

- An investigation is not complete until the information gained from the investigation has been communicated to others.
- Your communication piece could take the form of a poster, an article, a practical report, an oral presentation, multimedia presentation or a visual representation.

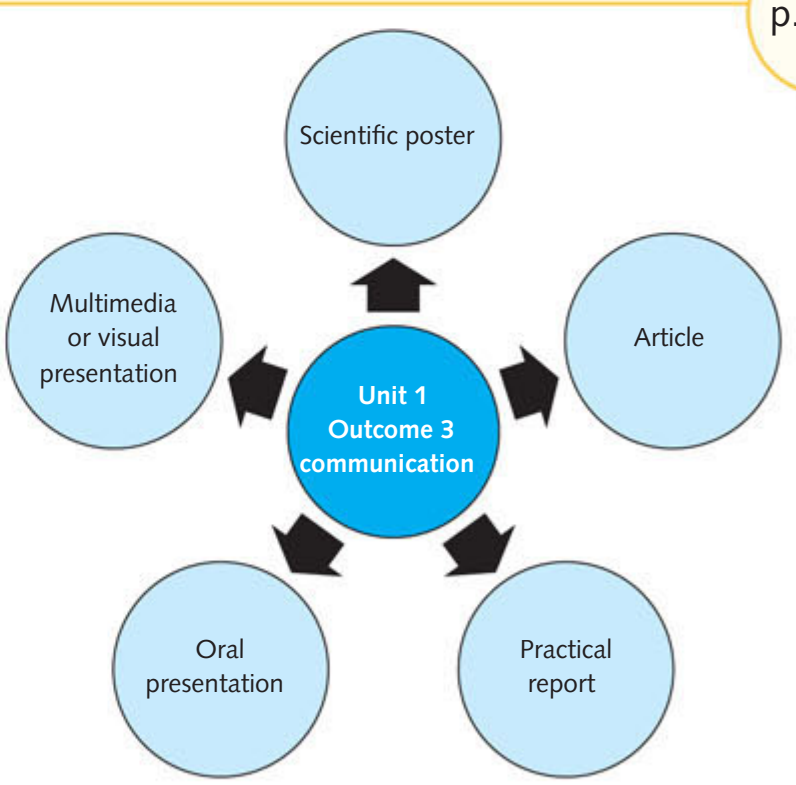


Figure 5.23 There are many different ways to present your findings.

WB 5.7.1 KEY TERMS Page 143

WB 5.7.2 PRACTICE TEST QUESTIONS PAGE 145

5 Chapter glossary

accurate a measurement that is close to the true value

aim the reason why you are undertaking the investigation

authentication showing that you undertook the research and wrote the report yourself

autoclave a device used to sterilise equipment, reagents or contaminated waste; autoclaves work by subjecting contents to pressurised steam at 121°C for a set time

beneficence the principle that an action should be done for the benefit of others; can be done by helping prevent or remove harm or by improving the situation of others; a duty to do more good than harm

bias the pushing by a source of a particular point of view

bibliography a list of sources consulted during research but not necessarily cited in the final report, paper or poster

bioethics ethics in the context of biological research

capture–mark–recapture an ecological survey technique used to measure animal populations: individual animals are captured, marked and released; after a time, the population is re-sampled and the proportion of marked animals among those caught gives an indication of population size

causation where a factor (the cause) can change another factor (the effect)

control group an experimental condition set up to compare to the condition receiving the independent variable

controlled variable a factor that is kept the same throughout an experiment so it does not influence the dependent variable

dependent variable the variable that is predicted to change as a result of changes to the independent variable; the variable that is measured

direct observation recording data on living things by looking at them in their natural habitat

ethics a system of moral principles to consider when undertaking scientific investigation; the principles are based on what is good and bad for society

extraneous variable a variable that could affect your results and that needs to be controlled

falsifiable able to be disproved

hypothesis a tentative prediction, usually based on an existing model or theory

independent variable the variable that is altered or manipulated in a scientific investigation

integrity an ethical concept that means being honest, transparent and professional about one's actions; a scientist shows integrity by reporting their data (even if it doesn't fit their hypothesis) and acknowledging all sources of information

International System of Units (Système International d'Unités, SI) a modern form of the metric system; a standardised worldwide system of measurements used in science and commerce

justice the moral obligation to consider competing claims, not to place an unfair burden on a particular group and to fairly distribute or allow access to the benefits of an action

law a general rule that explains repeated experimental observations and is usually in the form of a verbal statement or a mathematical statement

logbook the record of an experiment or investigation kept by the scientist performing the experiment; it is a legal record of the experiments and their results

mean the central value of a set of data points; also known as the average

method the numbered steps taken to carry out an investigation

methodology the broader framework of approach taken in the investigation to test your research question or hypothesis

model a representation of a system or phenomenon that explains the system or phenomenon; it may be mathematical equations, a computer simulation, a physical object, words or in some other form

non-maleficence the principle that we should act in ways that do not cause harm or inflict suffering upon others; a duty to minimise harm

outlier a data point that does not fit the pattern shown by other measured data points

personal error a mistake made by the investigator

precise describes repeated measurements that are close to each other

primary data data that you have measured or collected yourself

primary source a report of original research, such as an article in a scientific journal

quadrat a method used in population sampling where a square is placed on the ground to count each individual of a species and determine its density; useful for stationary organisms

qualitative data descriptive or non-numerical results

quantitative data measurements or results with numerical values

random error an error caused by an unknown and unpredicted factor

reference the source of a specific piece of information or quotation that you have used in writing your report

reliable highly likely to be true; a trustworthy source of information or reproducible data

repeatable giving the same result, within uncertainty limits, when repeated measurements are made by the original investigator

replicate one of several experimental samples subjected to all the treatment combinations to be compared in an experiment; for example, duplicate refers to two repetitions of the conditions, triplicate to three repetitions

reproducible giving the same result, within uncertainty limits, when repeated measurements are made by other researchers

research question the specific question that a particular experiment or investigation is attempting to answer

respect an ethical concept that considers the rights of an individual or group (person or other living organism); for example, respect for animals considers their welfare

risk assessment the process of evaluating potential risks involved in an investigation and how to manage them

sample a small group of organisms selected from the total population; is representative of the whole population

secondary source a summary, review or analysis of primary sources; a report, article, web page, person, institute or group from which background information was gathered

standard abbreviations shorter forms of a word or term that are conventionally used in scientific communication

subjective capable of being interpreted differently by different people, for example blueness of the contents in a test tube

systematic error a predictable error that arises through imperfections in the equipment used to take the measurements

theory a collection of models and concepts that explain specific systems or phenomena; scientific theories allow predictions to be made and hence are falsifiable

transect a method used in population sampling whereby a line is drawn through a community and information gathered along it is used to determine the distribution of species; can be used in conjunction with quadrats and is useful for stationary organisms

true value a value that would be obtained in an ideal measurement where there are no errors

uncertainty the doubt associated with the value derived from measuring a variable

valid describes results that are affected by only a single independent variable and hence are reproducible

Unit 2

How does inheritance impact on diversity?

Getty Images/Mint Imag

Area of Study 1: How is inheritance explained?

Area of Study 2: How do inherited adaptations impact on diversity?

Area of Study 3: How do humans use science to explore and communicate contemporary bioethical issues?

9780170452465

From chromosomes to genomes

6

By the end of this chapter you will have covered the following material.

Key knowledge

From chromosomes to genomes

- the distinction between genes, alleles and a genome pp. 225–231
- the nature of a pair of homologous chromosomes carrying the same gene loci and the distinction between autosomes and sex chromosomes pp. 231–233
- variability of chromosomes in terms of size and number in different organisms pp. 233–238
- karyotypes as a visual representation that can be used to identify chromosome abnormalities pp. 238–241
- the production of haploid gametes from diploid cells by meiosis, including the significance of crossing over of chromatids and independent assortment for genetic diversity pp. 241–247

Key science skills

Generate, collate and record data

- organise and present data in useful and meaningful ways, including schematic diagrams, flow charts, tables, bar charts and line graphs pp. 245–246

Construct evidence-based arguments and draw conclusions

- use reasoning to construct scientific arguments, and to draw and justify conclusions consistent with the evidence and relevant to the question under investigation pp. 245–246

Analyse, evaluate and communicate scientific ideas

- discuss relevant biological information, ideas, concepts, theories and models and the connections between them pp. 245–246

Online Chapter Map
Chapter 6 map

6 From chromosomes to genomes

Remember the cell nucleus? You learnt about this in Chapter 1. Well, this chapter is about what is inside the nucleus – the chromosomes – and how they contribute to heredity.

p. 225

6.1 Distinction between genes, alleles and a genome

A gene is a piece of DNA that codes for a specific protein. Different forms of a gene are called alleles. A genome is all the DNA in a cell or an organism. Studies of genomes shed light on the functions of genes.

p. 231

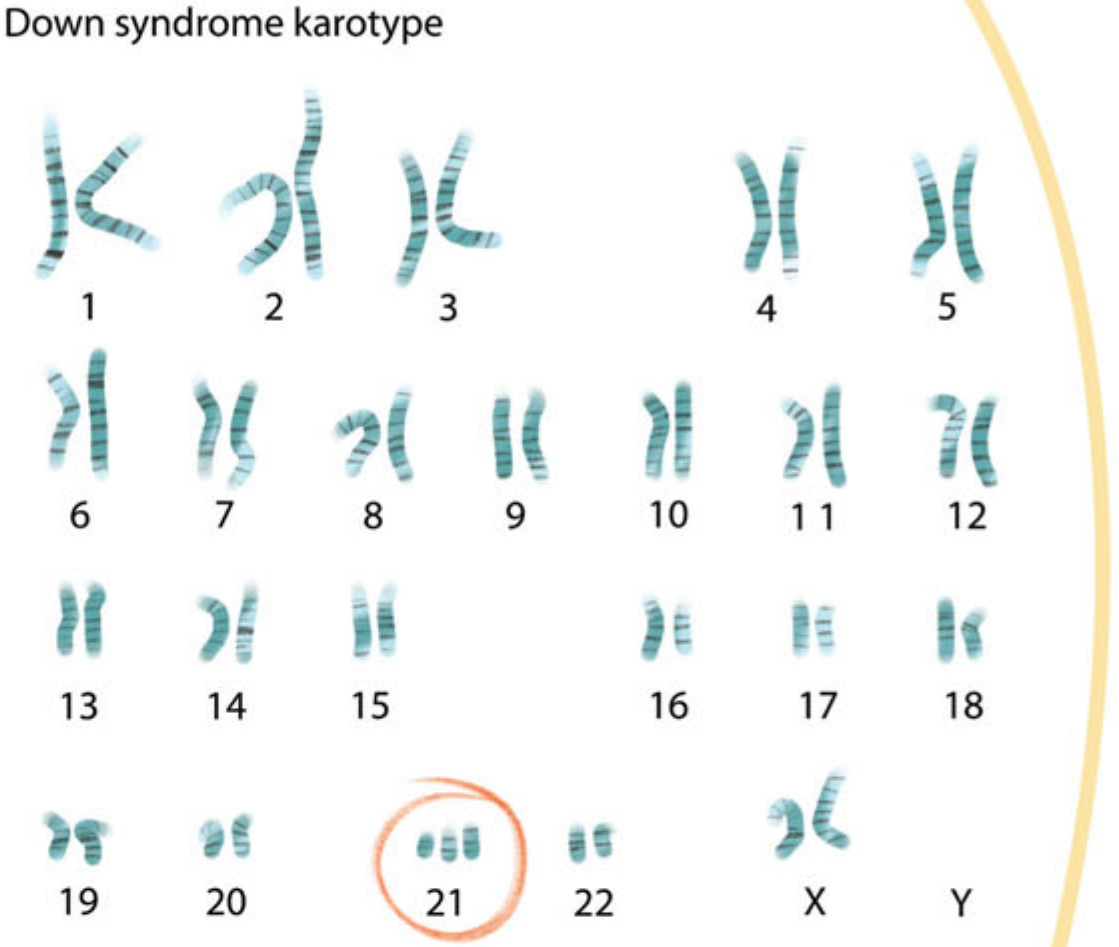
6.2 Chromosomes

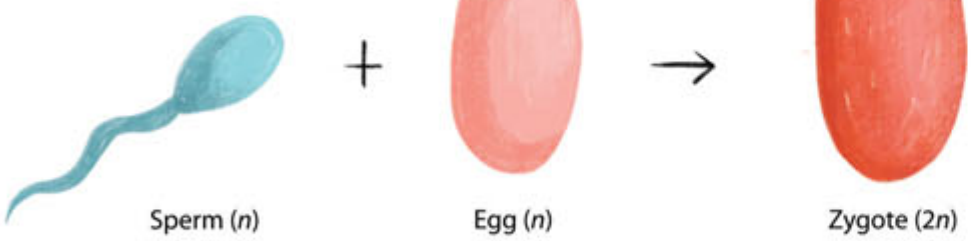
DNA is packed into chromosomes in the nucleus of eukaryotic cells. Homologous chromosomes carry the same genes at the same locations. The number of chromosomes depends on the species. Your body cells have 22 pairs of homologous chromosomes and one pair of sex chromosomes.

p. 238

6.3 Karyotypes for identifying chromosomal abnormalities

When images of a cell's chromosomes are paired and ordered according to size, the result is a karyotype. Chromosomal abnormalities can be identified from karyotypes because you can see if someone has too many or too few chromosomes.





p. 241

6.4 Production of gametes and sexual reproduction

Gametes are the sex cells – eggs and sperm in mammals. They have half the number of chromosomes as other cells – 22 autosomes and one sex chromosome (*n*). To make a gamete, a germline cell undergoes meiosis, halving the chromosome number in the nucleus. When gametes fuse at fertilisation, the chromosome number is restored (2*n*).

The first cell of a new organism is called a zygote. How the genes on the chromosomes within the zygote express themselves will determine what an individual will be like.

To access resources below, visit www.nelsonnet.com.au

Online Chapter Map:
- Chapter 6 map (p. 222)

Online Key Terms:
- Chapter 6 flashcards (p. 224)

Weblinks:
- PURA syndrome (p. 230)
- Diploid vs. haploid cells (p. 239)
- Overview of meiosis (p. 243)

Online Worksheets:
- Diploid vs. haploid cells (p. 239)
- Overview of meiosis (p. 243)

Online Key Concepts:
- Chapter 6 summary of key concepts (p. 248)

Know your key terms

Online Key Terms
Chapter 6 flashcards

allele
aneuploidy
autosome
base pair
bioinformatics
chiasmata
chloroplast DNA (cpDNA)
chromosome
coding DNA
complementary bases
crossing over
diploid
DNA sequence
double helix
gene
genetics
genome
genome size
genomics
haploid
heredity
heterosome
histone
homologous chromosomes
hydrogen bond
karyotype
law of independent assortment
law of segregation
locus
mitochondrial DNA (mtDNA)
monoploid
monosomy
nitrogenous base
non-coding DNA
non-disjunction
nucleoid
nucleotide
plasmid
polyploidy
proteomics
recombination
regulatory elements
sex chromosomes
sex-linked
somatic cell
synapsis
tetraploid
triploid
trisomy
zygote

Remember

This chapter will build on the following concepts that you will have already met. Take the time to refresh these concepts before you start this chapter.

REMEMBER PAGE 148

1. DNA is the molecule of heredity.
2. In prokaryotic cells, DNA is located in the chromosome within the nucleoid and plasmids.
3. In eukaryotic cells, DNA is located in the nucleus packaged into chromosomes.
4. Fertilisation is the union of two haploid cells to form a diploid zygote.
5. Mitosis is the division of the nucleus of a eukaryotic cell during cell division to form two identical daughter cells.

At a family gathering, we can be struck by how much we resemble some of our relatives but how little we resemble others (Figure 6.1). Over the centuries, many people have been intrigued by the inheritance of particular features. Selective breeding of crops, plants, pets and domesticated animals has made use of this ability of living things to transfer particular characteristics through successive generations.

Shutterstock.com/Franck Boston

Figure 6.1 Four generations of one family. Family characteristics are passed from one generation to the next through inheritance.

Heredity is the study of inheritance. Classic **genetics** deals with studying the mechanisms and patterns of inheritance through the transmission of coded chemical instructions from one generation to the next.

It is only since the secrets of DNA (deoxyribonucleic acid) were unlocked that we have been able to explain this at a cellular and molecular level. DNA stores information that influences almost all aspects of an organism's growth and function, from the way the organism is built to how its cells operate. However, the small differences in the way the DNA molecules are put together make individuals different and species distinct from one another.

DNA encodes heritable information. It is passed from parent to offspring, generation after generation. Because DNA is the same genetic material in all organisms, it must have appeared early in the evolution of life and remained essentially the same as new species evolved. This tells us that the ways in which DNA carries genetic information, and the way in which this information can be read to build organisms, must be a successful biological strategy. As we learn more about the structure and functions of DNA, and as scientists have learned to use DNA-based technologies, it has become clear that this special molecule is capable of encoding very complex information.

6.1 Distinction between genes, alleles and a genome

What do we have in common with mice, plants, flies and bacteria? At first glance, not a lot. But all living things inherit DNA from their parents. DNA is the same in all organisms. DNA functions as an information molecule. The information in DNA directs how cells, tissues and whole organisms are to be built and how they are to function.

The basic functional unit of DNA is the **gene**. The same gene may come in different forms, resulting in different outcomes for the organism that inherits them. Genes do not work in isolation. Many genes act together to influence the characteristics an organism displays. In addition, environmental conditions play a part. Genes make up only a small proportion of the total DNA in the cells of many organisms. It is therefore a major goal in biology to understand not only the genes of an organism but also how they work collectively with each other, with the rest of the DNA and with the environment. We begin this section with a recap of the structure of DNA. We then explore the functional aspects of DNA.

Structure of DNA

WB
6.1.1 STRUCTURE OF DNA: MAKING A MODEL PAGE 148

Commonly represented by the letters DNA (**d**eoxyribo**n**ucleic **a**cid), this large macromolecule is composed of two long strands wound around each other to form a **double helix**. Each strand is built of subunits called **nucleotides**.

A DNA nucleotide has three distinct chemical components:

- a five-carbon 2-deoxyribose sugar
- a negatively charged phosphate group
- an organic nitrogen-containing compound called a **nitrogenous base** (Figure 6.2).

EXAM TIP

Be sure to use the correct names to describe the structure of a DNA nucleotide. In DNA, the nucleotide comprises 2-deoxyribose (not ribose), sugars phosphate (not phosphorus), and a nitrogenous base.

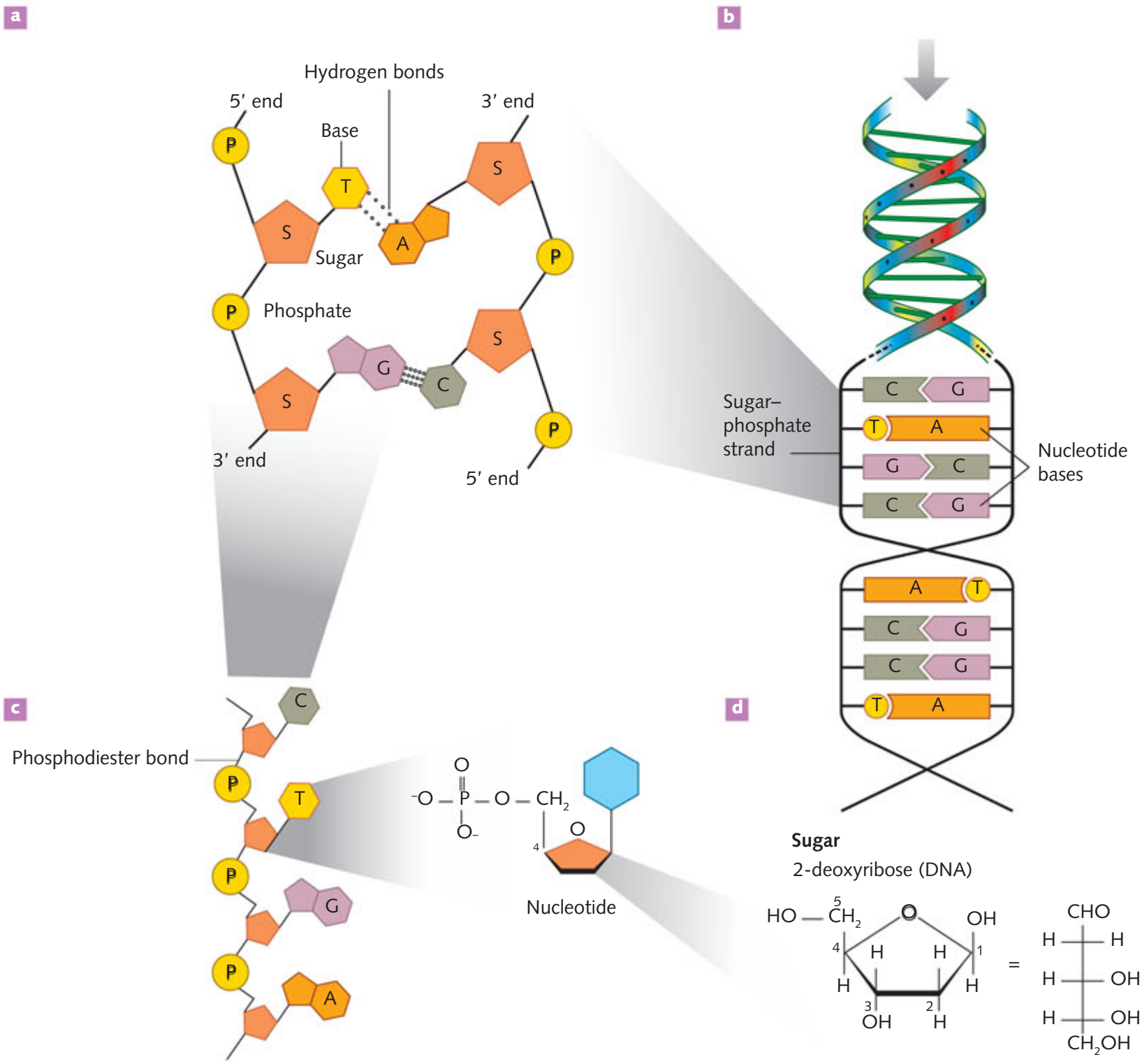


Figure 6.2a The two strands are held together by hydrogen bonding between complementary nitrogenous bases forming **b** the double-stranded helical DNA molecule. **c** As well as nitrogenous bases, nucleotides have a sugar–phosphate backbone linked by phosphodiester bonds. **d** DNA contains 2-deoxyribose sugars.

There are four kinds of nitrogenous bases in DNA:

» adenine (A)
» thymine (T)
» guanine (G)
» cytosine (C).

Nucleotides are joined together so that the sugar of one nucleotide is linked to the phosphate group of the next. Each DNA strand therefore comprises an alternating sugar–phosphate backbone. In each strand, the nitrogenous base sticks out from each sugar and opposite the nitrogenous base of the other strand. **Hydrogen bonds** between the opposing pairs of nitrogenous bases hold the double helix together, much like the rungs of a twisted ladder or a spiral staircase. The bonding of the nitrogenous bases does not happen by chance: A bonds with T and C bonds with G, giving rise to the base-pairing rule (Figure 6.2b).

The two strands of a DNA double helix link by hydrogen bonds between **complementary bases**: A and T link with two hydrogen bonds, G and C link with three hydrogen bonds. Each pair of complementary bases across the two strands is referred to as a **base pair**.

The DNA in eukaryotic cells is wound tightly around proteins called **histones** that help compact and package the DNA into a protein–DNA complex called chromatin. The chromatin is further wound and tightly coiled into the complete **chromosomes** that fit inside the nucleus of the cell. Each chromosome comprises a single double-stranded DNA molecule and its associated histone proteins. There are typically 46 chromosomes in a single human cell. A single chromosome may be made up of hundreds of millions of base pairs. All of the DNA in a single human cell exceeds 3 billion base pairs.

WB
6.1.2
THE ABC OF
DNA PAGE 152

Genes

A gene is defined in a couple of different but related ways. First, a gene is defined as a unit of inheritance. In other words, it is the information that is passed from parent to offspring that influences the structure, physiology or behaviour of an organism. At this level, we acknowledge genes in the effect they have. We might say, for example, there is a gene for eye colour or a gene for blood type. The information for a specific eye colour or blood type is carried in the gene. This definition represents the earliest understanding of a gene.

When DNA was studied in detail, it became apparent that there was a more concrete explanation for what genes were. At the molecular level, each gene is a specific segment of DNA that contains the information that codes for a specific protein or proteins (Figure 6.3). Although there are billions of base pairs of DNA in a typical human cell, only a fraction of these, around 1%, code for a protein product. These sections of **coding DNA** make up the genes.

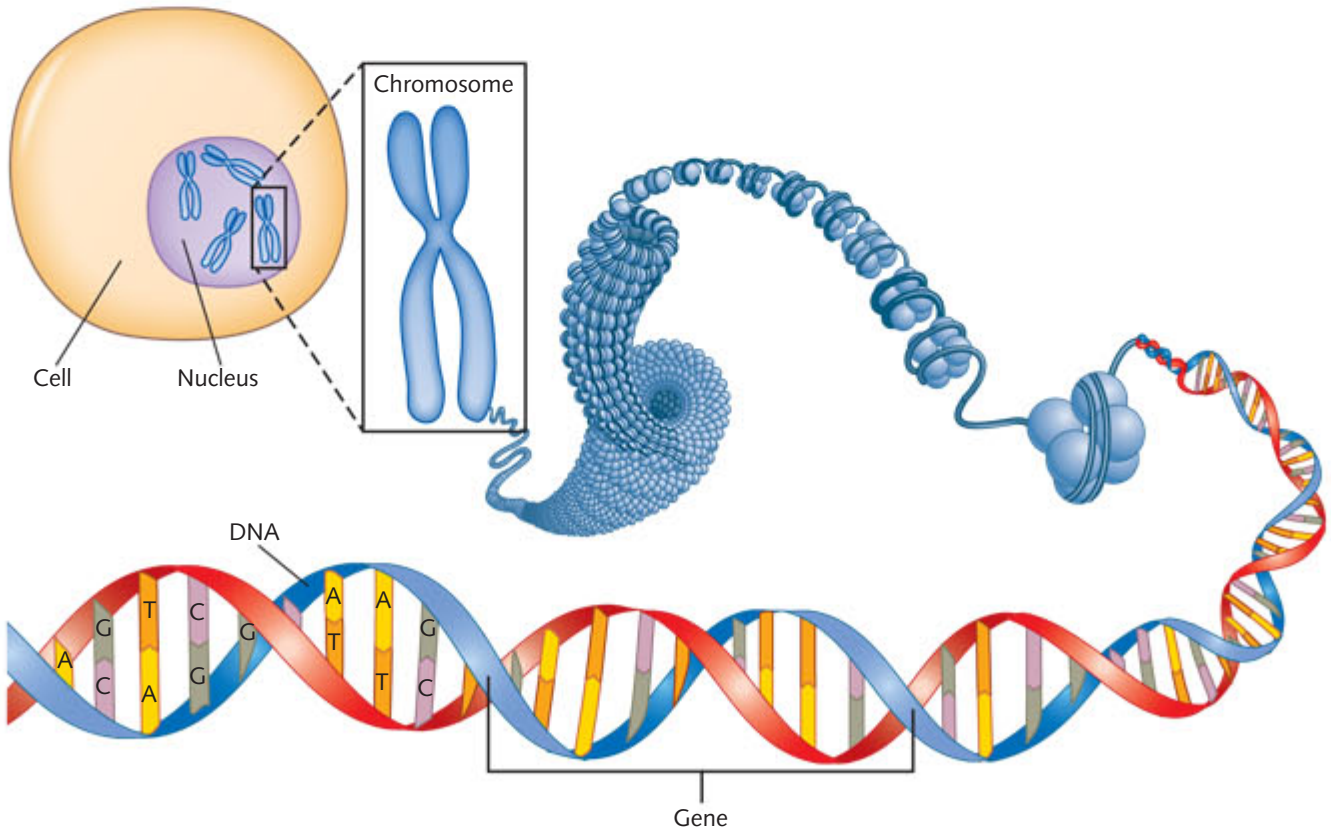


Figure 6.3 The relationship between chromosomes, DNA and genes. The segment of DNA composing a gene is normally hundreds to many thousands of nucleotides long.

CONNECT

VCE Biology Unit 3 explores in more depth how DNA sequences code for proteins.

The order of the nitrogen bases in a strand of DNA is how information is stored in DNA. The order of the nitrogen bases is referred to as the **DNA sequence**. In the case of genes, reading the DNA sequences in groups of three is the basis of the genetic code.

Alleles

WB
6.1.3 GENES, ALLELES AND GENOMES PAGE 153

Alternative forms of the same gene are called **alleles**. Alleles are versions of the same gene with slight differences. Sometimes the difference may be a single difference in the DNA sequence of the gene, but this may be enough to cause large variation in the functions of a gene or the way it behaves. For example, a single gene determines whether you get freckles or not (Figure 6.4). The gene has two alleles. One allele gives you freckles, the other gives you a non-freckled complexion. If you do get freckles, the number, size and colour of the freckles are controlled by other genes and the environment, including how much sun exposure you get.

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Figure 6.4 A single gene with two alleles determines whether you have freckled or non-freckled skin.

The genome

The **genome** is the sum of all the sequences of coding DNA (i.e. the genes) and **non-coding DNA** in a haploid cell of an organism.

If only ~1% of the DNA in a human cell codes for protein, what is the function of all the remaining non-coding DNA? This question perplexed biologists for years. For a while, the non-coding DNA was referred to as 'junk DNA', suggesting it had no purpose but had accumulated through evolution and was inherited along with the genes from generation to generation.

As non-coding DNA became increasingly studied, it was apparent that regions of non-coding DNA have very specialised functions. For example, some regions of DNA help the DNA pack into chromosomes. Some sections of DNA act as signals for initiating DNA replication. Other sections of DNA enable chromosomes to align during mitosis and meiosis, which is the process that produces the special cells called gametes. The ends of the chromosome have sections of DNA that act to stabilise them and prevent them degrading during the cell cycle.

CONNECT

The process of meiosis is explored in depth later in this chapter.

Of particular interest are segments of non-coding DNA with a regulatory function. Such **regulatory elements** influence the timing and circumstances for switching on or switching off the production of proteins from particular genes. These regulatory elements may be located far away from the affected gene, close to it, or even embedded within the gene. Regulatory elements are one of the chief ways that genes can interact with environmental conditions to influence the way an organism is built, functions or behaves.

Genome size

Genome size is measured as the total number of base pairs of DNA in a prokaryotic cell, or the total number of base pairs of DNA in a single (haploid) set of chromosomes for eukaryotic cells. The amount of DNA packaged in cells is highly variable between species. The size of the genome is broadly but not absolutely related to the complexity of the organism. The smallest genomes belong to viruses and are normally in the range of thousands to hundreds of thousands of base pairs. Bacterial genomes are in the order of half a million to several million base pairs. Eukaryotic genomes range from several million to hundreds of billions of base pairs. Within these ranges, genome sizes bear little relationship to the type of organism the genome comes from. For example, the genome size of a human (~3.2 billion base pairs) is comparable with that of a chilli pepper. Plants, particularly lilies and ferns, tend to have larger genomes than other eukaryotic organisms. Among animals, the largest genome sizes tend to belong to amphibians and lungfish. In eukaryotic organisms, the genomes are comprised mostly of non-coding DNA with only a small fraction occurring as genes.

Genomics

The study of the genomes of organisms is termed **genomics**. This significant branch of molecular biology and its related study of proteins – **proteomics** – have been made possible by advances in technology, particularly in robotics and computer technology. Automated processes in laboratories and the rapid collection and storage of data have made it possible to integrate, analyse and manipulate data at high speed (Figure 6.5).

These technologies assisted the complete mapping of the human genome by 2003, known as the Human Genome Project. The project's ultimate goal was to generate DNA sequences for the human genome's three billion base pairs and to identify all human genes.

When the project was launched in 1990, it was thought that the human genome contained some 100 000 genes.

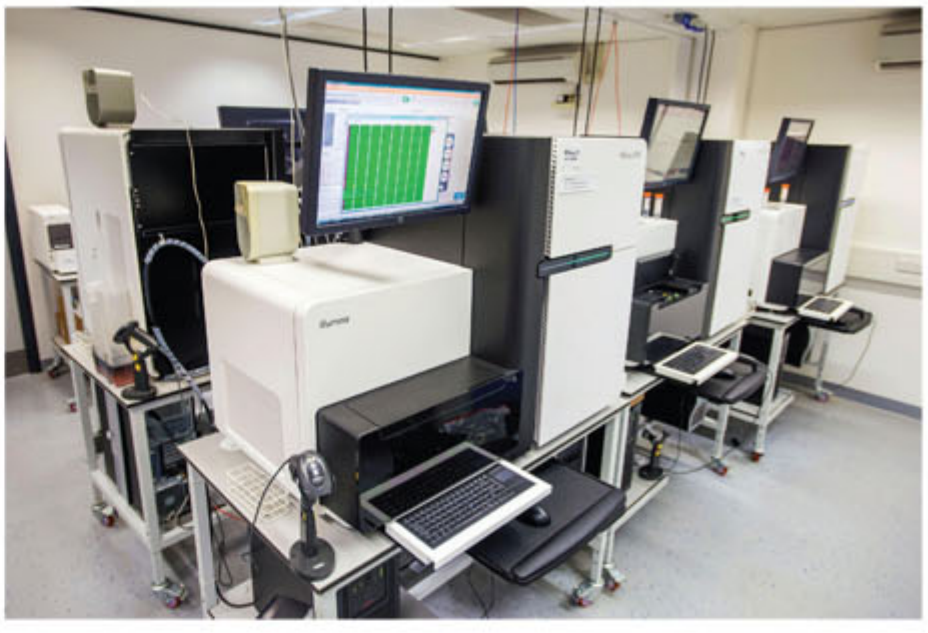

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Figure 6.5 A bank of automated DNA sequencing machines

In 2001, after 10 years of work and at a cost of US$400 million, those involved in the Human Genome Project had completed a draft sequence of the human genome. The first analyses of the details brought the estimate down to between 30 000 and 40 000 genes. The estimate of the number of human genes has been repeatedly revised down to between 20 000 and 25 000 genes. Even though the results of the Human Genome Project have solved some questions, they have created many more. Now the challenge is to find out what every gene actually does and how the genes are regulated.

WB 6.1.4 GENOMICS PAGE 155

Human genomics research

The rate at which genomes can be sequenced increased almost exponentially after the beginning of the 21st century until it plateaued around 2015. The current 'next-generation' sequencing technology allows a human genome to be sequenced for less than $1500, and it can be produced in about one week. Sequencing is also accelerated by focusing on just the ~1% of the human genome made up by the genes and then reconstructing the genome based on the reference human genome sequence.

WB 6.1.5 HUMAN GENOMICS RESEARCH PAGE 156

Genome sequences are digitised, stored and analysed using computers. **Bioinformatics** is a growing field that addresses the computer-based storage and analysis of DNA sequence data (Figure 6.6).

Figure 6.6 Bioinformatics allows DNA sequences to be stored and analysed using information and computer technology.

With the advent of new analytical tools, the ability of biologists' to compare and analyse genomic data will help reveal more about how genes work. Genomic research is helping scientists identify new genes and the functions of their encoded proteins, particularly those involved in human genetic disorders. This has been achieved by comparing the genomes of affected individuals with those of unaffected individuals.

Weblink
Pura Syndrome

Genomics research has already revealed the genetic basis for dozens of rare conditions caused by specific alleles of a single gene. One of these, called PURA syndrome, was first recognised as a genetic condition as recently as 2014. Children who have PURA syndrome show delayed patterns of growth, movement, speech and learning. The syndrome is caused by rare alleles for a single gene located on chromosome 5. The protein coded by the gene is involved in nerve cell development, and the function of the protein from these rare alleles is impaired. The child develops PURA syndrome if they inherit two alleles that cause the condition, one from each parent. Knowing the specific gene responsible allows the condition to be precisely diagnosed with a genetic test. Conceivably, in years to come, precisely diagnosed genetic conditions may be reversed by genetic therapies.

Understanding the genetic basis for conditions caused by two or more genes is much more challenging. This is particularly the case if individual genes add only a little to the overall effect. Much larger sets of genomic data are required for wide-scale comparisons between genomes of affected and unaffected individuals. A current drive in human genome research is to sequence very large collections of genomes. Several initiatives to sequence over a million human genomes are underway in Europe, the USA, China and the Middle East.

Genomes of other species

Many important varieties of agricultural crop plants and livestock animals are also being investigated with genomics. These studies may involve comparing the genomes of different varieties with each other, or with wild varieties from which the agricultural varieties were domesticated. These genome studies make it possible to identify genes and alleles that contribute to making the varieties hardier in challenging environments, resist disease or produce higher yields, among other features. The research may inform breeding regimes, or it could help identify genes for desirable characteristics that could be transferred to favoured breeds by genetic engineering.

Genomic research provides insights into how different species evolved and are related. There is a great deal of overlap in the genomes of closely related species, and some overlap even in the genomes of distantly related species. Researchers can compare the genomes of different species, or of different individuals within the same species. Genomic studies of this type provide an understanding of the diversity of organisms in a particular environment, or among individuals of a species. Current technologies make it possible to sequence the genomes of extinct organisms, even those tens of thousands of years old, and resolve their relationship to modern species (Figure 6.7). Genomic studies have also resulted in discoveries about previously unknown aspects of the physiology of organisms. These discoveries enable scientists to make predictions about how organisms may respond to future environmental challenges, such as those related to climate change.

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Figure 6.7 The woolly mammoth is one extinct species whose genome is being sequenced and reconstructed.

Sequencing genomes is also useful for identifying microbes by comparing their sequences to reference sequences stored in public databases. This has been applied to early detection and diagnosis of infections.

KEY CONCEPTS

- DNA is the common genetic material of all organisms. It is composed of four different types of nucleotides built into two strands that form a double helix that is held together by complementary base pairing.
- The information in DNA is coded in genes, which may occur in different forms called alleles.
- An organism's genome consists of all of its genes and its non-coding DNA. The non-coding DNA of the genome has many different functions.
- Genomics is useful for finding out how genes work, identifying genes that affect specific human conditions, determining how species are related, and detecting and diagnosing infections.

Concept questions 6.1

1 Draw a nucleotide, labelling its three distinct chemical components.
2 Explain the relationship between DNA, genes and alleles.
3 Define:
  a genome
  b genomics
  c bioinformatics.
4 Describe some of the functions of non-coding DNA.
5 Describe the relationship between the type of organism and the size of its genome.

HOT Challenge

6 Using PURA syndrome as an example, outline how genomics has helped scientists understand the basis of an inherited condition caused by a single gene.

6.2 Chromosomes

Chromosomes are the discrete physical structures of double-stranded DNA that occur within cells. Chromosomes vary in size, shape and appearance, depending on their location and how they stain and appear under the microscope. Chromosomes also vary in function, depending upon the types of genes they carry. In this section we explore the structures and functions of chromosomes across eukaryotic and prokaryotic organisms.

Homologous chromosomes

The nucleus of each **somatic cell** (or body cell) of a human is **diploid** ($2n$) in that it contains two sets of linear chromosomes, one **haploid** (n) set inherited from each parent. The total number of chromosomes in a diploid human cell is 46, which form 23 pairs, of which 22 are matched or homologous (Figure 6.9). One chromosome of each **homologous chromosome** pair comes from the male parent via the sperm cell and the other from the female parent via the egg cell (ovum).

Along the length of each DNA molecule, particular sequences (genes) code for different proteins that can determine particular characteristics or traits. The location of a particular gene in a chromosome is referred to as its **locus** (plural loci). In homologous chromosomes, the corresponding allele of each gene is found at the same locus (Figure 6.8). Because each member of a pair of homologous chromosomes contains one of each corresponding gene, there is in a sense a backup for the genes on those chromosomes. There may be many different alleles for a given gene in the human population but any individual has two alleles for every gene; they may be the same allele or two different alleles.

Autosomes

Chromosomes vary in length and in the position of the centromere, the waist-like constriction required for the movement of chromosomes during cell division. Chromosomes also have characteristic banding patterns when stained for microscopy. The matched pairs of chromosomes are called **autosomes**, the largest of which is numbered 1 and the smallest 22 in humans. Paired autosomes are

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6.2.1
CHROMOSOMES
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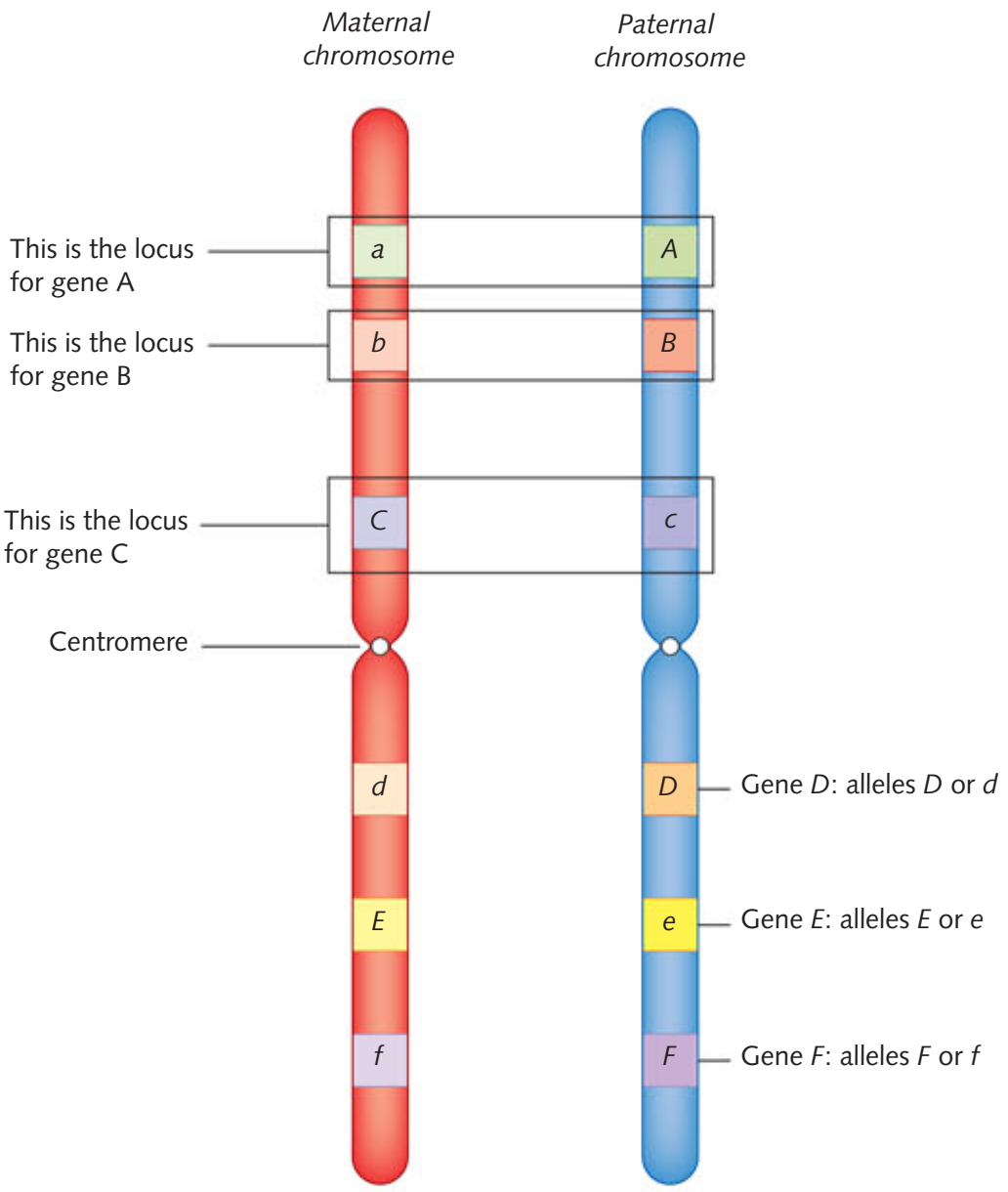

Figure 6.8 Stylised representation of a pair of homologous chromosomes. In diploid organisms, chromosomes exist in pairs in somatic cells. One of the chromosomes comes from the female (maternal) parent and one comes from the male (paternal) parent.

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6.2.2 AUTOSOMES AND SEX CHROMOSOMES PAGE 158

identical in size, shape, and position and number of genes, but may have different alleles at each gene locus (Figure 6.8).

The 23rd pair, which is matched in females but unmatched in males, is referred to as a **heterosome**. Because these chromosomes determine the sex of an individual, they are also called the **sex chromosomes**.

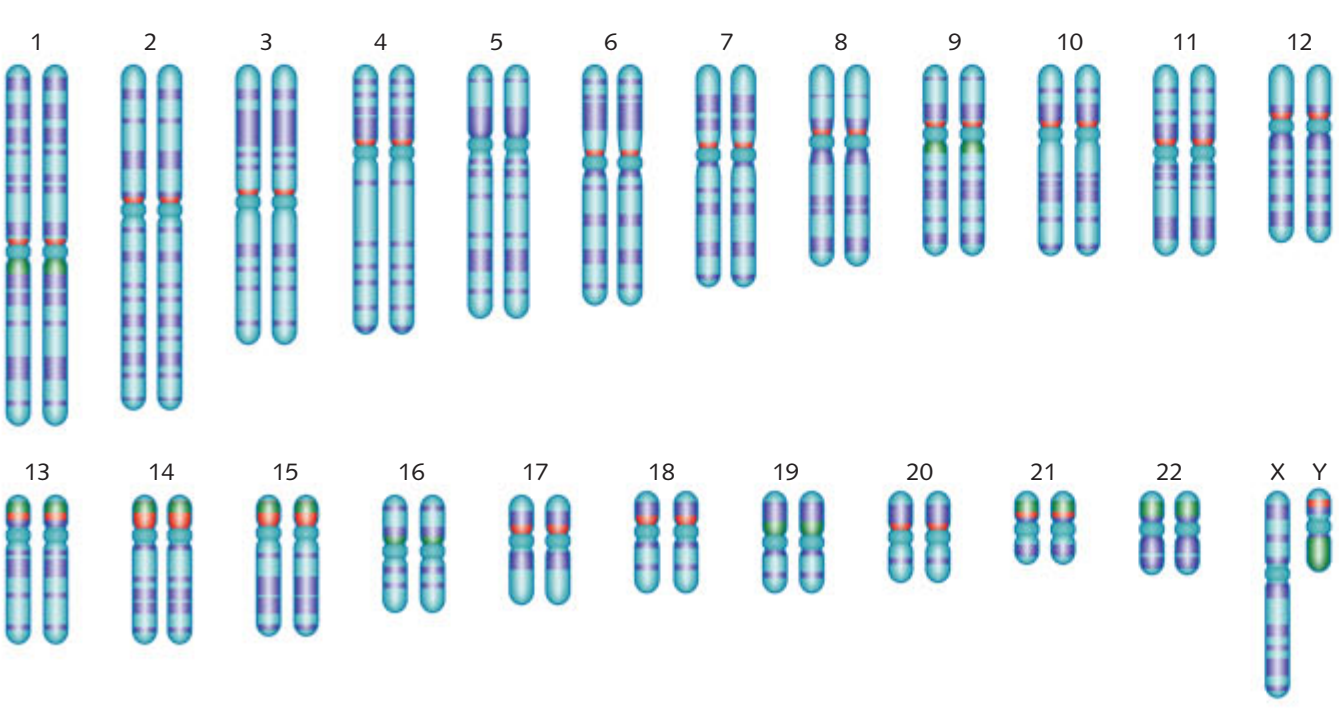

Figure 6.9 The 46 chromosomes of a typical human cell consist of 22 pairs of autosomes (numbered 1 to 22) and one pair of sex chromosomes (XX or XY).

Sex chromosomes

If you compare the cells of human males and females you see clear differences in the sex chromosomes. In males, one of the sex chromosomes is larger than the other, whereas females have two copies of the larger chromosome. The larger chromosome is referred to as the X chromosome and the smaller is the Y chromosome.

The distribution of sex chromosomes and the almost 50-50 split of females and males in a population makes sense in the context of sexual

reproduction. Gametes are the sex cells produced by females (eggs) and males (sperm). In humans, normally all female gametes contain 22 autosomes and an X chromosome. But 50% of male gametes contain 22 autosomes and a Y chromosome and 50% contain 22 autosomes and an X chromosome (Figure 6.10). Thus, at fertilisation, there is a 50% chance that a sperm cell bearing a Y chromosome will fuse with an egg cell, resulting in a male (XY), and a 50% chance that a sperm cell bearing an X chromosome will fuse with an egg cell, resulting in a female (XX).

Sex chromosomes contain not only the genes that determine male and female traits but also those for some other characteristics as well. Genes on the sex chromosomes are referred to as **sex-linked**.

Compared to the autosomes, the X chromosome is medium-sized. It contains about 1300 genes, with a range of functions. Some of these X-linked genes have relatively rare alleles that are responsible for abnormal conditions such as haemophilia, Duchenne muscular dystrophy and red-green colour blindness.

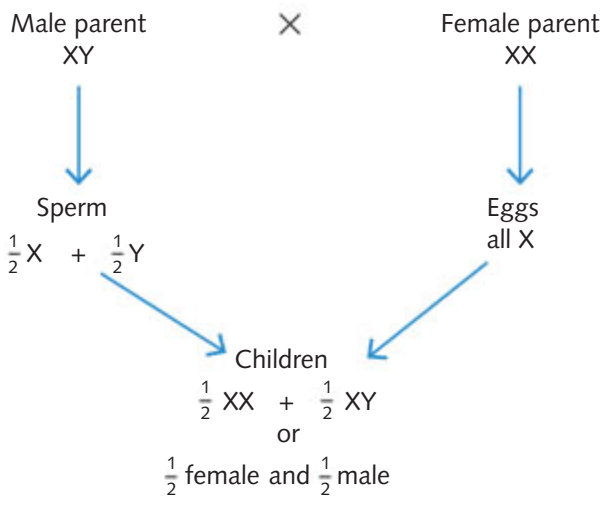

Figure 6.10 Chromosomal basis of sex determination

The Y chromosome is small, with few active genes. It is composed largely of repetitive DNA sequences. The SRY gene on the Y chromosome is responsible for developing a foetus into a male. There is a small region that is homologous between the X and Y and it is this area that pairs at meiosis. (See below.)

Variations in nuclear chromosomes of eukaryotes

The genome constitutes the chromosomes in the cell. So far we have examined in detail the characteristics of human nuclear chromosomes. However, there are considerable differences between the nuclear chromosomes of humans and those of other species. These variations occur in chromosome structure and chromosome number (Figure 6.11; also Table 6.1, p. 235). Variations in chromosome structure include differences in the sizes of the chromosomes, the positions of the centromeres and the banding patterns of the chromosomes when stained for microscopy.

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6.2.3 VARIATIONS IN NUCLEAR CHROMOSOMES OF EUKARYOTES PAGE 159

Variations in haploid number

The nucleus of each somatic cell or body cell typically contains pairs of chromosomes. The number of chromosomes in each somatic cell is called the diploid number and is represented as $2n$. Because chromosomes occur in pairs, n stands for the number of chromosomes that a particular species has in each of its cells, called the haploid number. This is also called a set of chromosomes. The haploid number of chromosomes is typical for the gametes of the organism. A human somatic cell, for example, has 2 sets or 23 pairs of chromosomes and so its diploid number ($2n$) is 46 and its haploid number (n) is 23. The human egg and sperm cells each contain 23 chromosomes.

The haploid number (n) varies between species. For example, it is 8 for red kangaroos, 34 for roadside hawks (a South American bird) and 52 for walking catfish (a freshwater fish from south-east Asia). Consequently, the diploid number ($2n$) for the body cells of these organisms differs. The diploid number is 16 for red kangaroos, 68 for roadside hawks and 104 for walking catfish (Figure 6.11).

Monoploidy

We have so far explored haploid and diploid number; however, the number of *sets* of chromosomes in the nucleus also varies within and between many species.

The males of many colonial insects such as ants, bees and wasps are **monoploid** ($1n$). By contrast, the females, including the queen, are diploid. The males are not haploid in the sense of the gametes of regular diploid animals. Their chromosomes represent a single complete and operational set and the males function as conventional, multicellular animals. By contrast, in haploid gametes, the chromosomes represent one set and are packaged in a dormant state awaiting the fertilisation event that will activate them. In these insects, the queen (Figure 6.12) produces eggs by meiosis, while the males produce sperm by mitosis.

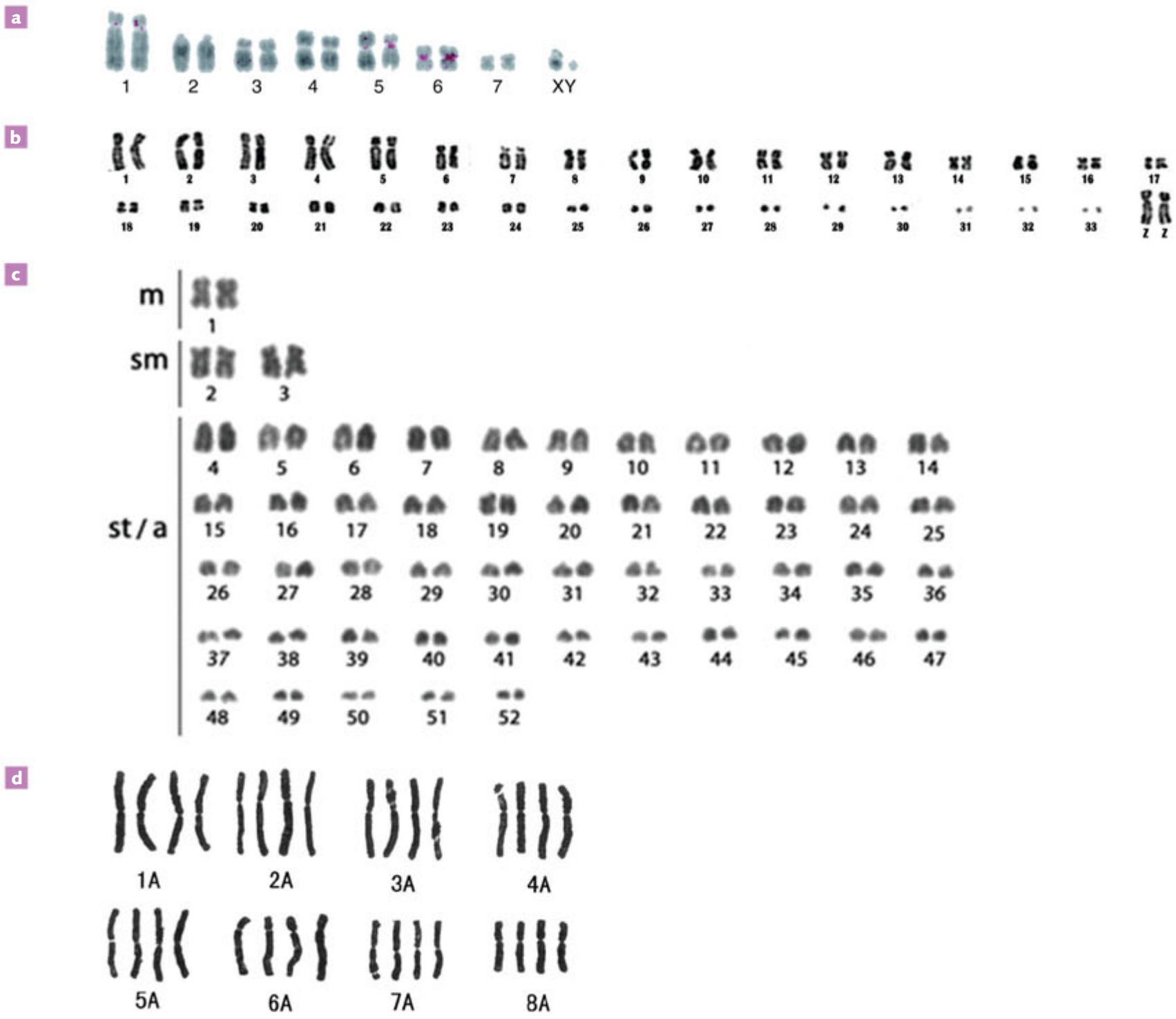

Figure 6.11 Chromosome maps ('karyotypes') showing variations in chromosome structure and number in various organisms. **a** Red kangaroo (*Macropus robustus*), **b** Roadside hawk (*Rupornis magnirostris*), **c** Walking catfish (*Clarias batrachus*), **d** shallot (*Allium cepa*), a variety of onion. Note the shallot has four copies of each chromosome. Karyotypes are discussed in more detail below.

Getty Images Plus/iStock/Andrew Haysom

Figure 6.12 **Bees maintain their colony structure with diploid females and monoploid males.**

Fertilisation results in diploid female offspring. The males are instead produced by parthenogenesis, a process by which the entire organism is regenerated from a single egg cell without the need for fertilisation. (See Chapter 8.)

Many fungi and algae are monoploid and there are also examples of monoploid fish, amphibians and reptiles. Monoploidy seems economical because only one set of chromosomes is required, so why are diploid organisms so much more common? The advantage for diploid organisms is that any defective alleles that arise can be masked by a functional allele on the corresponding chromosome. In monoploid organisms, any defective allele is the only allele available for a particular gene and the consequences are likely to be harmful.

Table 6.1 Genome size and chromosome composition of selected species

Type of organism	Common name	Species	Genome size (base pairs)	Chromosome composition
Bacteria	–	*Salmonella enterica*	4.94 million	1 chromosome + 2 plasmids
	–	*Escherichia coli*	5.59 million	1 chromosome + 2 plasmids
Fungi	Yeast	*Saccharomyces cerevisiae*	12.16 million	32 nuclear + 1 mitochondrial
	Edible mushroom	*Agaricus bisporus*	33.49 million	26 nuclear + 1 mitochondrial
Protists	Slime mould	*Dictyostelium discoideum*	34.21 million	12 nuclear + 1 mitochondrial
	Malarial parasite	*Plasmodium falciparum*	37.75 million	28 nuclear + 1 mitochondrial
Animals	Fruit fly	*Drosophila melanogaster*	143.73 million	14 nuclear + 1 mitochondrial
	Scallop	*Pecten maximus*	918.31 million	38 nuclear + 1 mitochondrial
	Crow	*Corvus moneduloides*	1.11 billion	72 nuclear + 1 mitochondrial
	Zebra fish	*Danio rerio*	1.68 billion	50 nuclear + 1 mitochondrial
	Octopus	*Octopus sinensis*	2.72 billion	60 nuclear + 1 mitochondrial
	Human	*Homo sapiens*	3.27 billion	46 nuclear + 1 mitochondrial
	Axolotl	*Ambystoma mexicanum*	32.40 billion	40 nuclear + 1 mitochondrial
	Waterdog (salamander)	*Necturus punctatus*	116.6 billion	20 nuclear + 1 mitochondrial
Plants	Wild rice	*Oryza minuta*	45.17 million	4 nuclear + 1 mitochondrial + 1 chloroplast
	Thale cress	*Arabidopsis thaliana*	119.67 million	10 nuclear + 1 mitochondrial + 1 chloroplast
	Corn (maize)	*Zea mays*	2.14 billion	20 nuclear + 1 mitochondrial + 1 chloroplast
	Chilli	*Capsicum baccatum*	3.22 billion	24 nuclear + 1 mitochondrial + 1 chloroplast
	Wheat	*Triticum aestivum*	14.55 billion	44 nuclear + 1 mitochondrial + 1 chloroplast
	Japanese canopy plant	*Paris japonica*	148.8 billion	40 nuclear + 1 mitochondrial + 1 chloroplast

Figure 6.13 Polyploid varieties of fruit are bigger and have bigger cells than regular diploid varieties. The application of polyploidy to creating infertile fruit, such as these seedless grapes, is of considerable commercial significance.

Polyploidy

Sometimes the cell divisions that give rise to haploid gametes fail altogether, and so half the gametes contain two copies of each chromosome (diploid, $2n$) and the rest have none. If a diploid gamete fuses with a normal haploid gamete, the resulting individual is **triploid** ($3n$), carrying three of each type of chromosome. If two diploid gametes fuse, a **tetraploid** ($4n$) individual will be produced. It is therefore possible for an organism to acquire one or more complete extra sets of chromosomes, a phenomenon called **polyploidy**.

Polyploidy is particularly common in flowering plants, ferns and green algae. Approximately half of all flowering plant species are polyploid (Figure 6.11d). Many varieties of commercial fruit and cereals, for example, are generated polyploids (Figure 6.13). Polyploidy is often associated with advantageous features, such as increased size and greater hardiness, although such advantages are sometimes offset by reduced fertility. Polyploidy also occurs in fungi and in some fish and amphibian species.

Variations in sex chromosomes

Most animals show different characteristics between males and females. The combination of sex chromosomes in humans is a matched XX pair for females and an unmatched XY pair for males. In other species it is not always the female that has the matched sex chromosomes. For example, in birds, males have matched sex chromosomes (called ZZ) and those of the female are unmatched (ZW). In some insects, females are XX and males are XO, with O denoting the absence of a chromosome, so the female sex cells must have two sex chromosomes but those of males have only one unmatched sex chromosome. As we have seen, in some social insects such as honeybees, females develop from fertilised eggs and are diploid, and males develop from unfertilised eggs and are monoploid.

Mitochondrial and chloroplast chromosomes

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6.2.4 THE ENDOSYMBIOTIC THEORY PAGE 160

Eukaryotic cells also contain chromosomes in organelles other than the nucleus. Chromosomes are located in the mitochondria of all eukaryotic cells and in the chloroplasts of photosynthetic organisms such as land plants and algae.

In contrast to the linear chromosomes of the nucleus, the DNA of these organelles takes the form of circular chromosomes similar to those of prokaryotic cells. (See next page.) This observation is evidence for the endosymbiotic theory, which proposes that these organelles first evolved as a result of a bacterial cell being ingested and retained by another primitive prokaryotic cell.

Mitochondria are a universal feature of the cells of all eukaryotic organisms. Each mitochondrion contains double-stranded **mitochondrial DNA (mtDNA)** in its circular chromosome. The genes within this chromosome code for some, but not all, of the proteins that make up that mitochondrion. Mitochondrial DNA usually comes only from the mother, because it is the ovum that provides the cytoplasm including all the organelles within it. Mitochondria from the sperm usually do not become part of the developing embryo because the sperm mitochondria are contained in the tail, which is not involved in fertilisation. Because of its simple pattern of maternal inheritance, mitochondrial DNA has been used extensively in evolutionary studies of animals.

Plant and algal cells have DNA in their chloroplasts. The chloroplast genome – **chloroplast DNA (cpDNA)** – is a circular, double-stranded molecule. It contains about 100 genes that code for proteins involved in photosynthesis.

Chromosomes of prokaryotes

Membrane-bound organelles, such as the nucleus, are not present in prokaryotic cells. The double-stranded DNA within these cells generally forms a single circular chromosome that lies in direct contact with the cytoplasm (Figure 6.14). Chromosomes are often joined to the plasma membrane at a single point. Although not contained by any internal structure, a chromosome can be in a distinct region of the cell called a **nucleoid**. Additional numerous small rings of DNA, called **plasmids**, may also be present in the cytoplasm. Non-essential genes are commonly encoded on these plasmids. Plasmids can replicate independently of the main chromosome and have become important tools in genetic engineering because they can easily be transferred from one bacterium to another and replicate rapidly.

CONNECT

Genetic engineering using plasmids is explored in VCE Biology Unit 3.

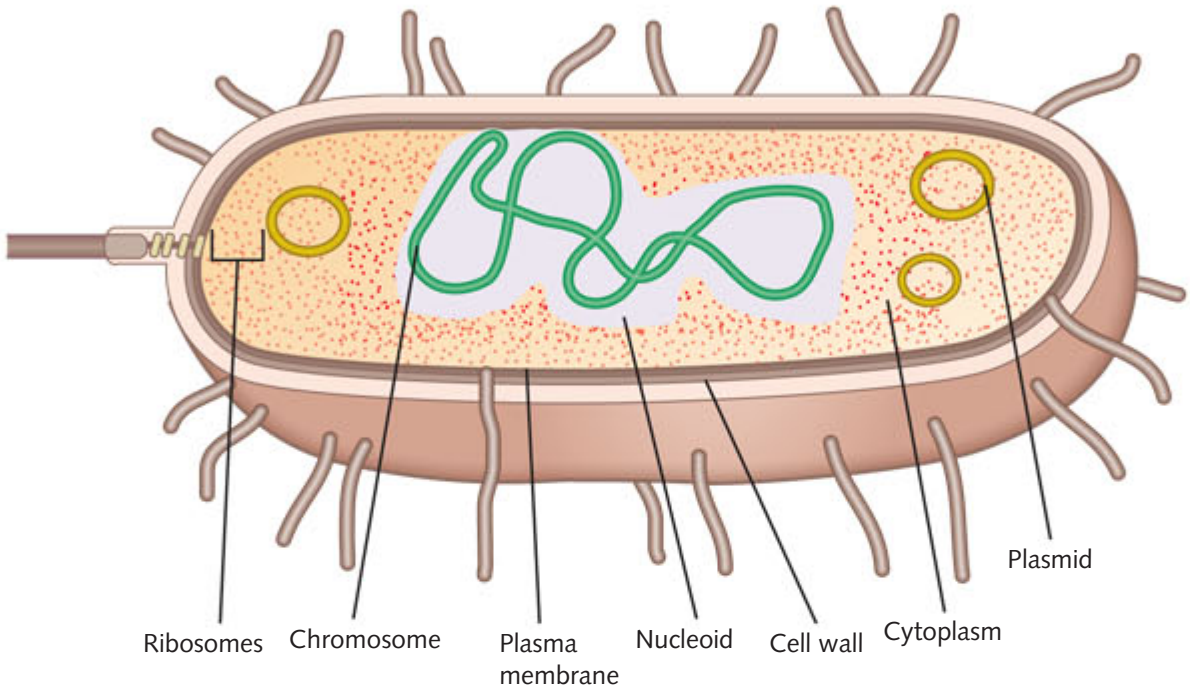

Figure 6.14 DNA in a prokaryotic cell, showing the circular chromosome (green) and plasmids (yellow)

Like eukaryotic chromosomes, the DNA of prokaryotic chromosomes needs to fit into a small area. This can be achieved by supercoiling, where a number of proteins act together to fold and condense the DNA. Prokaryotic cells are generally haploid; they contain only one copy of each gene. Furthermore, prokaryotic DNA contains very little repetitive and non-coding DNA.

However, just as with many other examples in nature, there are exceptions to the rules. Not all bacteria have a single circular chromosome. Some have more than one circular chromosome. Other bacteria have linear chromosomes and linear plasmids. Another notable difference between chromosomes in prokaryotes and eukaryotes is the presence of histones. Most prokaryotes do not have histones (with the exception of species in the domain Archaea).

KEY CONCEPTS

- Homologous chromosomes have the same genes at the same position (locus) but these genes may have alternative forms (alleles).
- The nucleus of human cells contains 22 pairs of autosomes and one pair of sex chromosomes. The sex chromosomes determine an individual's sex and are XX in females and XY in males.
- The chromosomes of different species vary in the structure and the haploid number of the chromosomes. Variation in chromosome number also occurs within species, which may be monoploid or polyploid.
- Apart from the linear chromosomes of the nucleus, eukaryotic organisms have smaller circular chromosomes in their mitochondria and chloroplasts.
- Prokaryotic cells generally have a single circular chromosome within a nucleoid region and smaller rings of DNA called plasmids.

Concept questions 6.2

1 Draw a labelled diagram to show your understanding of the following terms in relation to chromosomes.
   - **a** Homologous
   - **b** Autosome
   - **c** Locus
   - **d** Centromere

2 Distinguish between autosomes and sex chromosomes.

3 Explain how the sex of a child is determined at the time of fertilisation.

4 **a** Describe the ways the chromosomes of eukaryotic organisms can differ from one another.
   - **b** List two differences between prokaryotic and eukaryotic chromosomes.
   - **c** What does the similarity between prokaryotic, mitochondrial and chloroplast chromosomes suggest about the evolution of mitochondria and chloroplasts?

5 Describe the relationships between:
   - **a** monoploid and haploid
   - **b** monoploid diploid and polyploid.

HOT Challenge

6 **a** Provide two reasons why polyploid plants might be hardier than their diploid counterparts.
   - **b** Provide two reasons why polyploidy is so much more common in plants than in animals.

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6.3.1 CHROMOSOMAL ABNORMALITY PAGE 161

6.3 Karyotypes for identifying chromosomal abnormalities

Examination of a prepared microscope slide of stained cells undergoing mitosis reveals a jumbled cluster of chromosomes that differ in size and shape. Photographic images of the late prophase or metaphase chromosomes can be cut and arranged into matched and ordered pairs to create a **karyotype**. The karyotype is the standard form used to display and analyse chromosomes (Figure 6.15). For human cells, chromosomes are ordered by autosome length from largest (number 1) to smallest (number 22) followed by the sex chromosomes.

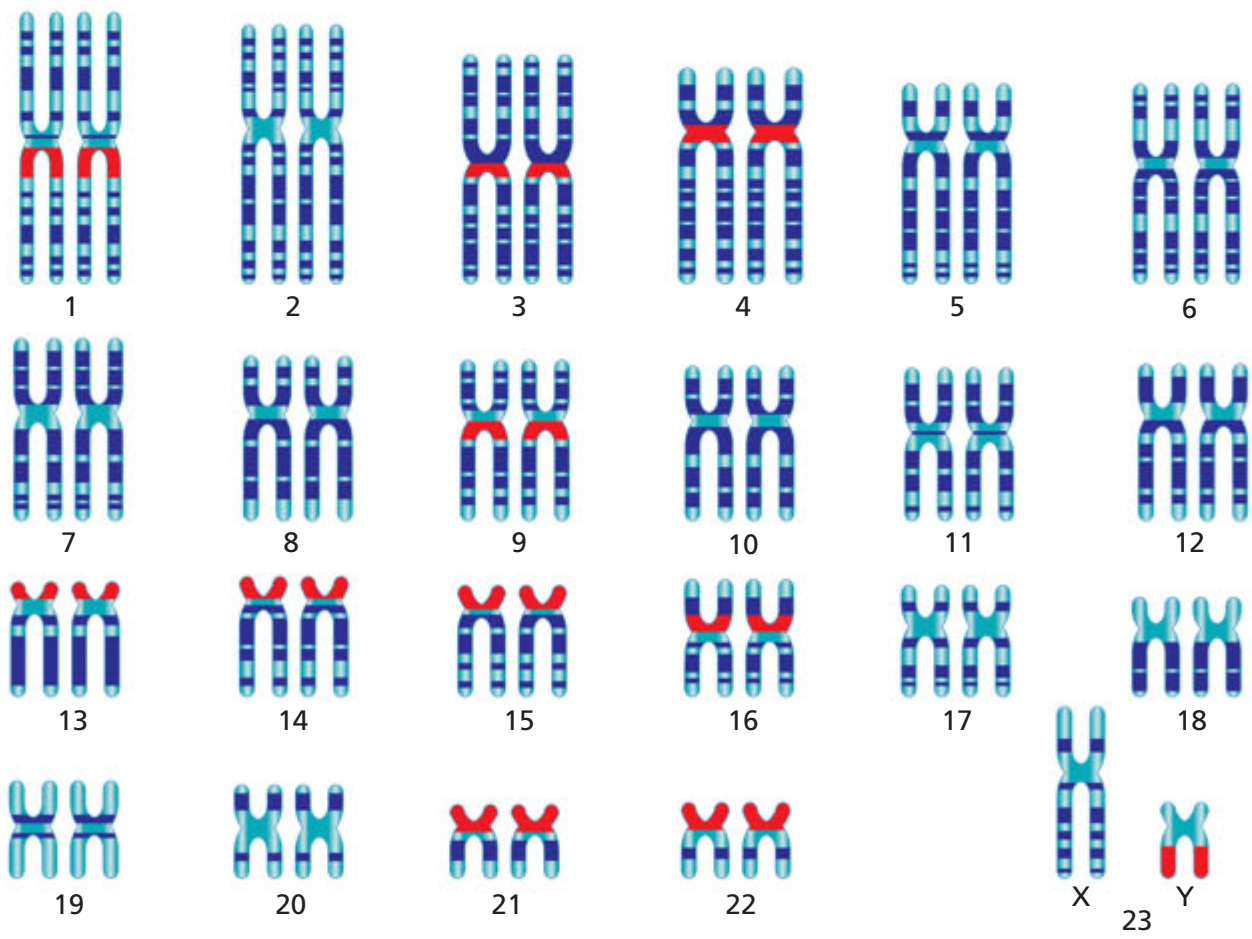

Figure 6.15 A karyotype of the 46 human chromosomes. They can be recognised and arranged by their size, position of centromere and banding pattern.

A standard human karyotype will display 22 pairs of matching autosomes and a single pair of sex chromosomes. However, variations can occur in the number or the structure of the chromosomes. Karyotypes are routinely used to diagnose chromosomal anomalies. These anomalies invariably affect the individual that possesses them.

Aneuploidy

Aneuploidy is the condition in which there is an addition or loss of one chromosome from a cell (that is, the chromosome number is $2n + 1$ or $2n - 1$). If the cells of an individual contain three copies of an autosome ($2n + 1$), the condition is described as **trisomy**. If the cells are missing one copy of an autosome ($2n - 1$), the condition is described as **monosomy**.

Occasionally, more than one chromosome may be affected. Reproductive failure by miscarriage is common and it has been found that many of the lost embryos are aneuploids.

Some types of aneuploidy survive in humans. Down syndrome is caused by the presence of an extra chromosome 21 (one of the smallest chromosomes) in every cell, thus giving three copies of chromosome 21 (Figure 6.16). Children with Down syndrome (Figure 6.17) vary in their symptoms but most show moderately to severely delayed development, characteristic almond-shaped eyes and round face with shortened body parts, loose joints, and weak muscles and muscle reflexes. About 40% develop heart defects and they are more susceptible to infections, both of which often cause their lives to be shorter. On the other hand, people with Down syndrome are more than capable of deriving great pleasure from life, particularly from music and dancing.

Down syndrome is an example of autosomal trisomy because the cells contain an additional non-sex chromosome. It is the most common autosomal trisomy in humans. Its incidence increases with increasing age of the mother (Table 6.2). Older men are also more likely to father a Down syndrome child, but their age has less of an effect on the chances of having a Down syndrome baby than does the age of the mother.

Karyotypes also reveal sex chromosome abnormalities in humans. For example, approximately two in every thousand men have the genetic constitution XXY, which is known as Klinefelter syndrome. This may result either from the fusion of a Y sperm with an XX egg or from the fusion of an XY sperm with an X egg. Although XXY individuals appear male, they have very small genitals and are infertile. In addition, they may develop breasts, but testosterone therapy at puberty can often help alleviate the symptoms.

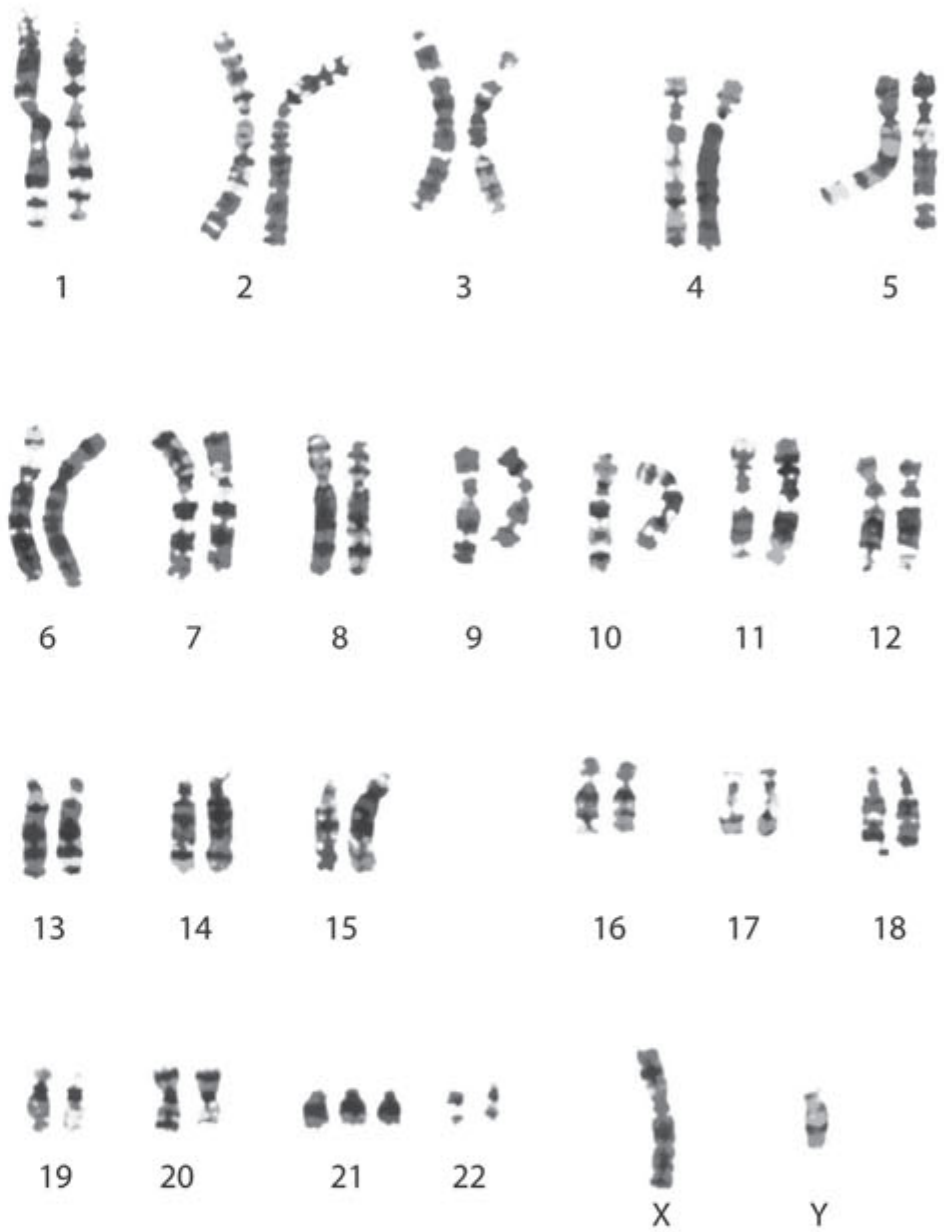

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Figure 6.16 **Karyotype of a Down syndrome male. The syndrome is the result of there being three copies of chromosome number 21. This condition is also known as trisomy 21.**

Turner syndrome arises when one of the sex chromosomes is missing. Foetuses with 22 normal pairs of autosomes and a single Y chromosome never survive to birth. However, children may be born with 22 normal pairs of autosomes and a single X chromosome. Such individuals have the genetic constitution XO, with O denoting the absence of a second sex chromosome. They are female, and occur with an incidence of approximately 0.4 per thousand live-born girls. The phenotypic effects of Turner syndrome are relatively minor but the person is infertile. Individuals are usually shorter than normal, with a characteristic webbed neck. Oestrogen replacement therapy can allow normal pubertal development and growth can be stimulated with growth hormone.

Weblink
Diploid vs. haploid cells

Online Worksheet
Diploid vs. haploid cells

Getty Images Plus/E+/adamkaz

Figure 6.17 A child with Down syndrome and her family

Table 6.2 The risk of a child being born with Down syndrome increases with increasing age of the mother.

Maternal age at birth of child (years)	Risk of child having Down syndrome
20	1 in 1925
25	1 in 1205
30	1 in 885
35	1 in 365
40	1 in 110
45	1 in 32
50	1 in 12

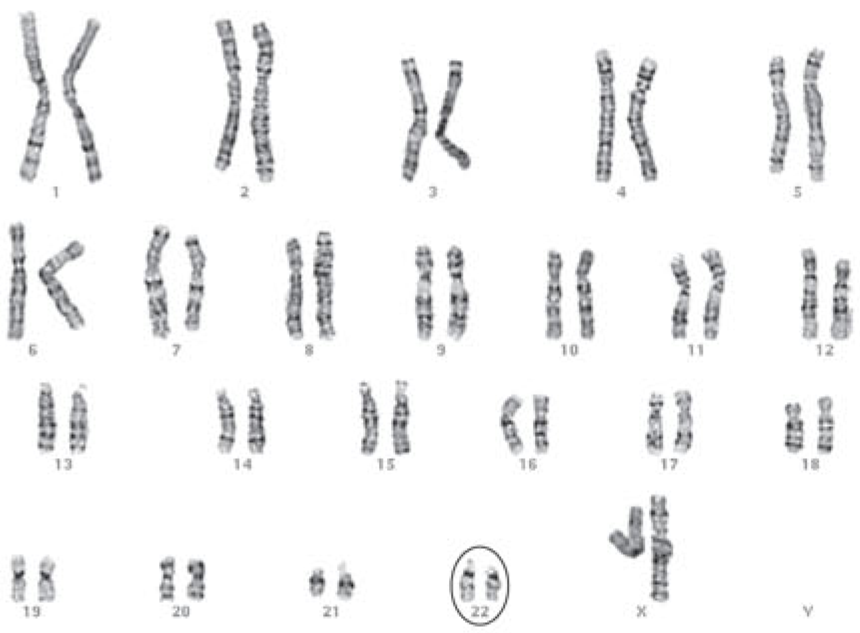

Figure 6.18 Karyotype of a female with DiGeorge syndrome with chromosome 22 circled; the shortened copy of the chromosome is on the right

Chromosomal rearrangements

Karyotypes also reveal situations where a single chromosome has become damaged or undergone some kind of change. An example of this is individuals with DiGeorge syndrome. These individuals are born with congenital defects, including heart disease and the absence of a thymus gland, which leads to other physiological disorders. Affected individuals also have a distinctively broadened facial structure with a cleft palate and they may exhibit developmental delays and a range of other signs.

The chief cause is a single damaged copy of chromosome 22 (Figure 6.18). The chromosome is often missing a segment of up to 3 million base pairs in affected individuals.

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KEY CONCEPTS

- When eukaryotic chromosomes are matched and ordered and displayed in a karyotype, different chromosome sizes, centromere positions and banding patterns can be observed.
- Karyotypes reveal anomalies resulting from a missing chromosome, the presence of an extra chromosome, or damaged chromosomes.

Concept questions 6.3

1. Describe how a karyotype is made and how the chromosomes are identified and ordered.
2. Name the types of chromosomal abnormalities that can be identified from examining a karyotype.
3. In terms of sets of chromosomes, describe the relationships between haploid, diploid and aneuploidy.
4. Distinguish between monosomy and trisomy.
5. Trisomy 21 can be observed on a karyotype of a Down syndrome child. Turner syndrome children would be described as XO. What would their karyotype look like?

HOT Challenge

6. From your knowledge of DNA and genes, explain why an extra or missing piece of DNA in a person's genome can have such a profound effect on their development. Provide an example of a condition where DNA is missing and a condition where additional DNA is part of the genome of an individual.

6.4 Production of gametes and sexual reproduction

The nucleus of each somatic cell contains pairs of chromosomes, or homologous chromosomes. The diploid number for human cells is 46. One chromosome of each pair comes from the male parent and the other chromosome of a pair comes from the female parent.

Meiosis

Meiosis is a complex process that occurs in specialised organs of sexually reproducing animals and plants. It results in the production of haploid gametes: the sex cells, sperm and eggs (or ova), as summarised in Figure 6.19 and detailed in Figure 6.20. It is a form of nuclear division that halves the chromosome number and allows the return to the diploid number of chromosomes at fertilisation. In meiosis, two divisions of the nucleus of the parent cell take place. In the first division, each chromosome of a pair separates and goes to each end, or pole, of the cell. In the second division, the chromatids of each chromosome separate from each other. Four gametes are thus produced, each carrying half the original number of chromosomes. Gametes are therefore haploid.

Because the number of chromosomes in the daughter cells has been reduced by half, meiosis is called a reduction division. During meiosis, the maternal and paternal chromosomes of each homologous pair separate to each gamete at random. Fertilisation, the joining of the sperm and egg cells, results in the **zygote** gaining one of each pair of chromosomes from its parents. Meiosis can be broken down into a number of steps or phases, which will be discussed individually, but the process is actually continual.

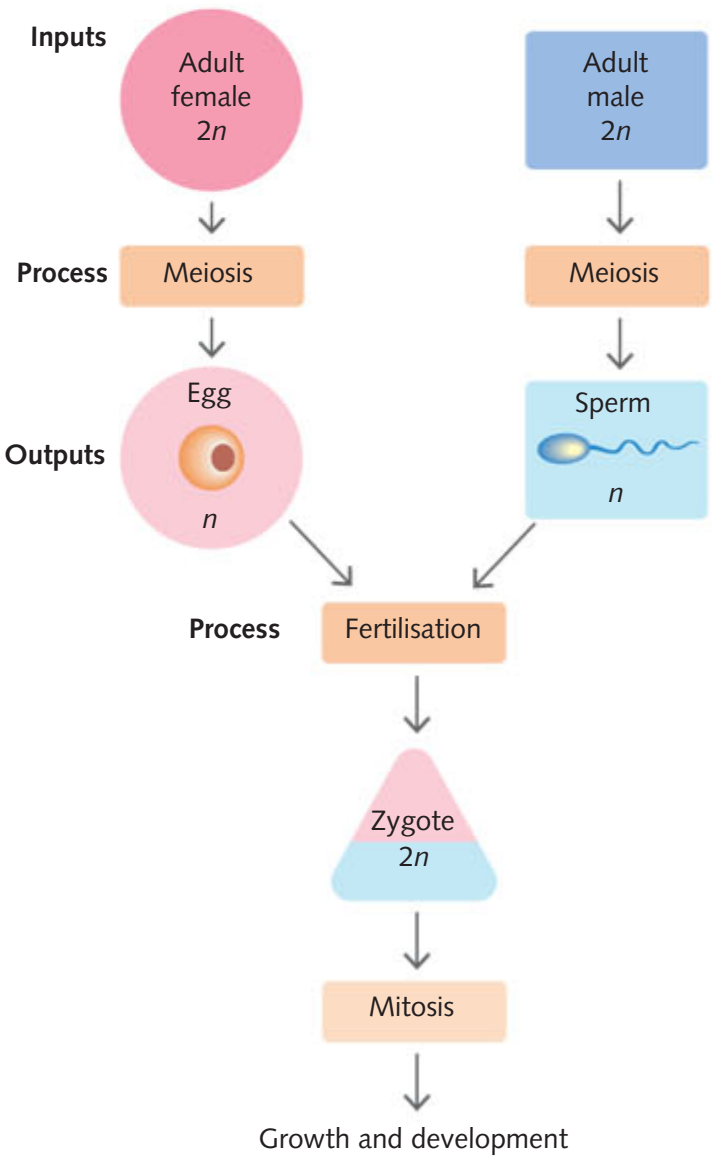


Figure 6.19 Inputs and outputs of meiosis

Meiosis I

The first division of meiosis, called meiosis I, is crucial for generating the haploid state.

Prophase I

CONNECT

See Chapter 7 for further discussion of the effect of crossing over and recombination on inheritance.

In prophase I the chromosomes condense, the nucleolus disappears and a spindle forms with centrioles, if present, at opposite ends. Homologous chromosomes lie side by side, a situation referred to as **synapsis**.

During synapsis, homologous chromosomes may coil around each other. Later, they move slightly apart but the chromatids remain in contact. These contact points are called **chiasmata**. At these chiasmata, the chromatids may break and re-join to other chromatids. This process is called **crossing over** and **recombination** and results in genes at the same loci being swapped between the chromatids. Crossing over and recombination is facilitated by segments of non-coding DNA. Sometimes the chromatids re-join back to the same chromatid with no crossing over; that is, they have the same sequences of DNA as previously.

The amount of crossing over and recombination varies between species, and within species it varies between different homologous chromosomes. The end result of crossing over is the production of gametes with new combinations of parental DNA. This is an important source of genetic variation.

Metaphase I

In metaphase I, the nuclear envelope breaks down and the homologous chromosomes move together to the equator of the spindle. Spindle fibres attach to the centromere of each homologous pair.

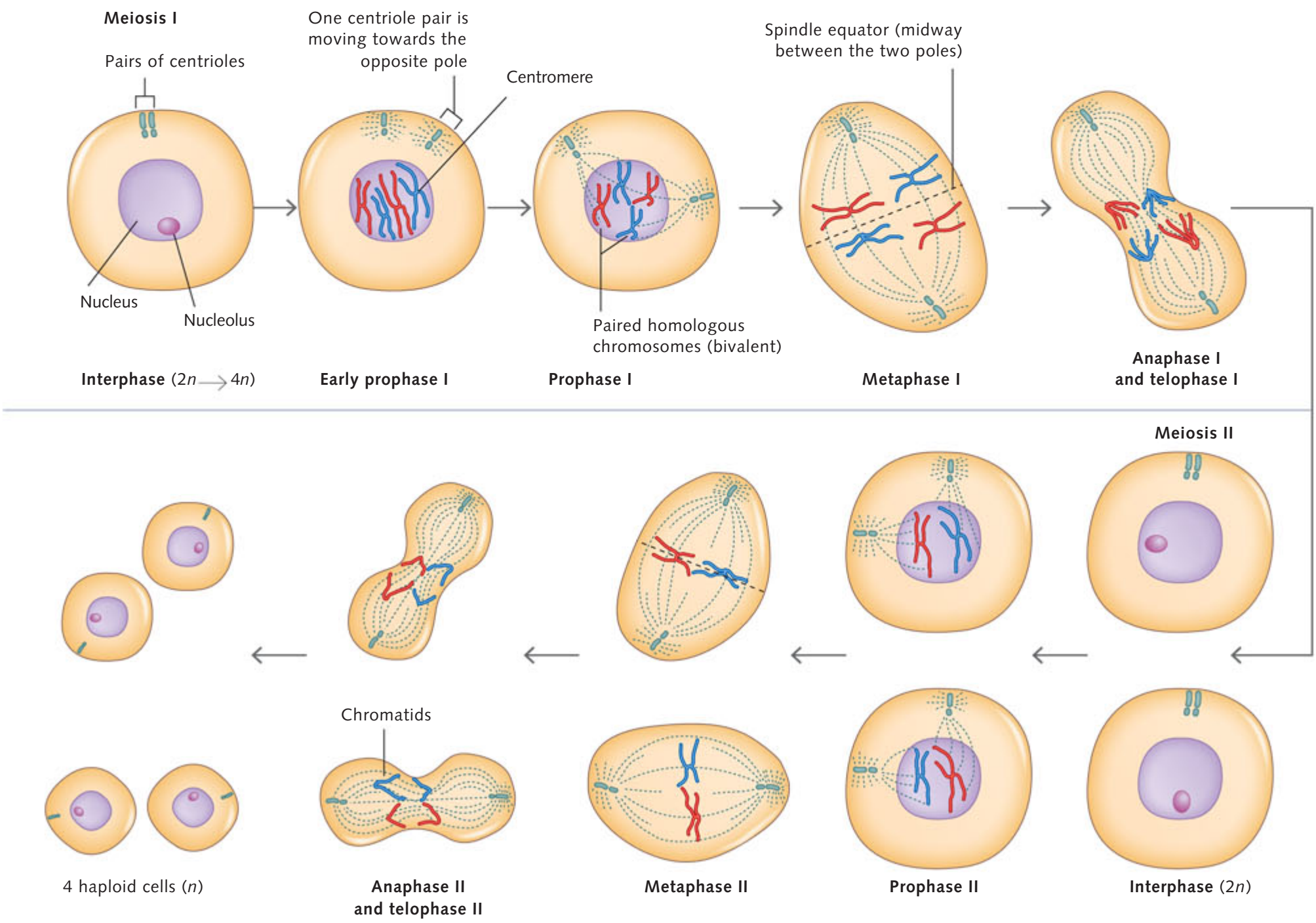


Figure 6.20 **The stages of meiosis. Blue represents a paternal chromosome and red represents a maternal chromosome.**

Anaphase I

In anaphase I, the spindle fibres retract towards the poles, pulling the maternal and paternal chromosomes of homologous pairs towards opposite poles of the spindle. The separation or disjunction of each pair of homologous chromosomes occurs independently of other chromosome pairs.

Telophase I

In telophase I, the spindle breaks down, the cell starts to separate across its middle and nuclear envelopes form around the two new nuclei.

Cytokinesis, the division of the cell and cytoplasmic contents, completes the first stage of meiosis.

Interphase

At the end of meiosis I, a brief interphase usually occurs. DNA does not duplicate during this interphase.

Meiosis II

The cell then enters the second meiotic division. The stages of meiosis II resemble those of mitosis except that the resulting cells are haploid.

In prophase II, a new spindle forms at right angles to the first one. In metaphase II, the sister chromatids move to the equator of the spindle, and spindle fibres attach to the centromere of each chromosome. In anaphase II, the spindle fibres retract towards each pole and the chromatids separate and move apart from each other. The chromatids become the chromosomes of the daughter cells. When they reach the poles, the cells enter telophase II. Characteristically of telophase, the spindle disappears, the chromosomes de-condense to their thread-like form and new nuclear envelopes and nucleoli form.

Meiosis is now complete. Cytoplasmic division follows, so that four haploid cells form from the original single diploid parent cell.

Meiosis and Mendel's laws

An examination of the process of meiosis reveals two key observations that affect the patterns of inheritance in all eukaryotic organisms.

The first of these relates to how genes (and therefore alleles) partition between gametes. Precisely half of the homologous chromosomes end up in each sperm or egg cell. Consequently, each gene pair separates equally into the egg and sperm cells. This is described as the **law of segregation**. This law implies that, for a diploid organism, half of its gametes contain one member of the gene pair and half contain the other member.

The second observation is that each pair of homologous chromosomes separates into gametes independently of each other pair. The genes carried on different homologous chromosomes therefore also segregate independently. Consequently, the combination of genes (and alleles) that ends up in each gamete occurs purely by chance. This is referred to as the **law of independent assortment**. For example, consider just two genes, each with two different alleles, located on different chromosomes (Figure 6.21). The law of independent assortment dictates that the alleles of each gene pair

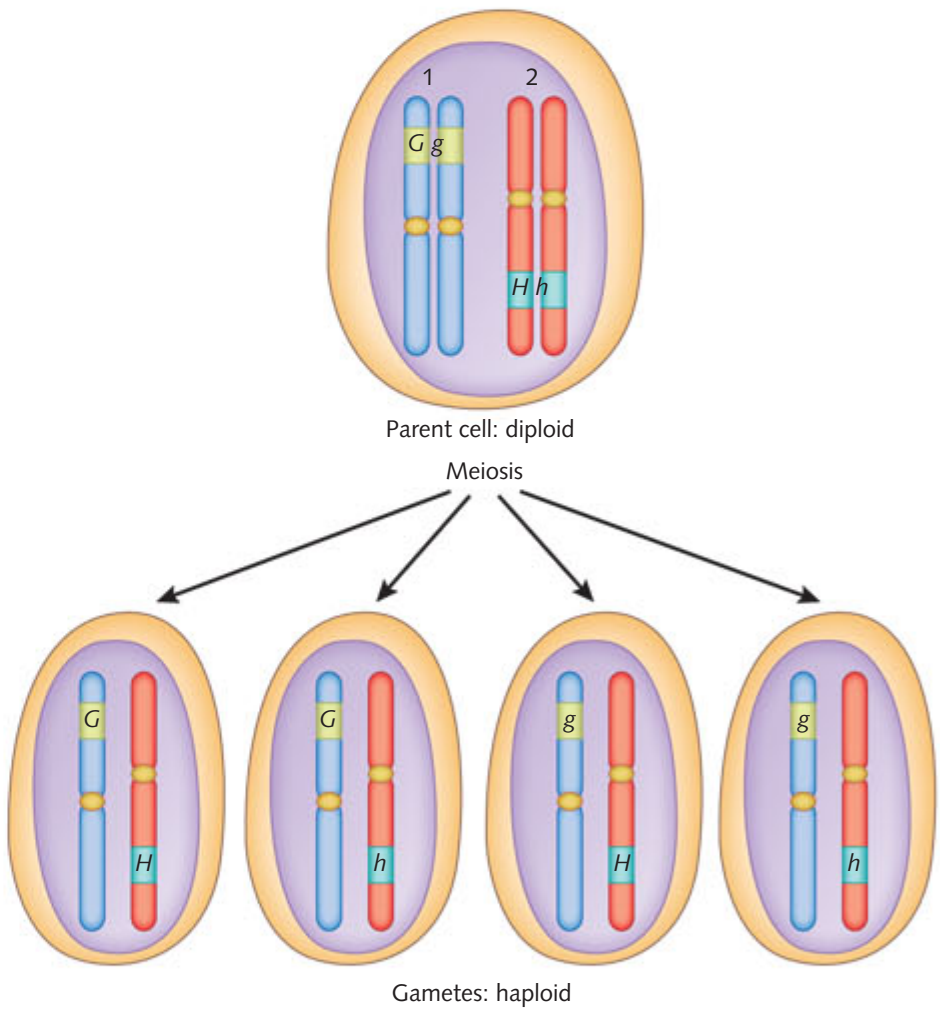


Figure 6.21 **Two key laws of inheritance emerge as a consequence of meiosis. Consider two genes located on different homologous chromosomes (1 and 2). Each gene has two alleles (*G*, *g* and *H*, *h*). After meiosis, the law of segregation determines that half the gametes will contain one member of each gene pair and half will contain the other member. The law of independent assortment determines that the gene pairs divide randomly relative to one another. As a result, the total pool of gametes contains four different combinations of the alleles derived from the parent cells (*GH*, *Gh*, *gH*, *gh*) .**

Weblink
Overview of meiosis

Online Worksheet
Overview of meiosis

WB 6.4.1 INTRODUCING VARIATION THROUGH MEIOSIS PAGE 163

separate randomly into the gametes during meiosis. A total of four different combinations of the alleles therefore occurs among all the individual's gametes.

During the mid-19th century, an Austrian monk named Gregor Mendel studied the patterns of inheritance of various characteristics in pea plants. Through his discoveries, he formulated the two laws of inheritance described here. He achieved this even before the process of meiosis was discovered. The two laws are therefore also referred to as Mendel's laws.

CONNECT

Mendel's research is discussed in detail in Chapter 7.

Fertilisation

WB
6.4.2 MEIOSIS, FERTILISATION AND MITOSIS PAGE 165

In the process of fertilisation, male and female haploid sex cells fuse to produce a diploid zygote. Two gametes from different individuals (usually one male and one female) of the same species need to combine to produce the new individual of that species. This is called sexual reproduction. Organisms produced by sexual reproduction will have a combination of DNA that is different from that of either parent.

The zygote formed is a cell with double the amount of DNA of the gamete. Therefore, meiosis halves the amount of DNA and fertilisation restores the amount of DNA to the required amount for that species. Human gametes produced by meiosis contain 23 chromosomes. Fertilisation restores the number of chromosomes to 46 (23 + 23 = 46), the chromosome number in somatic cells.

EXAM TIP

Take account of all the information in the question when calculating chromosome numbers following meiosis and fertilisation. Note whether the information includes the number of chromosomes in the organism's body cells (diploid) or the number in the gametes (haploid).

In mammals, gametes from the male are called sperm, and gametes from the female are called ova. In flowering plants, pollen grains contain cells that are male gametes and ova contain an egg cell or female gamete.

Origins of aneuploidy

The processes of meiosis and fertilisation help us to understand how aneuploidy comes about. In normal meiosis, identical chromosomes come together and then segregate into separate cells, so the gametes finish up with only one of each pair of chromosomes. Occasionally, however, instead of separating, the two identical chromosomes go into the same cell. This phenomenon is known as **non-disjunction**. It results in the formation of two types of gametes in equal proportions, but one type has two copies of a particular chromosome and the other type has none (Figure 6.22).

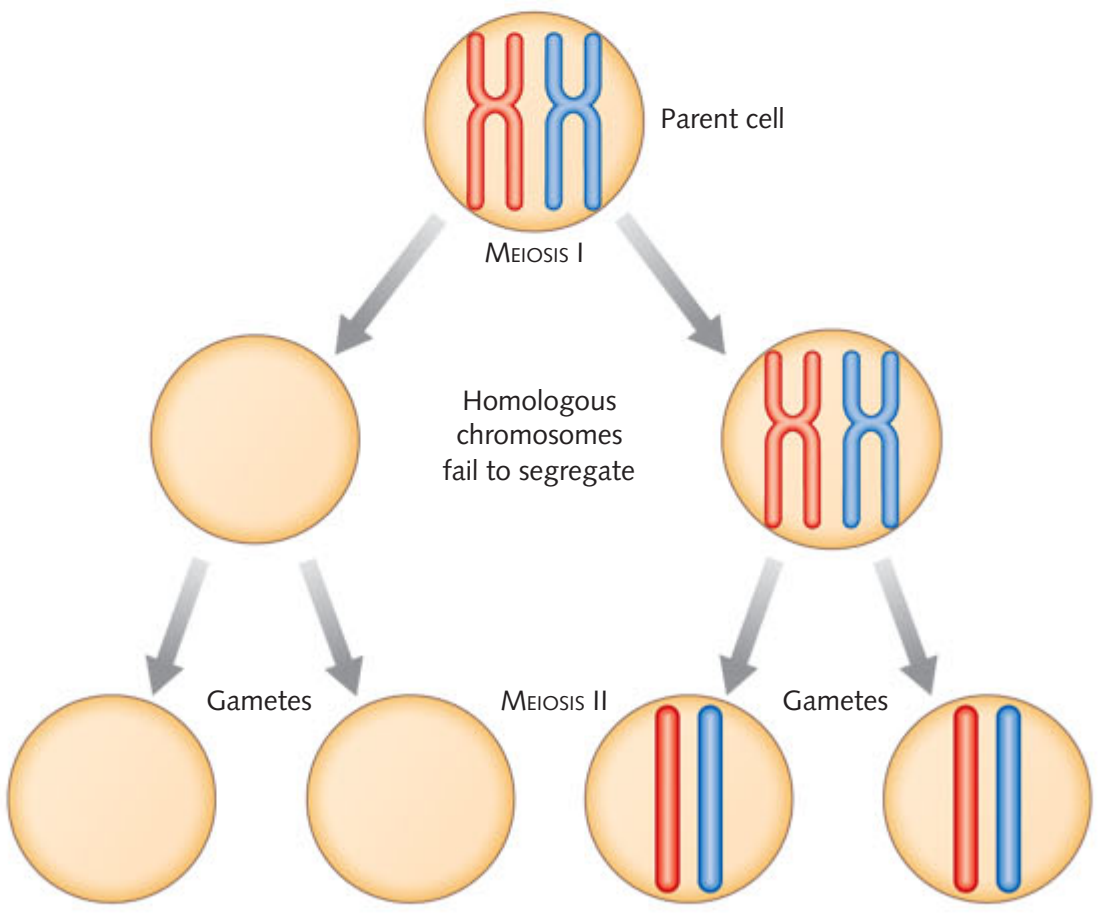


Figure 6.22 In non-disjunction, the chromosomes fail to segregate, so half the gametes contain two chromosomes of a pair (bivalent) each and the other half contain no chromosomes at all. Generally, non-disjunction only takes place with one pair of homologous chromosomes, while the rest behave normally. It can occur during either the first or the second meiotic division.

The fusion of a gamete containing both homologous chromosomes with a normal gamete containing one of the chromosomes gives a zygote with three such chromosomes; the normal pair plus an extra one. This is the trisomy condition. Fusion of a gamete containing none of the homologous chromosomes with a normal gamete gives an individual with only one of this particular type of chromosome in each cell. This is the monosomy condition.

Chromosomes and variation

During meiosis, when homologous chromosomes pair and then move to different daughter cells independently of each other, gametes with many different combinations of parental chromosomes are possible. In fact, the number of possible combinations that can occur is 2^n, where n is the number of haploid chromosomes. Humans have 2^{23} possible combinations, which is almost 10 million.

When homologous chromosomes separate and recombine in the first division of meiosis, pieces of chromosomes sometimes break and exchange with their homologous pair during crossing over. This can lead to variations in the appearance of the offspring.

The process of fertilisation also provides the potential for different combinations of characteristics in the offspring because it is by chance that particular gametes combine.

Although these processes produce variations in characteristics in sexually reproducing organisms, they do not generate new DNA. Existing DNA is merely reshuffled through different combinations.

ACTIVITY 6.1

Displaying chromosomes

When a prepared microscope slide of stained cells in the process of nuclear division is examined, a jumbled cluster of chromosomes can be seen. A karyotype is produced when the images of chromosomes are arranged into matched and ordered pairs. Chromosome alterations can be observed and analysed by examination of a karyotype.

Aim

To examine a human karyotype and investigate anomalies in chromosome sets

What to do

1. Photocopy Figure 6.23 in colour, then cut out each chromosome and assemble the cut-out chromosomes into a karyotype by pairing the homologous chromosomes from biggest to smallest. Label the pairs 1 to 23. Use Figure 6.15 as a guide.
2. Create a cell that would be seen in an individual with:
   - **a** Down syndrome
   - **b** Klinefelter syndrome.

What did you discover?

1. List three features of chromosomes that guided you in matching up the homologous pairs.
2. Identify the sex of the individual with the karyotype you have constructed. Explain what the karyotype would look like if it was from the other sex.
3. Name the type of cells that contain two sets of chromosomes.
4. Describe the type of human cells that would contain one set of chromosomes. What term would you use to describe the number of sets of chromosomes in these cells?
5. Explain and draw a diagram of the events that would have occurred during meiosis and fertilisation to form cells showing the chromosome anomalies associated with Down syndrome and Klinefelter syndrome.

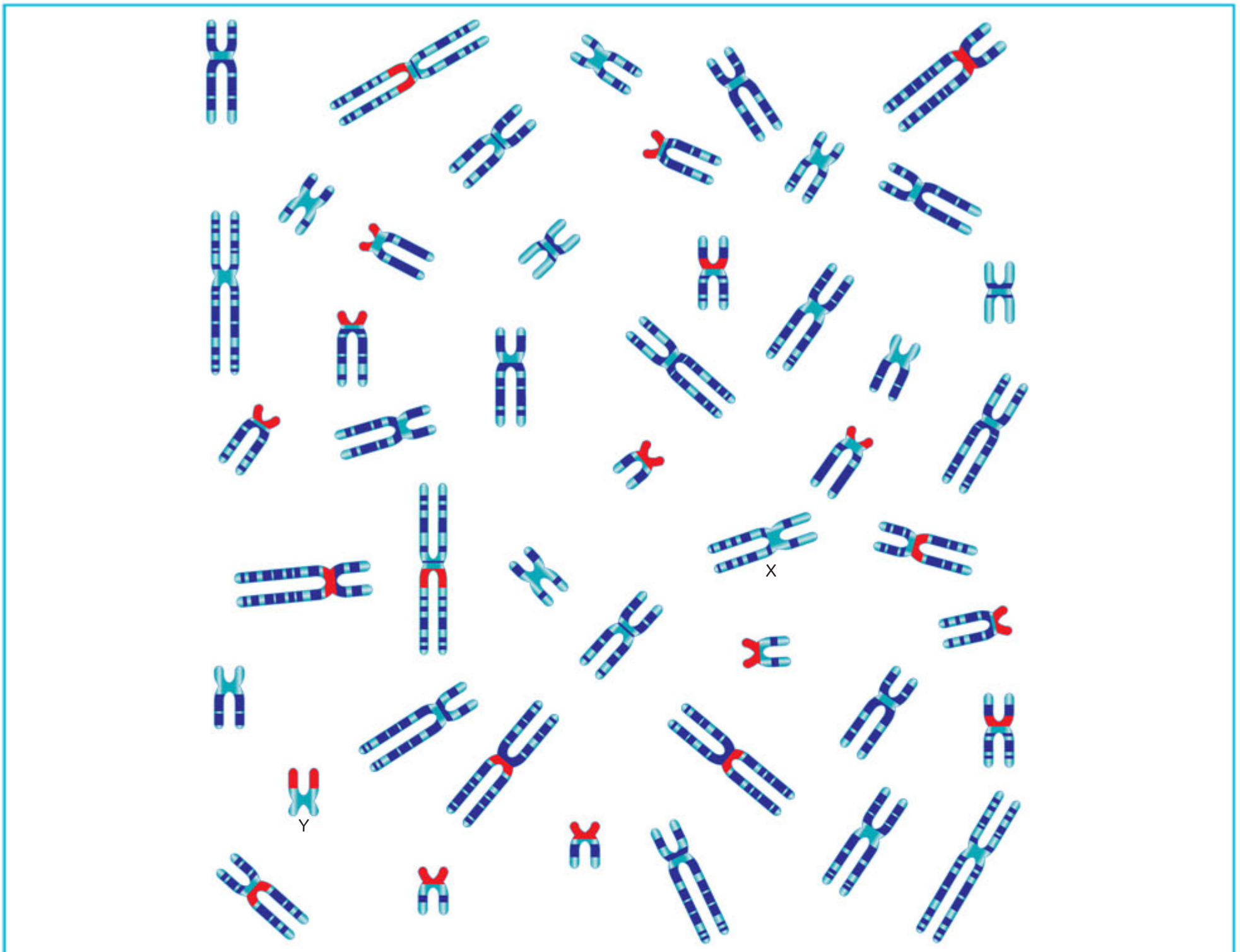


Figure 6.23 Stylised representation of chromosomes of a human cell

KEY CONCEPTS

- Haploid gametes are formed by the process of meiosis and fuse together in sexual reproduction to form a new diploid cell with genetic material from two different parents.
- In meiosis, two divisions of the nucleus of the parent cell take place. In the first division, the chromosomes of a pair separate and go to opposite ends of the cell. In the second division, the chromatids of each chromosome separate from each other and go to new cells.
- Non-disjunction during meiosis helps to explain how aneuploidy occurs.
- Sexual reproduction generates variation among the individuals of a population. Variation results from the random shuffling of alleles into gametes during meiosis and the chance outcome of which gametes unite during fertilisation.

Concept questions 6.4

1 Distinguish between gametes, germline cells and normal body (somatic) cells.
2 Using an annotated flow chart, describe what happens in each of the two stages of meiosis.
3 Explain why the process of crossing over and recombination in meiosis is biologically important.
4 Explain the role of the spindle fibres in meiosis and aneuploidy.
5 Differentiate between disjunction and non-disjunction and explain why one of these produces a problem in meiotic divisions. At which stage of meiosis does disjunction occur?
6 a Link the following terms together, and explain them as the basis of variation in sexually reproducing populations of organisms: sexual reproduction, meiosis, segregation and independent assortment.
b What is crossing over, when does it occur and how can it contribute to variation?

HOT Challenge

7 Sperm cells have a high concentration of mitochondria but mitochondrial DNA (mtDNA) does not follow typical cell replication processes in living organisms. A woman that lived 150 000 to 200 000 years ago has been found via her mtDNA to be related to everyone currently alive. How can this be?

BRANCHING OUT

Surviving trying conditions with polyploidy

A team of scientists from Ghent University in Belgium, South Australian Museum and Australian National University have started studying Australia's burrowing frog species from the genus *Neobatrachus*. They are wanting to find out how these frogs survive the extreme environmental conditions in some parts of Australia and if their genetic makeup assists in this survival.

The team has discovered that some of the nine burrowing frog species under investigation have tetraploidy or four sets of chromosomes in each cell (4n), rather than the usual diploid or two sets (2n). This is a condition that is commonly seen in plants (it has been estimated that up to 80% of plant species are polyploid) where it shields the effects of deleterious mutations and provides increased hybrid vigor. Normally a hybrid is sterile as chromosomes from two different species will not form homologous pairs to enable meiosis to proceed. If however, the chromosome complement is doubled, then all chromosomes will instantly have a homologous pair and meiosis can proceed to completion. Polyploidy ensures that a sterile hybrid becomes a fertile species as it can now reproduce. Potatoes, canola, wheat and cotton are all polyploids.

Polyploidy is less common in animals, although it does happen as shown by these frog species. What is unusual is that it appears to have happened three times, all independent of each other, in three separate species from the one genus. Polyploids in these species exhibit higher genetic diversity and it is this that could be enabling the frogs to occupy harsher environments. The team think that the diploid *Neobatrachus* species are not surviving in environments altering due to climate change. They are trying to find out if this is an evolutionary response to climate-induced habitat loss.

Adapted from https://phys.org/news/2020-06-australia-burrowing-frogs.html

Questions

1 What is the research question?
2 Write a hypothesis from this research question.
3 What results would support this hypothesis?
4 How does polyploidy come about in nature?
5 At what stage of meiosis is polyploidy advantageous?
6 What are the implications of this research for the survival of some threatened species in the future?

Online Key Concepts
Chapter 6 summary of key concepts

6 Summary of key concepts

6.1 Distinction between genes, alleles and a genome

KEY CONCEPTS

p. 225

- DNA is the common genetic material of all organisms. It is composed of four different types of nucleotides built into two strands that form a double helix that is held together by complementary base pairing.
- The information in DNA is coded in genes, which may occur in different forms called alleles.
- An organism's genome consists of all of its genes and its non-coding DNA. The non-coding DNA of the genome has many different functions.
- Genomics is useful for finding out how genes work, identifying genes that affect specific human conditions, determining how species are related, and detecting and diagnosing infections.

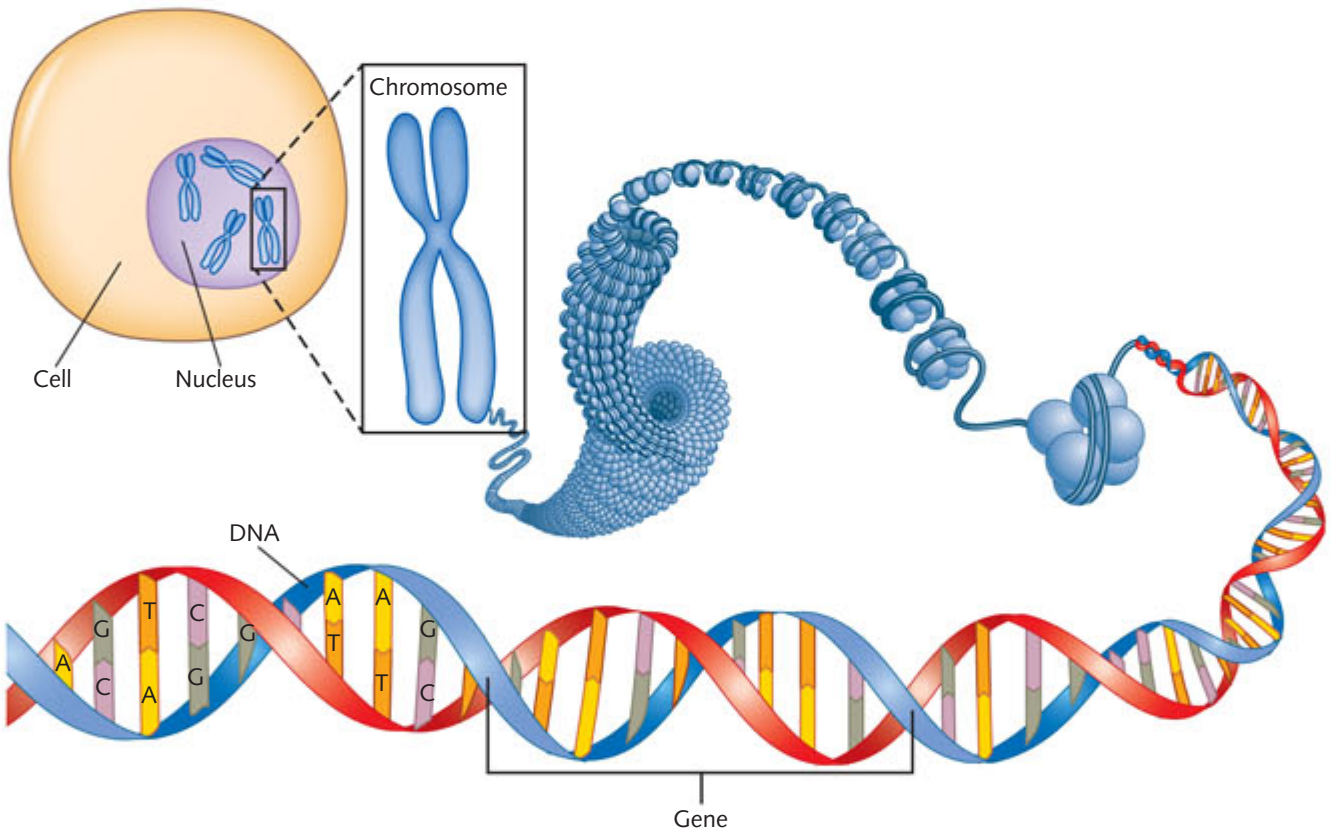


Figure 6.3 The relationship between chromosomes, DNA and genes. The segment of DNA composing a gene is normally hundreds to many thousands of nucleotides long.

6.2 Chromosomes

KEY CONCEPTS

p. 231

- Homologous chromosomes have the same genes at the same position (locus) but these genes may have alternative forms (alleles).
- The nucleus of human cells contains 22 pairs of autosomes and one pair of sex chromosomes. The sex chromosomes determine an individual's sex and are XX in females and XY in males.
- The chromosomes of different species vary in the structure and the haploid number of the chromosomes. Variation in chromosome number also occurs within species, which may be monoploid or polyploid.
- Apart from the linear chromosomes of the nucleus, eukaryotic organisms have smaller circular chromosomes in their mitochondria and chloroplasts.
- Prokaryotic cells generally have a single circular chromosome within a nucleoid region and smaller rings of DNA called plasmids.

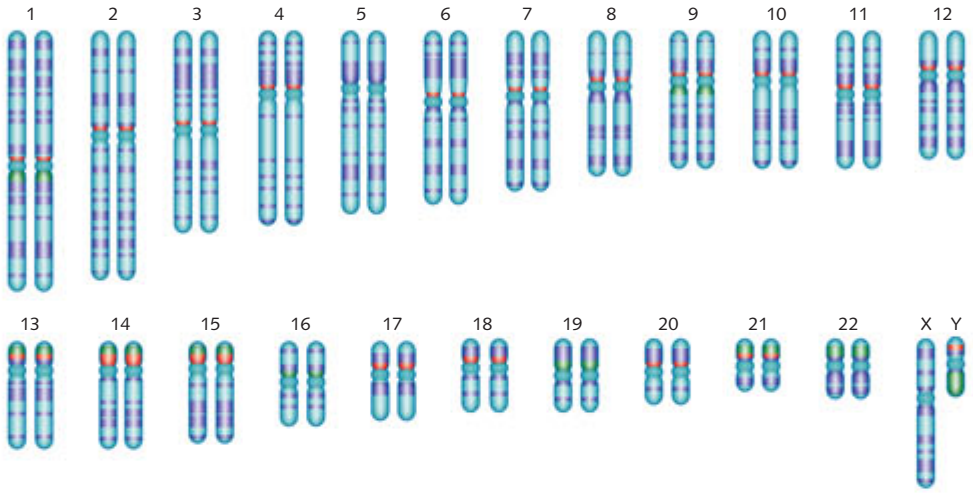


Figure 6.9 The 46 chromosomes of a typical human cell consist of 22 pairs of autosomes (numbered 1 to 22) and one pair of sex chromosomes (XX or XY).

6.3 Karyotypes for identifying chromosomal abnormalities

KEY CONCEPTS

p. 238

- When eukaryotic chromosomes are matched and ordered and displayed in a karyotype, different chromosome sizes, centromere positions and banding patterns can be observed.
- Karyotypes reveal anomalies resulting from a missing chromosome, the presence of an extra chromosome, or damaged chromosomes.

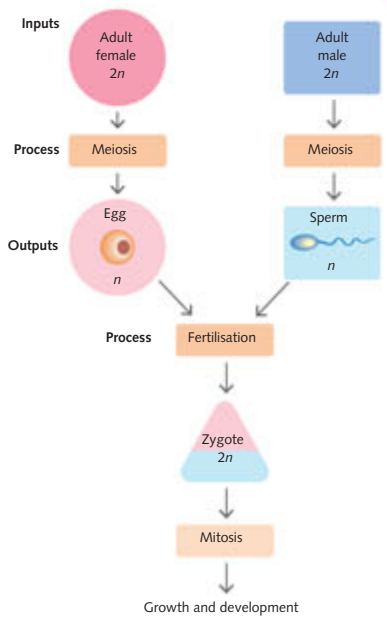


Figure 6.19 Inputs and outputs of meiosis

6.4 Production of gametes and sexual reproduction

KEY CONCEPTS

p. 241

- Haploid gametes are formed by the process of meiosis and fuse together in sexual reproduction to form a new diploid cell with genetic material from two different parents.
- In meiosis, two divisions of the nucleus of the parent cell take place. In the first division, the chromosomes of a pair separate and go to opposite ends of the cell. In the second division, the chromatids of each chromosome separate from each other and go to new cells.
- Non-disjunction during meiosis helps to explain how aneuploidy occurs.
- Sexual reproduction generates variation among the individuals of a population. Variation results from the random shuffling of alleles into gametes during meiosis and the chance outcome of which gametes unite during fertilisation.

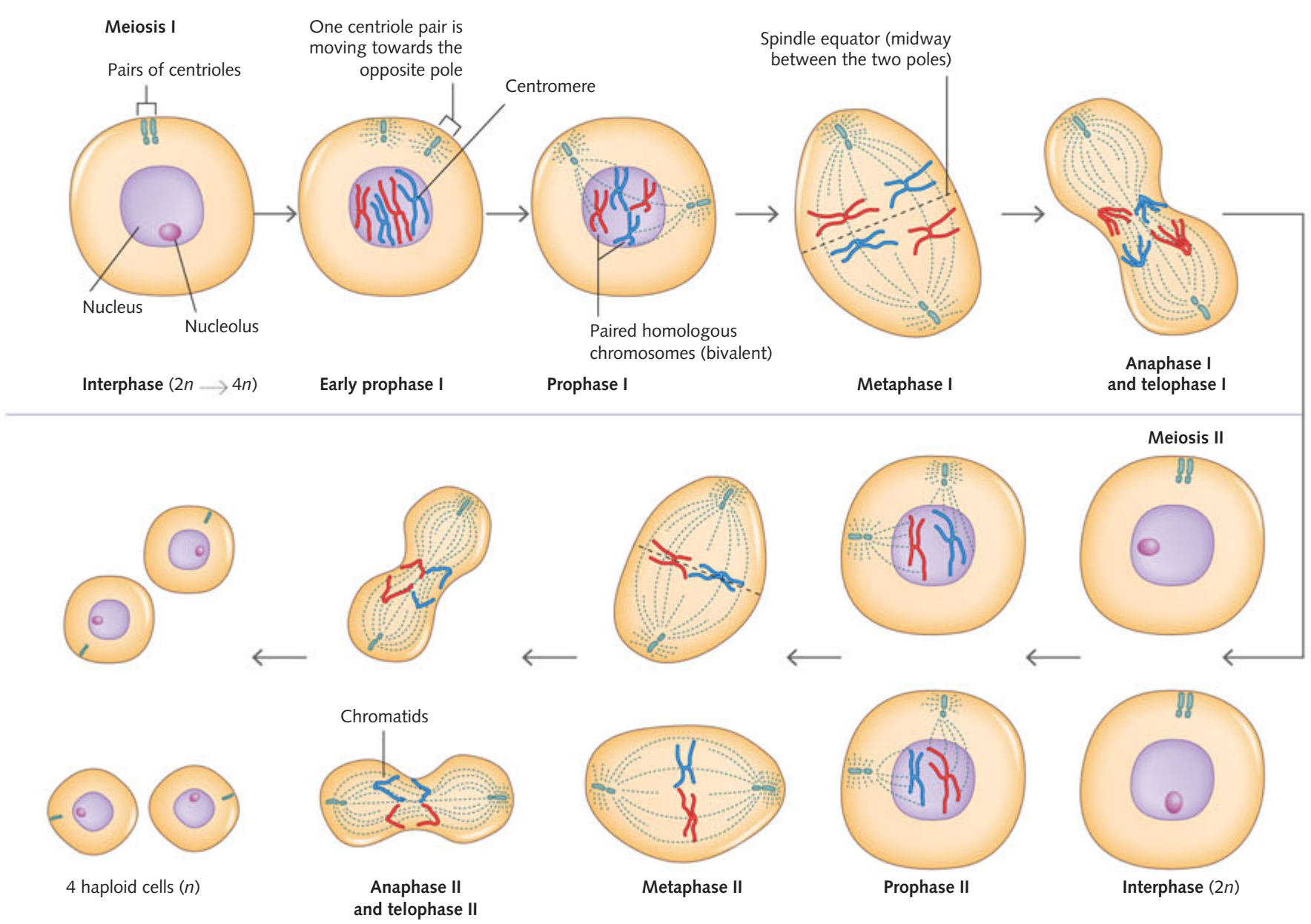


Figure 6.20 The stages of meiosis. Blue represents a paternal chromosome and red represents a maternal chromosome.

6.5.1
KEY TERMS
PAGE 168

6 Chapter glossary

allele one of different versions of the same gene (at the same locus); the differences are determined by small differences in the DNA sequence of the gene

aneuploidy describes a genome that varies from the conventional by the loss or addition of one or just a few chromosomes

autosome a chromosome that is the same in both males and females of a species; autosomes do not include sex chromosomes

base pair two complementary nucleotide bases that are joined together by hydrogen bonding in a DNA double strand

bioinformatics the science of managing and analysing biological data using advanced computing techniques

chiasmata (singular: chiasma) contact points between chromatids of homologous chromosomes that may become sites for crossing over and recombination during meiosis

chloroplast DNA (cpDNA) DNA contained in a chloroplast

chromosome one of the structures which comprise the double-stranded DNA molecule that physically carry genes from one generation to the next; chromosomes occur as a circular DNA molecule in prokaryotes, mitochondria and chloroplasts and as linear DNA molecules associated with proteins inside the nucleus of eukaryotic cells

coding DNA a sequence of DNA that codes for a protein

complementary bases the nucleotide bases that pair on the opposite strands of DNA; A pairs with T and C pairs with G

crossing over the process during meiosis in which chromatids break and re-join to other chromatids, resulting in the chromatids swapping genes at the same loci

diploid having two haploid sets of chromosomes in each cell, represented by $2n$, the standard condition for human somatic cells

DNA sequence the order of nucleotide bases within a DNA molecule

double helix the spiral shape of a DNA molecule

gene a unit of heredity that transmits information from one generation to the next; a segment of DNA that codes for a protein

genetics the study of the mechanism and patterns of inheritance through the transmission of coded chemical instructions from one generation to the next

genome all the genetic material contained in an organism or a cell; in eukaryotes, includes the chromosomes within the nucleus and the DNA in mitochondria and chloroplasts

genome size the total number of base pairs of DNA in a prokaryotic cell or in the haploid set of chromosomes of a eukaryotic cell

genomics the study of the genome – how genes interact with each other and the environment, and the resultant proteins produced; it requires a knowledge of an organism's entire DNA sequence, so studies rely on powerful sequencing technologies and bioinformatics

haploid the condition of gametes having a single set of chromosomes, represented by n

heredity the study of inheritance; the genetic transmission of characteristics from one generation to another

heterosome non-identical chromosomes that pair up at meiosis (e.g. the X and Y chromosomes in human males)

histone a protein around which DNA winds in eukaryotic cells

homologous chromosomes a pair of chromosomes that have the same size, shape and genes at the same locations

hydrogen bond a weak molecular chemical bond

karyotype a display of the number and appearance of the chromosomes of an organism or cell observed at late prophase and metaphase

law of independent assortment the principle that genes on different homologous chromosomes separate independently into gametes during meiosis; the combination of genes (and alleles) that occurs in each gamete is therefore the result of chance

law of segregation the principle that half the gametes formed during meiosis contain one member of each gene pair and half contain the other member

locus the position a gene occupies in a chromosome

mitochondrial DNA (mtDNA) DNA contained in mitochondria

monoploid describes a cell or organism that has a functional genome consisting of one copy of each chromosome, represented by $1n$

monosomy the condition in which somatic cells contain one copy of a particular chromosome

nitrogenous base a structural component of nucleotides: DNA has adenine (A), cytosine (C), guanine (G) and thymine (T)

non-coding DNA DNA that does not code for a protein but may have other functions in chromosome structure or regulating production of proteins from genes

non-disjunction the failure of paired chromatids in mitosis or homologues in meiosis to separate and go to opposite poles

nucleoid the region within a prokaryotic cell that contains the genetic material

nucleotide the basic building block of DNA, made up of a five-carbon sugar, a phosphate group and a nitrogenous base

plasmid a small circular piece of DNA, found in bacteria, which is able to replicate independently of the cell's chromosomes

polyploidy describes a cell or organism that has a genome comprising three or more copies of each chromosome, represented by $3n$, $4n$, $5n$, $6n$ etc.

proteomics the study of the entire protein content produced by a cell, tissue or organism

recombination breaking and rejoining of pieces of chromosome during crossing over leading to a new combination of alleles in any resulting offspring

regulatory elements segments of non-coding DNA with a role in switching on or switching off the production of protein from a gene

sex chromosomes the pair of chromosomes that determines the sex of an individual

sex-linked describes genes that are found on the sex chromosomes

somatic cell a normal body cell, as compared with a germ-line cell from which a gamete (sperm or ovum) is derived

synapsis the state of homologous chromosomes laying side by side during prophase I of meiosis

tetraploid having four haploid sets of chromosomes in each cell, represented by $4n$

triploid having three haploid sets of chromosomes in each cell, represented by $3n$

trisomy the condition in which somatic cells contain three copies of a particular chromosome

zygote the diploid cell that results from the fusion of two haploid gametes

WB
6.5.2
PRACTICE TEST
QUESTIONS
PAGE 169

6 Chapter review

Remembering

1 State the chemical components of DNA.

2 Describe the composition of an organism's genome.

3 a In humans, the diploid number is $2n = 46$. State what n equals.
b State what type of cells have the $2n$ number of chromosomes.
c Which type of cells in humans are haploid?

4 Describe the difference in appearance between the X and Y chromosomes.

5 What are the main events in meiosis? List these in a table.

Understanding

6 If you know the sequence of bases on one strand of DNA, is it possible to determine the sequence of bases on the other strand? Explain.

7 Relate the concept of a gene to the concept of a chromosome.

8 Non-coding DNA is not 'junk' DNA. Explain this statement with reference to some examples.

9 Explain how genomic research can improve detection and diagnosis of genetic conditions in humans.

10 Relate the size of chromosomes X and Y to the number of genes you would expect to find on each.

11 a How many molecules of DNA are in a chromosome immediately before replication?
b How many molecules of DNA are in a chromosome immediately after replication?
c How does a chromatid differ from a chromosome?

12 Explain why meiosis is an appropriate process for gamete formation.

Applying

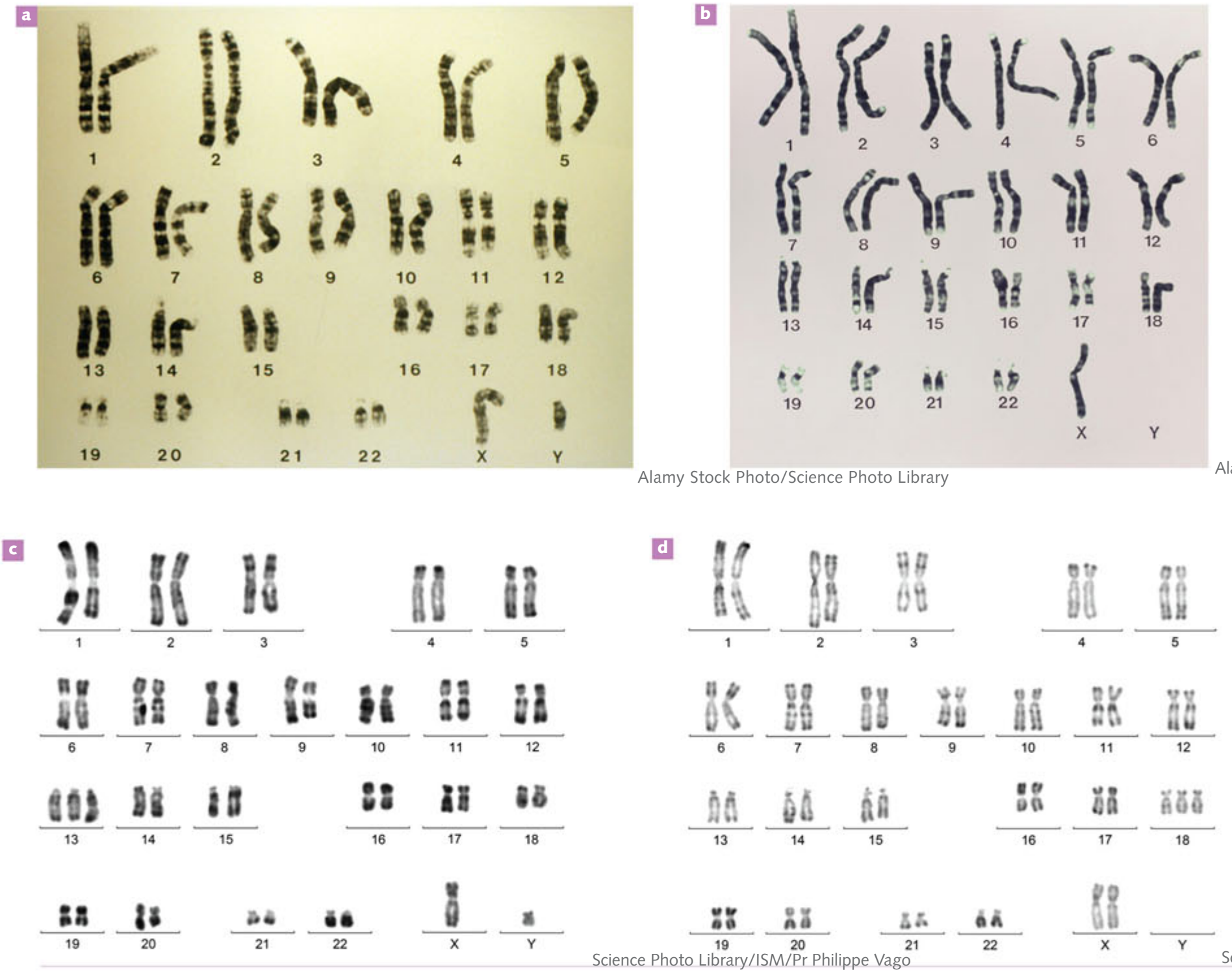
13 The normal diploid number of chromosomes in the nucleus of a eukaryotic cell must be even. Do you agree with this statement? Justify your answer.

14 Explain why mitochondrial DNA can be used to trace a direct female (maternal) genetic line.

15 Turner syndrome is described as an example of aneuploidy. Give reasons why.

16 List and explain the ways that meiosis contributes to genetic variation within a species.

17 Compare the four human karyotypes labelled i to iv in Figure 6.24.
a Determine which of the four is a normal karyotype and identify the sex of the individual.
b Determine the aberration in each of the other three karyotypes.
c Explain how the three aberrations could have come about.



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Science Photo Librar

Figure 6.24 Four human karyotypes

18 The time taken to sequence the genome of an organism has been dramatically reduced in the past 20 years. Describe two applications resulting from improved understanding of the variation and similarities of the genomes of similar species, such as bacteria.

19 Discuss how studying the genome of a wild grass species that is drought resistant may lead to applications for an agricultural crop such as wheat.

20 Human cells have a diploid number of 46. Consider a cell in an ovary undergoing meiosis. State the number of chromosomes in the cell during each of the following stages of meiosis.

- a Prophase of the first meiotic division
- b At the end of telophase of the first division
- c Prophase of the second meiotic division
- d At the end of telophase of the second division

Analysing

21 Scientists from the Australian Museum and Queensland University of Technology have sequenced the koala genome. Analysis of the data reveals between 12 000 and 20 000 genes on the 16 chromosomes of its somatic cells.

- **a** Name the nucleotide expected to have approximately the same number as the adenine nucleotides sequenced.
- **b** Explain whether you would expect the sequence of DNA to be exactly the same in all members of the koala species.
- **c** Estimate how many chromosomes a baby koala would get from its mother.
- **d** State a koala's diploid number and its haploid number.
- **e** Find out how the knowledge gained by sequencing the genome can help in managing koala populations.

22 Chromosome 1 in humans contains more than 3000 genes, while chromosome 21 contains about 400 genes. Using this data, discuss reasons why embryos with an extra chromosome 1 will not develop, yet embryos with an extra chromosome 21 will often survive to develop into a baby with Down syndrome.

Evaluating

23 Decide whether two number 21 chromosomes in humans are homologous, and justify your answer. Explain whether all human chromosomes have a homologous pair.

24 All chromosomes are double stranded and linear in shape. Do you agree with this statement? Justify your answer.

25 **a** Defend or refute this statement: 'Aneuploidy is always deleterious.' Explain your reasoning.

b If non-disjunction occurs in a diploid cell with four chromosomes undergoing meiosis, predict the kind of chromosome anomalies that can arise in a zygote formed by fertilisation with each of the resulting gametes and one normal gamete. Draw an annotated diagram of your predictions.

Creating

26 Draw Meiosis I of a species that has $2n$ of 4. Show crossing over in one of its homologous pairs and the expected resulting gametes.

7 Inheritance

By the end of this chapter you will have covered the following material.

Key knowledge

Genotypes and phenotypes

- the use of symbols in the writing of genotypes for the alleles present at a particular gene locus pp. 261–264
- the expression of dominant and recessive phenotypes, including codominance and incomplete dominance pp. 264–269
- proportionate influences of genetic material, and environmental and epigenetic factors, on phenotypes pp. 269–271

Patterns of inheritance

- pedigree charts and patterns of inheritance, including autosomal and sex-linked inheritance pp. 271–275; 277–284
- predicted genetic outcomes for a monohybrid cross and a monohybrid test cross pp. 275–277
- predicted genetic outcomes for two genes that are either linked or assort independently pp. 285–296

Key science skills

Develop aims and questions, formulate hypotheses and make predictions

- identify, research and construct aims and questions for investigation pp. 273–274
- identify independent, dependent and controlled variables in controlled experiments pp. 273–274
- formulate hypotheses to focus investigation pp. 273–274
- predict possible outcomes pp. 273–274; 290–292

Plan and conduct investigations

- determine appropriate investigation methodology: case study; classification and identification; controlled experiment; correlational study; fieldwork; literature review; modelling; product, process or system development; simulation pp. 273–274
- design and conduct investigations; select and use methods appropriate to the investigation, including consideration of sampling technique and size, equipment and procedures, taking into account potential sources of error and uncertainty; determine the type and amount of qualitative and/or quantitative data to be generated or collated pp. 273–274
- work independently and collaboratively as appropriate and within identified research constraints, adapting or extending processes as required and recording such modifications pp. 273–274; 290–292

Comply with safety and ethical guidelines

- demonstrate safe laboratory practices when planning and conducting investigations by using risk assessments that are informed by safety data sheets (SDS), and accounting for risks pp. 273–274

» apply relevant occupational health and safety guidelines while undertaking practical investigations pp. 273–274

» demonstrate ethical conduct when undertaking and reporting investigations pp. 273–274

Generate, collate and record data

» systematically generate and record primary data, and collate secondary data, appropriate to the investigation, including use of databases and reputable online data sources pp. 273–274; 290–292

» record and summarise both qualitative and quantitative data, including use of a logbook as an authentication of generated or collated data pp. 273–274; 290–292

» organise and present data in useful and meaningful ways, including schematic diagrams, flow charts, tables, bar charts and line graphs pp. 273–274; 290–292

» plot graphs involving two variables that show linear and non-linear relationships pp. 273–274

Analyse and evaluate data and investigation methods

» process quantitative data using appropriate mathematical relationships and units, including calculations of ratios, percentages, percentage change and mean pp. 273–274; 290–292

» identify and analyse experimental data qualitatively, handling where appropriate concepts of: accuracy, precision, repeatability, reproducibility and validity of measurements; errors (random and systematic); and certainty in data, including effects of sample size in obtaining reliable data pp. 273–274; 290–292

» identify outliers, and contradictory or provisional data pp. 273–274

» repeat experiments to ensure findings are robust pp. 290–292

Construct evidence-based arguments and draw conclusions

» use reasoning to construct scientific arguments, and to draw and justify conclusions consistent with the evidence and relevant to the question under investigation pp. 290–292

Analyse, evaluate and communicate scientific ideas

» use appropriate biological terminology, representations and conventions, including standard abbreviations, graphing conventions and units of measurement pp. 273–274; 290–292

» discuss relevant biological information, ideas, concepts, theories and models and the connections between them pp. 273–274; 290–292

» analyse and explain how models and theories are used to organise and understand observed phenomena and concepts related to biology, identifying limitations of selected models/theories pp. 290–292

To access resources below, visit www.nelsonnet.com.au

Online Chapter Map:
- Chapter 7 map (p. 258)

Online Key Terms:
- Chapter 7 flashcards (p. 260)

Weblinks:
- Epigenetics (p. 271)
- Mendel's law of segregation (p. 272)

Online Worksheets:
- Epigenetics (p. 271)
- Mendel's law of segregation (p. 272)

Video:
- Dihybrid crosses (p. 287)

Online Key Concepts:
- Chapter 7 summary of key concepts (p. 298)

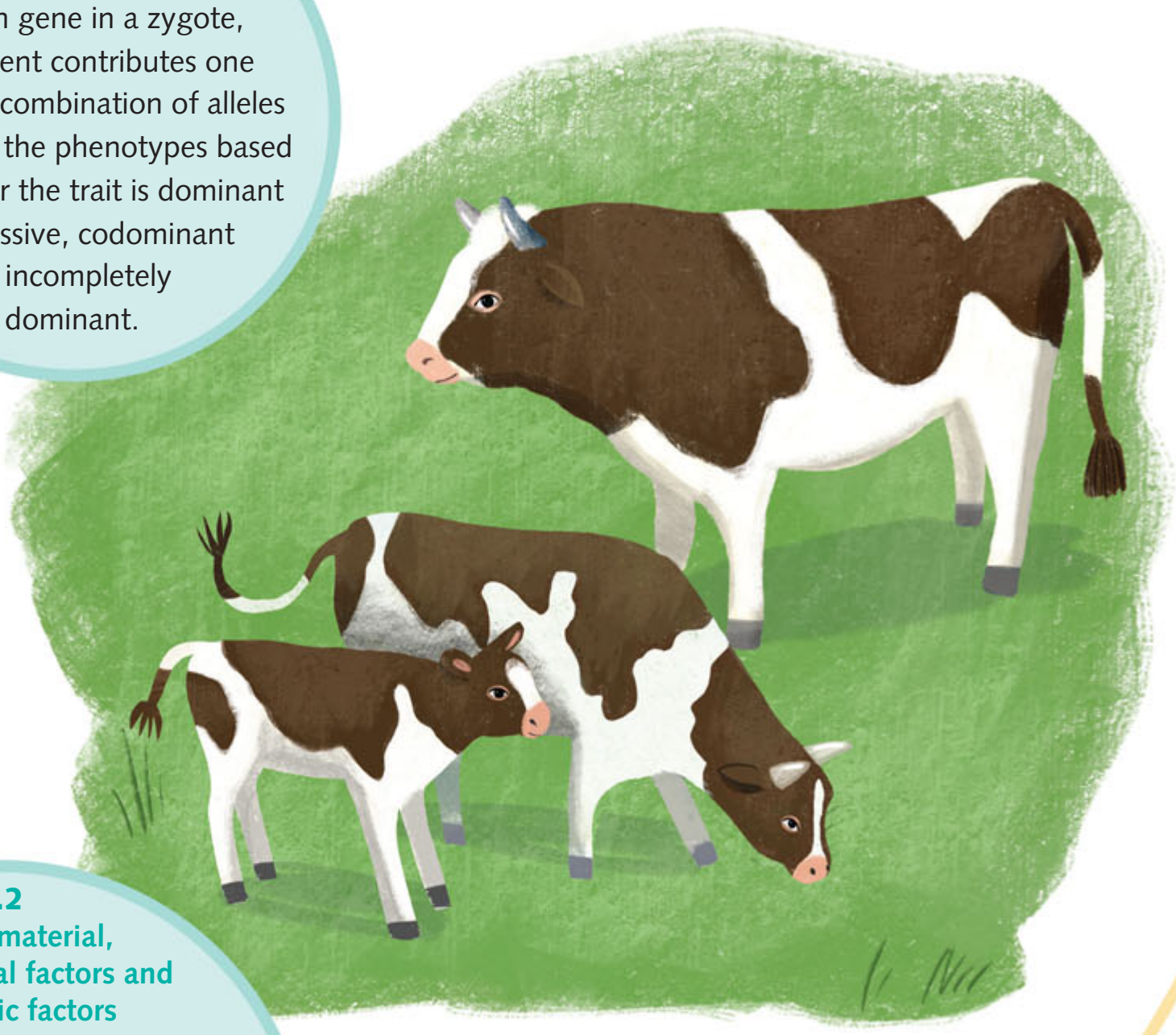
Online Chapter Map
Chapter 7 map

7 Inheritance

The alleles of the genes that make up the chromosomes of the zygote, together with the environment, determine the appearance and functioning of the new individual.

7.1 Patterns of inheritance p. 261

For each gene in a zygote, each parent contributes one allele. The combination of alleles determines the phenotypes based on whether the trait is dominant or recessive, codominant or incompletely dominant.



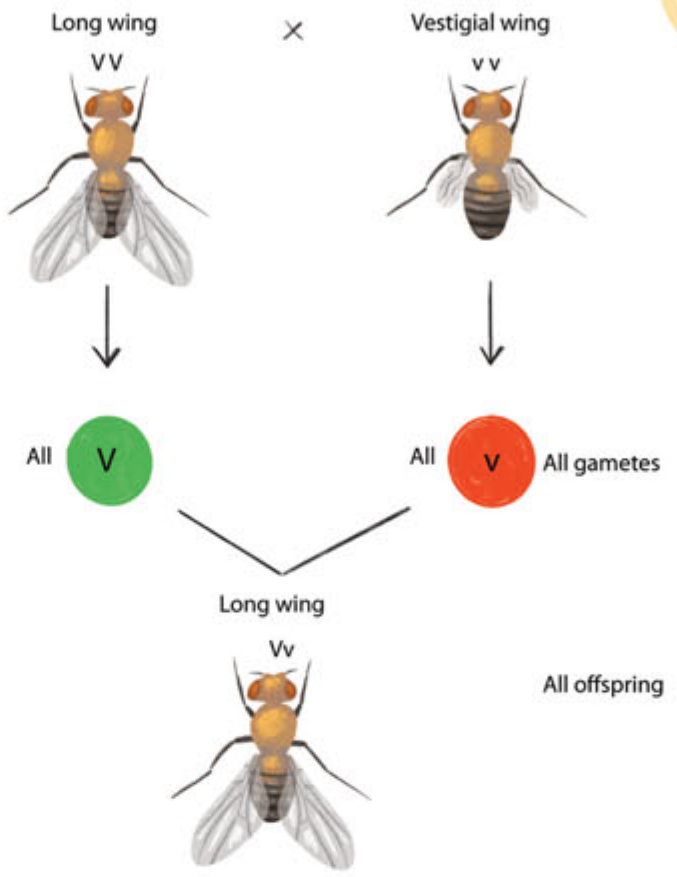
7.2 Genetic material, environmental factors and epigenetic factors p. 269

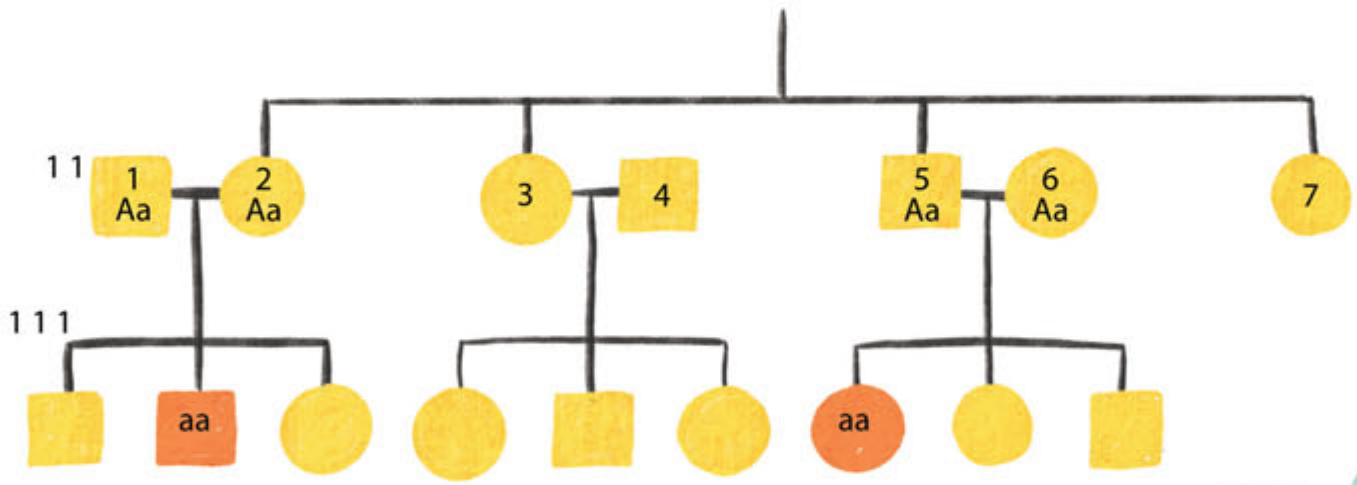
Sometimes environmental factors, such as temperature, light and pH, can affect the phenotype of the organism. Other factors, such as diet, smoking and pollution, can modify the structure of DNA, which will also influence the phenotypic expression of the gene. This is called epigenetics.

7.3 Patterns of inheritance

p. 271

If you know the alleles for the same single specific gene in each parent, the allele combination of the offspring can be predicted. This is called a monohybrid cross.





7.5 Predicted genetic outcomes for two autosomal genes

p. 285

The inheritance of two genes, each controlling a different characteristic, is called a dihybrid cross. These genes can be on different chromosomes or on the same chromosome.

7.4 Pedigree charts for autosomal and sex-linked inheritance

p. 280

A good way to see and analyse what is happening with a monohybrid cross is to show it as a pedigree chart.

Inheritance of genetic material from two parents ensures that offspring are not identical to either parent. This is important to understand as you move into the next chapter.

Online Key Concepts
Chapter 7 Flashcards

Know your key terms

autosomal gene
carrier
codominant
dihybrid cross
dihybrid inheritance
DNA methylation
dominant
epigenetics
first filial generation (F_1)
genotype
heterozygous
homozygous
incomplete dominance
independent assortment
inheritance
linkage group
linked genes
Mendelian genetics
monohybrid cross
parental generation (P)
partial dominance
pedigree analysis
pedigree chart
phenotype
Punnett square
purebred
pure breeding
recessive
recombinant gametes
recombinant offspring
second filial generation (F_2)
sex-linked gene
sex-linked inheritance
test cross
trait
unlinked genes
X-linked
Y-linked

Remember

This chapter will build on the following concepts that you will have already met. Take the time to refresh these concepts before you start this chapter.

REMEMBER PAGE 171

1 Genes are a sequence of DNA nucleotides that code for the production of a gene product, usually a protein.
2 Alleles are different forms of the same gene located at the same locus on the same chromosome.
3 Autosomes are non-sex chromosomes.
4 Sex chromosomes carry the genes that determine gender. In humans, the sex chromosomes are the X and Y chromosomes.
5 Homologous chromosomes are of the same length and centromere position and have the same gene sequence or loci.
6 Haploid (*n*) cells are produced during meiosis and the diploid (2*n*) number is restored at fertilisation.

Can you roll your tongue into a U-shape? When you clasp your hands together, is your left or right thumb on top? Look at a classmate's ears. Are the lobes attached or free? These and many more of your characteristics are inherited from your parents. Because you have two of each chromosome, one from each parent, you inherit two copies, or alleles, of the gene for each characteristic determined by a single gene. If a gene has two different alleles, different forms of the characteristic or trait are possible. Either you can roll your tongue or not; either your left thumb or your right thumb is on top when you clasp your hands together; either your ear lobes are attached or free.

Shutterst

Figure 7.1 The ability to roll your tongue is an inherited characteristic.

7.1 Patterns of inheritance

To study patterns of **inheritance**, a review of the innovative experiments and observations of an Austrian monk, Gregor Mendel (1822–84), is enlightening (Figure 7.2). He spent 2 years studying mathematics at university and was also an expert in agricultural practices, especially breeding experiments. In 1856, he carried out breeding experiments on pea plants in the garden at his monastery. The conclusions he drew form the foundations on which the study of heredity is built. The significance of his work was recognised after his death and the principles of heredity established by him are called **Mendelian genetics**.

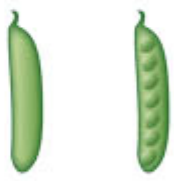
Mendel's peas

In the early stages of his work, Mendel studied the inheritance of seven pairs of contrasting characteristics in pea plants, as listed in Table 7.1. These included variations such as yellow or green pea pods, round or wrinkled seeds and tall-stemmed or dwarf-stemmed plants (Figure 7.4). Pea plants were ideal for his work: the characteristics, or traits, had no intermediate forms; pea plants self-pollinated and therefore self-fertilised; and the characteristics that he studied were largely unaffected by environmental factors.

Alamy St

Figure 7.2 Mendel discovered key principles of inheritance from breeding experiments in his pea garden.

Table 7.1 The characteristics that Mendel studied in his pea plant experiments

Characteristics	Seed (endosperm)	Seed shape	Flower colour	Pod colour	Pod shape
					
Different forms of the characteristics	Yellow Green	Round Wrinkled	Purple White	Green Yellow	Inflated Constricted

Characteristics	Flower position	Stem length
		
Different forms of the characteristics	Axial (along stem) Terminal (at tip of stem)	Tall Short

WB
7.1.1
MENDEL'S PEAS
PAGE 172

Figure 7.3 Hand pollination involves taking the pollen from the anther of one plant and dusting it onto the stigma of another plant, after removing the second plant's anthers to ensure that no self-pollination occurs.

In one experiment, Mendel took a **pure breeding** tall pea plant and crossed it with a pure breeding short pea plant. Pure breeding plants, when crossed among themselves, always give rise to offspring that are like the parents. This is because their alleles, or different forms of the gene, are identical. Mendel crossed the plants by taking pollen grains, containing the male sex cells, from the anthers of one plant and dusting them onto the stigma (female part) of another plant, having first removed the anthers of this second plant to ensure that it could not self-pollinate (Figure 7.3).

Mendel collected the seeds that resulted from the crosses between the pure breeding tall and short pea plants and grew them (Figure 7.4). The resulting plants were always tall offspring (Figure 7.5). This was the case whether pollen grains from tall plants were placed on to the stigmas of short plants, or pollen grains from short plants were placed on to the stigmas of tall plants. In these crosses, the original parent plants are called the **parental generation (P)** and the offspring are called the **first filial generation (F_1)**.

Figure 7.4 Tall and short pea plants: the two different forms for the characteristic of plant height

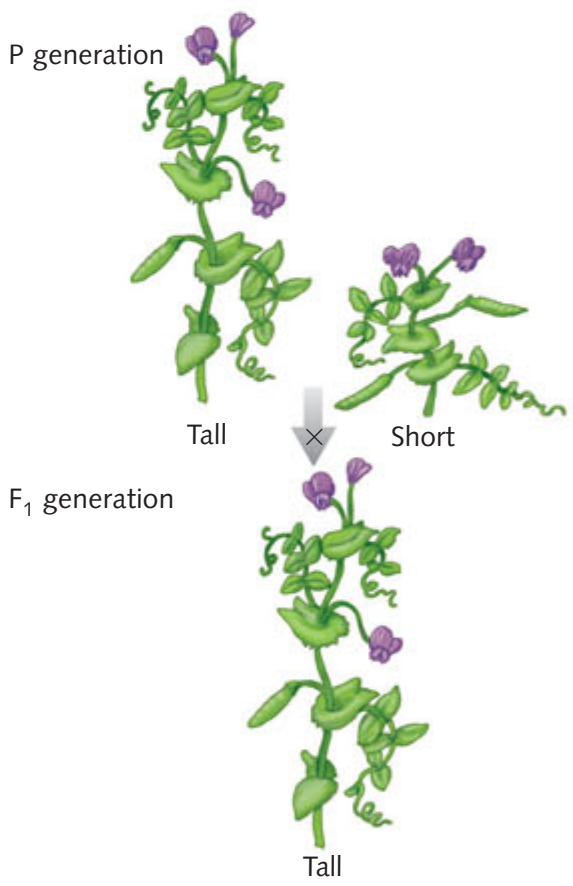


Figure 7.5 Mendel found that pure breeding tall pea plants crossed with pure breeding short pea plants always gave rise to tall pea plants.

Mendel then took the tall F_1 plants and self-pollinated each of them, again taking precautions to prevent them being pollinated by any other kind of pollen. The resulting offspring, called the **second filial generation (F_2)**, were found to contain both tall and short plants. Of the 1064 plants observed, 787 (74%) were tall and 277 (26%) were short. Approximately three-quarters of the F_2 generation were tall and one-quarter were short, a ratio of 3 : 1.

The relationship between genes, alleles and traits

From his results, because there were no plants observed intermediate between the tall and short, Mendel concluded that inheritance is not necessarily a process in which features of two parents blend to produce an intermediate result. Rather, definite 'factors', which may or may not show themselves in the outward appearance of the organism, pass from parents to offspring. Despite the absence of the short form in the F_1 generation, its reappearance in the F_2 generation supports the existence of such 'factors'. As short plants reappeared in the F_2, it can be concluded that the F_1 plants must have received a factor for shortness from their short parent, but it was 'hidden' in the F_1 plants. This factor must be masked by the factor for tallness and will only appear if the factor for tallness is absent. In other words, the characteristic for tallness is **dominant** to that for shortness, so shortness is described as **recessive**.

Although Mendel knew nothing of chromosomes and genes, he suggested that the 'factors' he described pass from parents to offspring via the gametes or sex cells. Each F_1 plant would receive one factor for tallness from its tall parent and one factor for shortness from its short parent via the gametes. The gametes contain only one of the two factors for height and, when they fuse, the plants produced contain a pair of these factors.

Figure 7.6 shows a summary of what Mendel discovered. Instead of 'factors', today the term 'gene' is used. As Mendel observed, the gene controlling height in the pea plant exists in two forms, now called alleles – they are alternative forms of the gene. One allele is responsible for producing a tall plant. The other allele influences development in such a way that, if two copies of this allele are present together, a short plant will result.

Letters are used to represent the different alleles of a gene. A capital letter is used for the allele of the trait expressed when two different alleles are present, while a small letter is used for the allele that is not expressed. In Figure 7.6, the allele for tallness is represented by *T*, and the allele for shortness by *t*. Each parent plant contains a pair of identical alleles: *TT* in the case of the tall parent, *tt* in the case of the short parent. An organism that contains identical alleles is said to be **homozygous**.

The genetic composition of an organism is known as its **genotype**. It describes the alleles that a cell or organism has at a specific locus for a particular **trait**. The way in which genes are expressed in the characteristics of the organism (whether structural, functional or even behavioural) is known as its **phenotype**.

In the case of the parent generation of pure breeding pea plants, pea plants with the tall phenotype have the genotype *TT*. **Purebred** pea plants with the short phenotype have the genotype *tt*. The *T* allele present in each gamete produced by meiosis by the tall parent and the *t* allele present in each gamete produced by the short parent are brought together in fertilisation so that all the F_1 offspring have the genotype *Tt*. Phenotypically they are all tall, because tallness is dominant to shortness. An organism that contains two different alleles for a gene, as in the F_1 pea plants, is said to be **heterozygous**. The *T* allele expresses itself in the phenotype while the expression of the *t* allele is masked.

WB
7.1.2 THE RELATIONSHIP BETWEEN GENES, ALLELES AND TRAITS PAGE 174

EXAM TIP

Do not call the alleles dominant and recessive; this is not true. It is the trait or characteristic determined by the allele that is dominant or recessive.

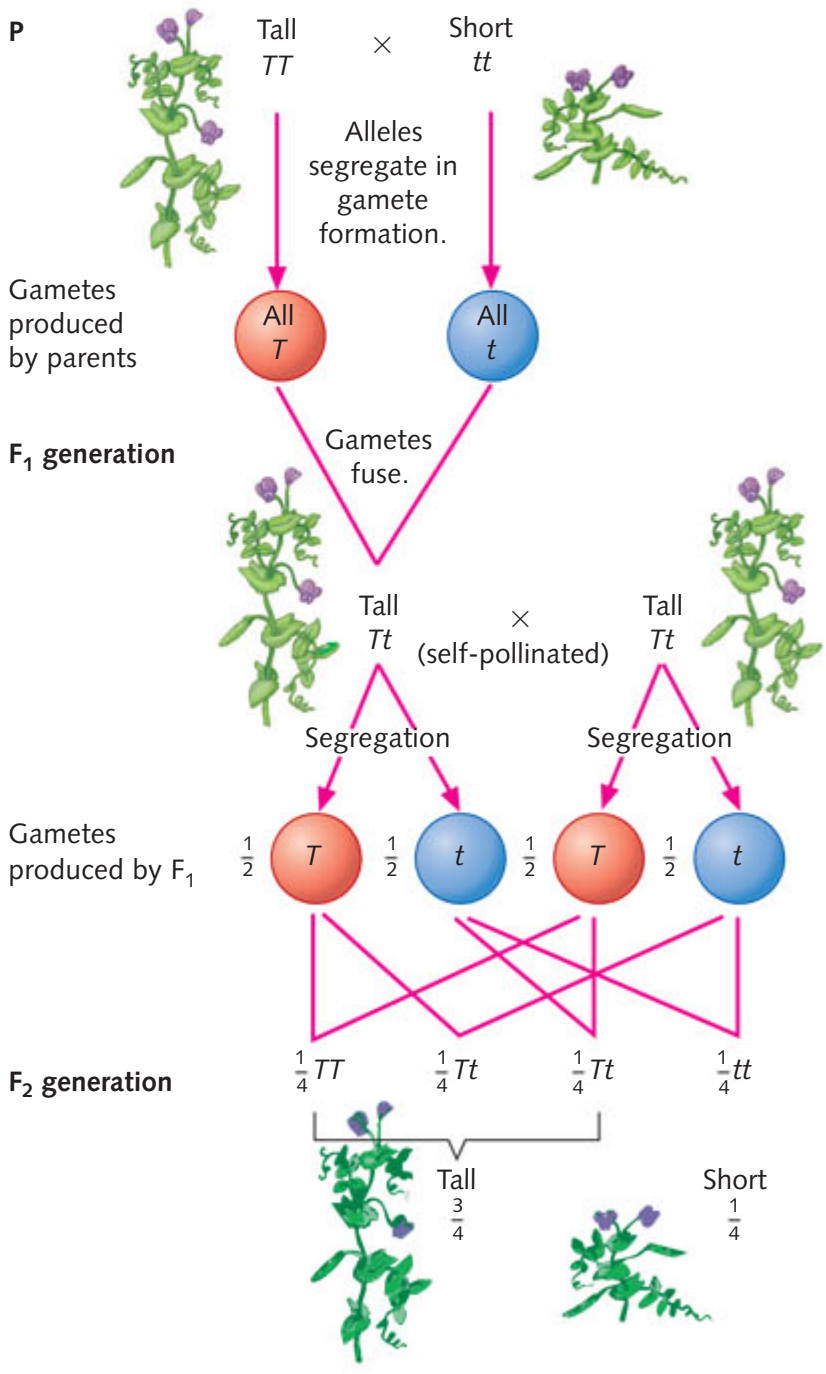


Figure 7.6 Summary of pattern of inheritance when purebred tall pea plants are crossed with purebred short pea plants, showing the predicted phenotypes and genotypes of the F_1 and F_2 offspring and their probabilities.

It is important to note that the terms dominant and recessive are not used with reference to the alleles; rather they are used in reference to the characteristic expressed in the phenotype of the organism. A dominant phenotype is expressed whether the organism is homozygous or heterozygous for the alleles of the gene; a recessive phenotype is only expressed when the organism is homozygous.

KEY CONCEPTS

- Gregor Mendel's study of peas established the principles of heredity.
- Crosses of pure breeding tall and short pea plants (P) produced offspring (F_1) which were all tall.
- Interbreeding the F_1 plants produced tall and short offspring (F_2) in the approximate ratio of 3 :1.

Concept questions 7.1a

1 What is the meaning of a characteristic in the context of heredity?
2 Define pure breeding.
3 'Filial' is a word derived from Latin. Find out its literal meaning.
4 Explain the meaning of P, F_1 and F_2 generations.
5 Construct a table with the headings P, F_1 and F_2 to describe the breeding experiments carried out by Mendel using pure breeding short and tall pea plants and the pattern of results observed.

HOT Challenge

6 a 'Pure breeding tall plants were crossed with pure breeding short plants.' In your own words, explain what this means.
b In Mendel's experiments, the F_1 generation always produced tall plants. In the next generation, F_2, short plants reappeared in the offspring. Where do you think the allele for shortness in the plants in the F_1 went?
c In natural settings, bees pollinate different plants of the same species and fertilisation may follow to eventually produce new plants. How did Mendel control this initial process?

Genetic crosses and Punnett squares

The most straightforward way of showing a genetic cross is using a **Punnett square**, an idea conceived by Sir Reginald Punnett. In a Punnett square, the possible alleles in the gametes of one parent are written along the top of the boxes and the possible alleles in the gametes of the other parent are written down the side. The products of the various combinations are written in the intersecting boxes and their relative numbers estimated (Worked Example 7.1).

WORKED EXAMPLE 7.1

A pea plant that is purebred for green pea pods is crossed with a pea plant purebred for yellow pods. Their offspring all have green pods (Figure 7.7). If two of the F_1 generation plants are crossed, work through the following stages to predict the proportion of the F_2 generation that will also produce green pea pods using a Punnett square.

a Assign the alleles for the dominant trait and the recessive trait.
b Draw the Punnett square and enter the letters for the female and male haploid gametes.
c Determine the genotypes of all the possible offspring.
d Determine the proportions of the phenotypes of the offspring.

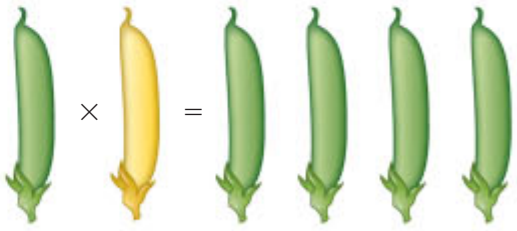


Figure 7.7 A pure breeding pea plant with green pods is crossed with a pure breeding pea plant with yellow pods, producing offspring that all have green pods.

<table>
<tr><th>Answer</th><th>Logic</th></tr>
<tr><td>a G = green pods
g = yellow pods</td><td>If the plants of the parental generation are pure breeding, each must be homozygous for their respective trait.
As both the parents are homozygous, all the offspring must be heterozygous (Figure 7.7), and they carry one allele for the green phenotype and one allele for the yellow phenotype.
All the heterozygous F_1 plants have green pods, indicating that the green phenotype is dominant.
Choose a capital letter to represent the allele for the dominant phenotype. In this case, G is appropriate for ‘green’.
The corresponding lowercase letter is used to represent the allele for the recessive phenotype. In this case, g is appropriate for ‘yellow’.</td></tr>
<tr><td>b<table><tr><td>Gametes</td><td>$\frac{1}{2}G$</td><td>$\frac{1}{2}g$</td></tr><tr><td>$\frac{1}{2}G$</td><td></td><td></td></tr><tr><td>$\frac{1}{2}g$</td><td></td><td></td></tr></table></td><td>All the F_1 plants have the genotype Gg. The alleles segregate on their homologous chromosomes during meiosis, so half their gametes have the G allele and the other half have the g allele.</td></tr>
<tr><td>c<table><tr><td>Gametes</td><td>$\frac{1}{2}G$</td><td>$\frac{1}{2}g$</td></tr><tr><td>$\frac{1}{2}G$</td><td>$\frac{1}{4}GG$</td><td>$\frac{1}{4}Gg$</td></tr><tr><td>$\frac{1}{2}g$</td><td>$\frac{1}{4}Gg$</td><td>$\frac{1}{4}gg$</td></tr></table></td><td>All the squares of the Punnett square represent the products of the fertilisation events of each of the gametes and are filled with the genotypes of the diploid offspring.
Start with the empty top left square. This square is the intersection of the female gamete $\frac{1}{2}G$ and male gamete $\frac{1}{2}G$. As half the female gametes possess a G allele and half the male gametes possess a G allele, the proportion of offspring inheriting these alleles together is $\frac{1}{2}G \times \frac{1}{2}G = \frac{1}{4}GG$.
The next square to the right is the intersection of the female gamete $\frac{1}{2}g$ and male gamete $\frac{1}{2}G$. The empty square must be filled with the product of these two gametes: $\frac{1}{2}g \times \frac{1}{2}G = \frac{1}{4}Gg$.
Note: By convention, the allele for the dominant phenotype is always written first.
Continue through each square until the Punnett square is complete.</td></tr>
<tr><td>d Three-quarters, or 75%, of the F_2 offspring are predicted to be green.</td><td>Each genotype with at least one G allele must express the dominant phenotype. The Punnett square shows that three of the four squares for the offspring have at least one G allele. In other words, $\frac{1}{4}GG + \frac{1}{4}Gg + \frac{1}{4}Gg = \frac{3}{4}$ of the offspring will show the dominant phenotype, green. This solves the original problem.
Only the gg genotype will express the recessive phenotype. The Punnett square shows that just one of the four squares for the offspring has this genotype. In other words, $\frac{1}{4}$ of the offspring will show the recessive phenotype, yellow.</td></tr>
</table>

Try these yourself

Using the alleles T and t, draw Punnett squares to show the ratio of tall to short plants among the offspring from the following crosses.

1 A pure breeding tall pea plant crossed with a pure breeding short pea plant, yielding all tall plants
2 A cross between two pea plants of the F_1 generation from the parental cross in question **1**
3 A heterozygous tall plant crossed with a homozygous tall plant.

EXAM TIP

In the F_2 of a cross between two pure breeding parents, one homozygous tall and one homozygous short, there are two phenotypes in the offspring: the $\frac{1}{4}$ short will all be *tt*; the $\frac{3}{4}$ tall will be *TT* or *Tt*. Of these three groups of tall, $\frac{1}{3}$ will be *TT* and $\frac{2}{3}$ will be *Tt*. If asked the chance of a heterozygous tall plant in the tall offspring, the answer will $\frac{2}{3}$.

Probability in genetic ratios

It is important to clarify the statement that three-quarters of the F_2 generation will be tall and one-quarter short, or 75% tall and 25% short. This is what is predicted based on probability. This outcome will most likely only be seen when large numbers of F_2 offspring are observed and counted. Even then, some of the gametes may die or the fusion of the gametes may not be totally at random. For these reasons, the observed or actual ratios obtained in genetic crosses may only be approximately the same as the predicted or expected ratios. The bigger the sample and therefore the more individuals that are counted, the closer the observed ratios are likely to be to the expected ones. Mendel looked at more than 1000 pea plants and only then was he convinced that the ratios he observed were close to the ones he expected.

KEY CONCEPTS

- Punnett squares are a convenient way to represent crosses and predict the resulting genotypes and phenotypes and their proportions.
- Observed phenotypic ratios for any cross may vary from those predicted by a Punnett square. This is due to random assortment of alleles on chromosomes during meiosis and the fertilisation of random gametes.
- Alleles are alternative or different forms of the same gene. Many genes have two alleles; some genes have more than two alleles. Alleles are found at a gene locus on a chromosome. In inheritance involving sexual reproduction, one allele is found on a chromosome that came from one parent gamete and the other allele is found on the homologous chromosome of the pair and came from the other parent gamete.
- The combination of alleles an organism has for a particular gene is its genotype. The two alleles may be identical (homozygous) or different (heterozygous).
- A trait is a characteristic of an organism; for example, eye colour.
- A dominant trait is expressed in both homozygous and heterozygous conditions.
- A recessive trait is expressed only in a homozygous condition.
- The way a genotype is expressed is termed its phenotype; for example, blue eyes.

Concept questions 7.1b

1. Describe the difference between the genotype and phenotype of an organism.
2. Define heterozygous and homozygous.
3. In Mendel's experiments, the trait initially investigated was height of plant. What were the genotypes of the P generation? What were the phenotypes of the P generation? What were the alleles in the gametes produced by the P generation?
4. List three conclusions that can be drawn from Mendel's experiments.
5. Under the headings of tall phenotype and short phenotype for Mendel's peas, list the different genotypes possible from the pure breeding crosses. Write next to each one whether it is homozygous or heterozygous.

HOT Challenge

6. Punnett squares can be used to determine the results of a cross. It is a way to determine the probability of genotypes and phenotypes of offspring.

   Refer to Table 7.1 and use a Punnett square to show the cross of a homozygous dominant purple flowered pea plant and a homozygous white flowered pea plant. Create another Punnett square to show the F_2 generation. Express the predicted genotypes as fractions and the expected phenotypes as a ratio.

Dominance is not always clear cut

Mendel's experiments were based on characteristics that were not only determined by genes found on different chromosomes, but also all showed one phenotype dominant over another phenotype. However, the expression of genes is not always so straightforward. Phenotypic variations can result when the characteristics of offspring show both parental characteristics, either both at the same time such as patches of colour, or as a combination or blend of parental characteristics.

If a pure breeding red snapdragon plant is crossed with a pure breeding white snapdragon plant, as shown in Figure 7.8, the F_1 offspring all have pink flowers. When these F_1 pink snapdragons are crossed, the F_2 offspring have flowers in the ratio of 1 red: 2 pink: 1 white. This is known as **incomplete dominance** or **partial dominance** because one allele does not completely mask the other allele and the heterozygous phenotype (pink) is intermediate between the homozygous parental phenotypes (red and white).

Getty Ima

Figure 7.8 In pure breeding snapdragons, incomplete dominance of the red flower colour and white flower colour results in a pink flower colour.

A special notation is used to indicate inheritance of partially dominant traits. A suitable upper-case letter designates the gene for the trait (for example: *C* for colour) and upper-case superscript letters indicate the alleles of the gene (for example: C^R = red colour, C^W = white colour). Figure 7.9 shows a diagram using the appropriate notation to show inheritance of colour in snapdragons. An alternative way of showing the allele symbols for inheritance of partially dominant traits is to use two different uppercase letters; in the case of flower colour, *R* = red and *W* = white. Figure 7.9 uses the first method.

WB
7.1.3 DOMINANCE IS NOT ALWAYS CLEAR CUT PAGE 176

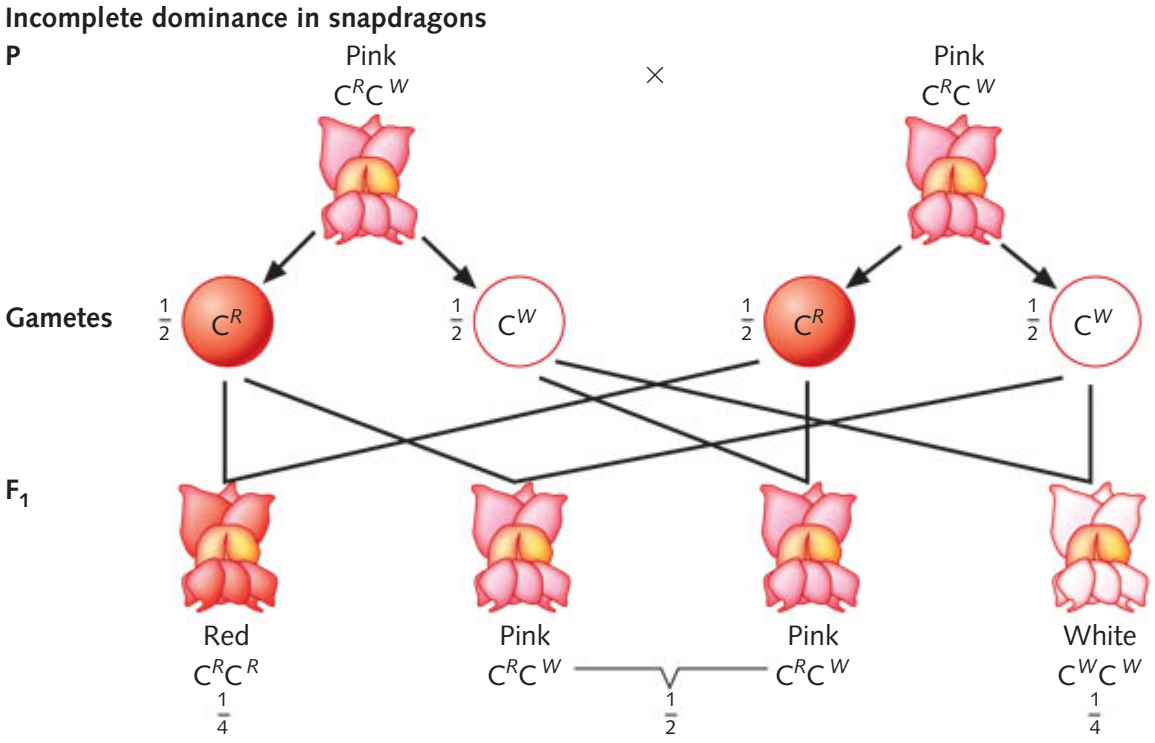


Figure 7.9 Crossing snapdragons with pink flowers results in a predicted phenotypic ratio of approximately 1 red : 2 pink : 1 white.

The study of certain coat colours in horses and cattle reveals another type of dominance relationship. In this case, both alleles in the genotype are fully expressed in the heterozygote, so they both show up in the hair colour together: either as red and white hairs together, called roan in cattle; or as red and white patches of hair. Such traits are said to be **codominant**. In shorthorn cattle, alleles for coat colour are inherited in this way and the two alleles are expressed as red (C^R) and white (C^W). This is similar to the incomplete dominance shown in snapdragons but the offspring of pure breeding red and white parents have roan coats (C^WC^R). This codominant inheritance of coat colour in shorthorn cattle is shown in Figure 7.10. An outline of the differences between the types of dominance relationships is given in Table 7.2.

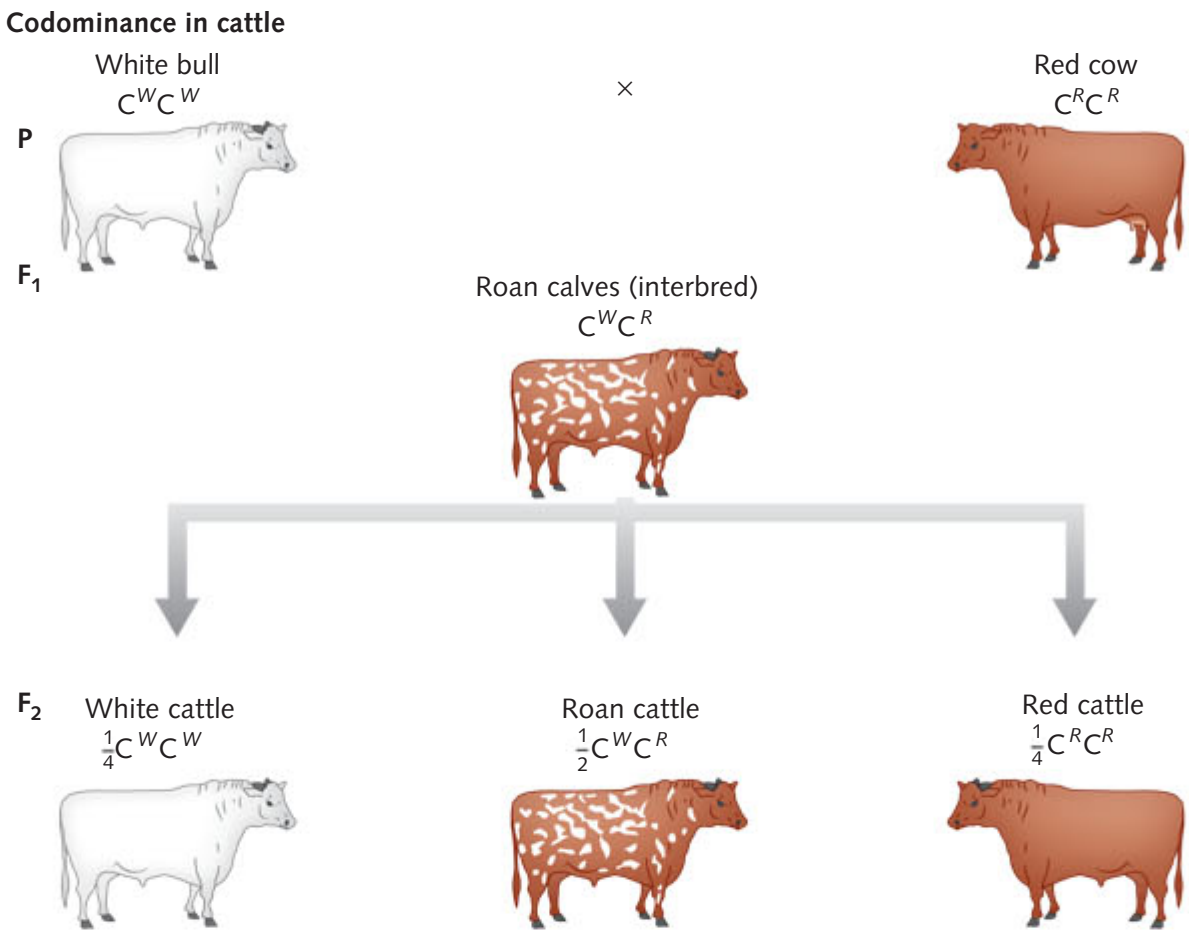


Figure 7.10 In shorthorn cattle, codominant inheritance results in a roan coat colour in the offspring of pure breeding red and white parents.

Table 7.2 Differences between the types of dominance relationships using the example of black and white coat colour

	Complete dominance	Incomplete (partial) dominance	Codominance
Parents	BB, bb	C^BC^B, C^wC^w	C^BC^B, C^wC^w
Gametes	all B and all b	all C^B and all C^w	all C^B and all C^w
F_1 genotype	Bb	C^BC^w	C^BC^w
Phenotype	Black	Grey	Black and white stripes
Gametes	$\frac{1}{2}B$, $\frac{1}{2}b$ and $\frac{1}{2}B$, $\frac{1}{2}b$	$\frac{1}{2}C^B$, $\frac{1}{2}C^w$ and $\frac{1}{2}C^B$, $\frac{1}{2}C^w$	$\frac{1}{2}C^B$, $\frac{1}{2}C^w$ and $\frac{1}{2}C^B$, $\frac{1}{2}C^w$
Punnett square	F_1 | $\frac{1}{2}B$ | $\frac{1}{2}b$ $\frac{1}{2}B$ | $\frac{1}{4}BB$ | $\frac{1}{4}Bb$ $\frac{1}{2}b$ | $\frac{1}{4}Bb$ | $\frac{1}{4}bb$	F_1 | $\frac{1}{2}C^B$ | $\frac{1}{2}C^w$ $\frac{1}{2}C^B$ | $\frac{1}{4}C^BC^B$ | $\frac{1}{4}C^BC^w$ $\frac{1}{2}C^w$ | $\frac{1}{4}C^BC^w$ | $\frac{1}{4}C^wC^w$	F_1 | $\frac{1}{2}C^B$ | $\frac{1}{2}C^w$ $\frac{1}{2}C^B$ | $\frac{1}{4}C^BC^B$ | $\frac{1}{4}C^BC^w$ $\frac{1}{2}C^w$ | $\frac{1}{4}C^BC^w$ | $\frac{1}{4}C^wC^w$
F_2 genotype	$\frac{1}{4}BB$, $\frac{1}{2}Bb$, $\frac{1}{4}bb$	$\frac{1}{4}C^BC^B$, $\frac{1}{2}C^BC^w$, $\frac{1}{4}C^wC^w$	$\frac{1}{4}C^BC^B$, $\frac{1}{2}C^BC^w$, $\frac{1}{4}C^wC^w$
Phenotype	$\frac{3}{4}$ black $\frac{1}{4}$ white	$\frac{1}{4}$ black $\frac{1}{2}$ grey $\frac{1}{4}$ white	$\frac{1}{4}$ black $\frac{1}{2}$ black and white stripes $\frac{1}{4}$ white
Phenotype of heterozygote	Same as dominant	Intermediate or blend between the phenotypes of homozygous parents	Phenotype has features of phenotypes of both homozygous parents
Phenotypic ratio	3 : 1	1 : 2 : 1	1 : 2 : 1

Note: B and C^B are both symbols for the alleles for black coat colour; b and C^w are both symbols for the alleles for white coat colour.

KEY CONCEPTS

» The combination of alleles inherited by an organism from its parents is one factor that determines its phenotype.
» Incomplete dominance or partial dominance refers to a situation when one allele does not mask the effect of the other allele completely and the heterozygous phenotype is intermediate or a blend between the homozygous parental phenotypes.
» When both alleles in a genotype are fully expressed in the phenotype of the heterozygote, such traits are said to be codominant.

Concept questions 7.1c

1 The petal colour of carnations is determined by a single gene with two alleles: one for white, one for red. Describe the phenotypes you would expect in the F_1 generation of two pure breeding parents, one white, one red, in the following circumstances:
- **a** White is dominant to red.
- **b** The red and white traits are codominant.
- **c** The red and white traits are partially dominant or show incomplete dominance.

2 Explain why the offspring of a tall pea plant and a short pea plant are not all of intermediate height.

3 Compare incomplete dominance with codominance.

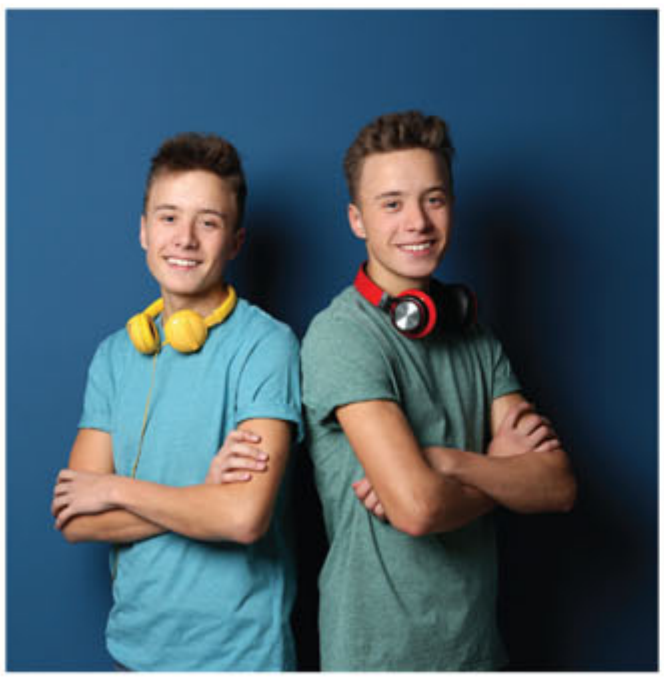
4 Roan cattle are an example of codominant inheritance. What is the probability of a roan calf if the cross involves parents with the genotypes $C^WC^R \times C^RC^R$?

5 A farmer prefers cattle without horns. The allele for no horns is *N*, and the allele for horns is *n*.
- **a** Judging from the notation being used, what type of inheritance is the farmer talking about?
- **b** The farmer crosses a true breeding hornless bull with a horned cow. What genotypes will be present in the F_1 generation?
- **c** Does this produce the result she wants?

HOT Challenge

6 A cat breeder wanted to obtain some grey kittens for a client. The breeder had black cats and white cats but no grey cats. They had bred these black and white cats before and the result was kittens with a coat of black and white. What type of inheritance is this and is there any chance that these black cats and white cats would produce grey kittens?

7.2 Genetic material, environmental factors and epigenetic factors



Shutterstock.com/New Africa

Figure 7.11 Even identical twins show variations in their characteristics.

Identical twins are formed when one egg fertilised by one sperm separates into two at the two-cell stage of development. Even though the identical twins have the same genotypes, they often show variations in the characteristics of their phenotype (Figure 7.11). They may have slightly different weights and heights, for instance. How can this be explained if there is a direct relationship between genes and their expression? This is because both epigenetic factors and environmental conditions affect gene expression. One of the identical twins may play more sport, eat less carbohydrates, and be more active than the other twin. This could explain a difference in weight due to environmental factors, not just the genes expressed.

A well-documented example of environmental impact on phenotype is the effect of temperature on the colour of the fur of Himalayan rabbits. At birth, the Himalayan rabbit has a white fluffy body, but soon after birth it

grows black hair on its ears, nose, feet and tail (Figure 7.12). This pattern may initially appear to be purely under genetic control but a simple experiment shows that this is not the case. If a cold pad is fixed to the rabbit's back in a shaved area, left in position for a few weeks and kept cold, black hair starts to grow beneath the pad. It appears that the lower temperature of the local environment activates dark pigment production and therefore black hair growth. A similar temperature difference would normally occur soon after the birth of the baby rabbit and result in the dark extremities developing. The same thing happens in Siamese cats. Owners of such cats sometimes find that the dark areas enlarge in winter and that they get smaller in warmer weather.

There are many other cases of the environment influencing an organism's development and therefore its phenotype. In plants, chlorophyll will only develop if light is available. If seedlings that possess the gene for chlorophyll production are left in a dark cupboard after seed germination, the stems and leaves will be white. Some plants will only develop flower buds if the night length is of a certain duration and the temperature is suitable. It is easy to underestimate the importance of the environment on the development of organisms and to assume that everything is under genetic control. Development is the result of a subtle and complex interaction between the genetic make-up of the organism and its environment.

Alamy Stock Photo/Neil Twigg

Figure 7.12 **The Himalayan rabbit is normally white with black hair only on its long ears, nose, tail and lower leg limbs.**

In the last 50 years, it has also been discovered that chemical modification of DNA may influence the phenotypic expression of genes. One of the first observations of chemical modification was in the 1970s when scientists noticed a pattern shown by altered DNA. In some DNA, they found a methyl group or 'chemical cap' attached to part of the molecule. When this **DNA methylation** occurred, it switched off the expression of the genes containing the modified DNA, so the trait was not expressed. Another type of structural DNA modification discovered is caused by histone modification in the DNA molecule (Figure 7.13). Most of these changes only occur within the course of an individual's lifetime; however, they can be transmitted from the organism to their offspring.

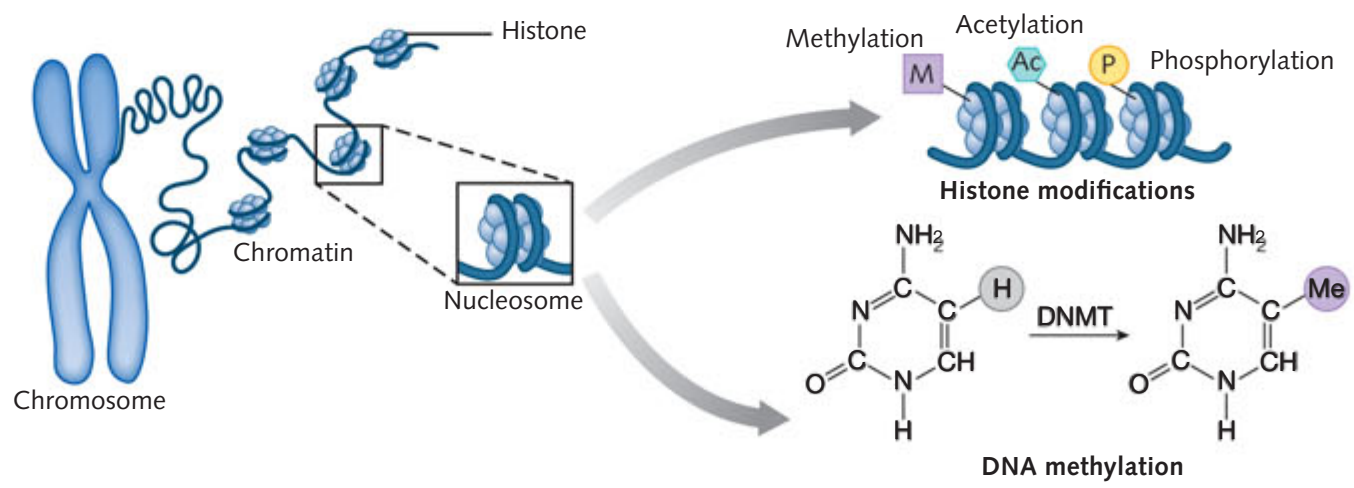


Figure 7.13 **Methylation and histone modification are epigenetic factors that alter the structure of the DNA but not the base sequence in the DNA**

Epigenetics is the study of heritable changes in the phenotype of organisms caused by modification of gene expression due to physical changes in the structure of DNA, rather than alteration of the genetic code itself. Several environmental lifestyle factors have been identified that may modify epigenetic patterns, such as diet, obesity, tobacco smoking, alcohol consumption and environmental pollutants. New and ongoing research is continuously uncovering the role of epigenetics in a variety of human disorders and fatal diseases, such as syndromes involving chromosomal instabilities, mental retardation and various cancers.

WB 7.2.1 EPIGENETICS PAGE 179

In 1983, cancer was the first human disease to be linked to epigenetics. Researchers observed that diseased tissue from patients with colorectal cancer had less DNA methylation than normal tissue from the same patients. As genes that are methylated are usually switched off and not expressed, loss of DNA methylation can cause high gene activation by altering the DNA in the chromatin. Similarly, if there is too much methylation, the work of protective tumour suppressor genes can be undone, and cancer can occur (Chapter 2).

Weblink
Epigenetics

Online Worksheet
Epigenetics

Fragile X syndrome is the most frequently inherited intellectual disability, especially in males. In people who have over 200 repeats of a particular segment of DNA, the promoter region of the *FMR1* gene becomes methylated. This turns off the gene, stopping the *FMR1* gene from producing an important protein. Loss of this protein causes Fragile X syndrome. Other mental retardation disorders have also been found to be associated with epigenetic changes, including Coffin-Lowry and Rett syndromes.

KEY CONCEPTS

- The phenotypic expression of genes can be influenced by environmental factors such as light, temperature and various chemicals.
- Epigenetic mechanisms such as DNA methylation and histone modification can also alter the phenotype by altering expression of the genes without changing the genetic sequence of the DNA.

Concept questions 7.2

1. Describe how the environment can affect a phenotype.
2. Recount the effect of temperature on the colour of the fur of Himalayan rabbits.
3. List two environmental conditions that affect plant characteristics.
4. Define epigenetics. Describe the effect of DNA methylation on gene expression.

HOT Challenge

5. Monozygotic twins have identical genotypes and, at birth, their epigenetic patterns are similar. Even then, there are differences between the twins that people closely involved with them can observe. How might these differences have arisen even at this early stage?

7.3 Patterns of inheritance

In diploid cells, alleles occur in pairs, one of each pair being located on each of two homologous chromosomes (Figure 7.14). When homologous chromosomes separate in meiosis, the haploid gametes receive only one of each type of chromosome and therefore only one of a pair of alleles (Figure 7.15). When the gametes from each parent fuse, the offspring inherits one chromosome and thus one allele from each parent. From our understanding of meiosis and fertilisation, the outcomes of several different types of crosses can be predicted.

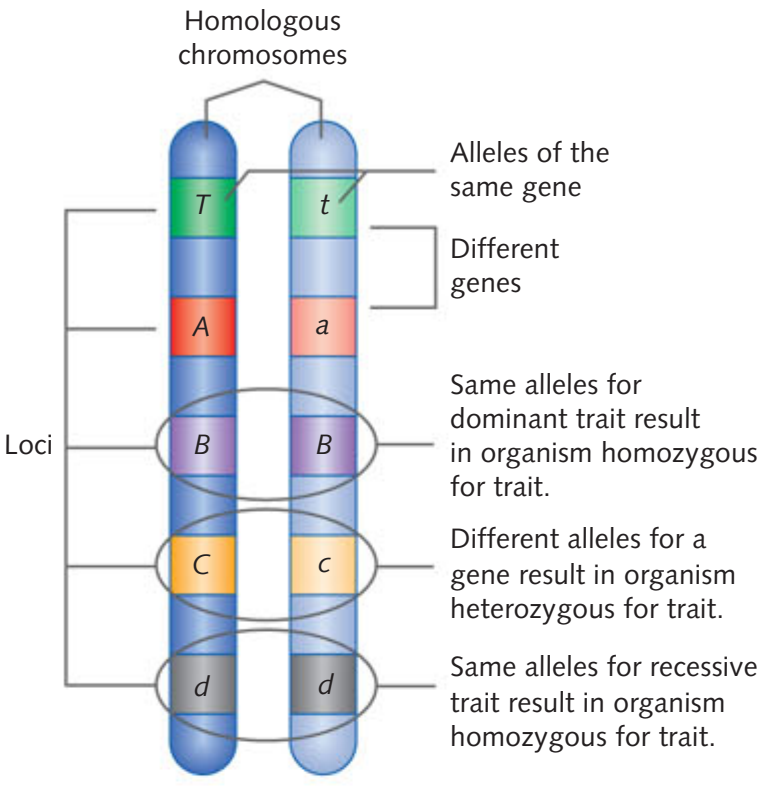


Figure 7.14 Homologous chromosomes contain alleles of the same gene at the same gene locus. This diagram shows the various combinations of alleles possible at different gene loci.

In describing the genotype of a plant as *Tt* we mean that there is a pair of alleles for height, or tallness. One chromosome of the pair carries a *T* allele and the other a *t* allele.

In meiosis the two homologous chromosomes come together in prophase I.

Then they segregate into separate gametes in anaphase I.

Thus each gamete contains one of each of the original pair of alleles.

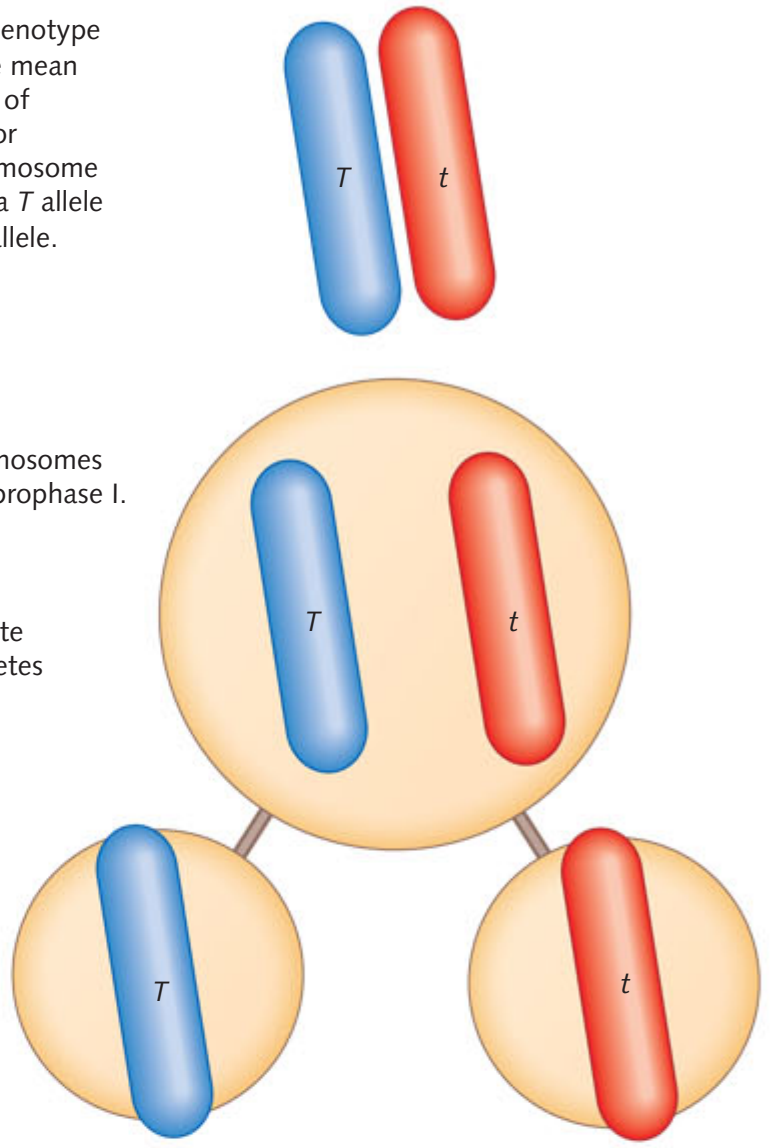


Figure 7.15 The segregation of alleles in inheritance corresponds to the segregation of homologous chromosomes in meiosis.

WB
7.3.1 MONOHYBRID CROSSES PAGE 180

Predicted genetic outcomes for a single autosomal gene

The simplest cross is a **monohybrid cross**. A monohybrid cross is a cross between individuals that have different pairs of alleles of one gene at a specific gene locus. Genes located on non-sex chromosomes, or autosomes, are called **autosomal genes**. Offspring inherit two alleles of a single autosomal gene, one from each parent. The cross between the tall and short pea plants studied by Mendel is an example of a monohybrid cross involving a single autosomal gene. Using the allele symbols *T* for tall and *t* for short, the parental generation has the genotypes *TT* and *tt*. Segregation of the alleles into the gametes during meiosis would produce gametes containing either a *T* allele or a *t* allele. When these gametes fuse at fertilisation, the F_1 offspring would inherit two alleles, one from each parent, with the resulting genotype *Tt*.

Mendel's studies helped him to explain the outcome of breeding experiments between tall and short pea plants in mathematical terms. The 3 : 1 ratio he predicted in the F_2 generation was based on observations of many different crosses using a variety of pea plant characteristics (Table 7.3). Mendel could not explain why this ratio occurred because he had no knowledge of meiosis, the process of cell division to produce gametes.

Weblink
Mendel's law of segregation

Online Worksheet
Mendel's law of segregation

Table 7.3 Results of some of Mendel's crosses on the garden pea (Pisum sativum)

Pure breeding parental phenotypes	F_1 phenotypes	F_2 phenotypes	Observed ratio
Tall plants × short plants	All tall	787 tall, 277 short	2.84 : 1
Purple flowers × white flowers	All purple	705 purple, 224 white	3.15 : 1
Green pods × yellow pods	All green	428 green, 152 yellow	2.82 : 1
Yellow peas × green peas	All yellow	6022 yellow, 2001 green	3.01 : 1
Round peas × wrinkled peas	All round	5474 round, 1850 wrinkled	2.96 : 1

INVESTIGATION 7.1

Patterns of inheritance in heterozygous barley seeds

Background

Barley (*Hordeum vulgare*) was one of the first cultivated grains. A member of the grass family, barley is now grown in more than 100 countries. Barley has 14 chromosomes in each somatic (body) cell and self-pollinates sexually to reproduce. A single gene with two alternative alleles controls pigmentation in barley. The allele for pigmentation results in the dominant green phenotype whereas the allele for no pigmentation results in the recessive white (albino) phenotype. In the heterozygote, the expression of the dominant green pigment masks any expression of the allele coding for no pigment (albino).

Aim

To perform a monohybrid cross and predict phenotypic ratios

Time requirement

20 minutes

Materials:

- 25 seeds of genetically selected barley
- Filter paper
- Disposable plastic Petri dish
- Plastic pipette
- Forceps

What are the risks in this investigation?	How can you manage these risks to stay safe?
Some people may be gluten intolerant or allergic to particular seeds.	Do not eat seeds. Wash hands thoroughly after handling seeds.

Method

1. Place a piece of filter paper in the bottom half of the Petri dish. Trim the paper as necessary so that the paper lies flat in the bottom of the dish.
2. Soak the filter paper with tap water, using a pipette. Remove or drain any excess water that is not absorbed by the paper.
3. Sprinkle the seeds evenly over the moistened paper in the Petri dish. Using the forceps, ensure the seeds are evenly spread out (approximately 1 cm apart).
4. Place the Petri dish with seeds on a bench with sufficient access to sunlight, ensuring they remain at room temperature.
5. Water the seeds twice a day using a pipette to prevent them from drying out. This process of twice daily rehydration should continue until the barley seedlings reach 2 cm tall (Figure 7.16). This will take approximately 1 week.

6 In your logbook, copy and complete the Punnett square (monohybrid cross) below, where *A* represents the allele for green pigment produced and *a* represents the allele for no pigment produced. Use the information for the alleles in the seeds given in the Punnett square to formulate a hypothesis of the phenotypic ratio you expect to see in the seedlings growing in the Petri dish.

Gametes	*A*	*a*
A		
a		

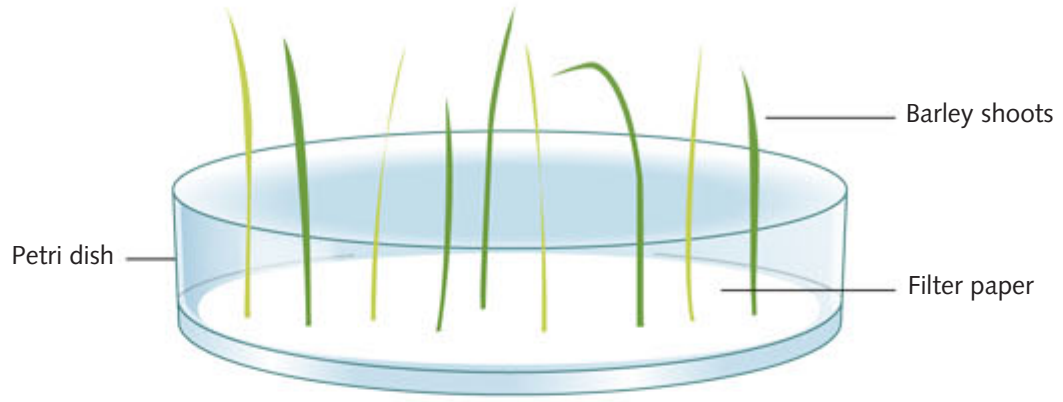


Figure 7.16 After a week the barley seeds should have germinated.

Predicted ratio

7 Observe the Petri dishes at the end of 1 week. Some seedlings will be pale in colour (albino) with little or no green pigment. Other seedlings will be green. When nearly all the seedlings have germinated, count each seedling as either green or albino. Record your results and contribute your individual results to the class data.

Results

1 Copy Table 7.4 into your logbook and use it to record your individual and class data.

Table 7.4

	Total number of seedlings	Number of seedlings of each colour	
		Green	Albino
Individual data			
Class data			

2 Calculate the ratio of green seedlings to albino seedlings for:
   a your individual data
   b the class data.
3 How does your ratio for your individual data compare to the ratio for the class data?

Discussion

1 What is one limitation in this method?
2 How would you improve the reliability and validity of the data in this method?
3 Was your predicted ratio based on your Punnett square shown in the results observed?
4 Were there any inconsistencies in the results? If so, explain why they may have occurred.
5 Based on your individual and class results, what is the mode of inheritance for green pigmentation in barley?
6 If presented with 120 seedlings; approximately how many would you expect to be green? Show your working.

Conclusion

Summarise your findings of this investigation, commenting on your hypothesis and the mode of inheritance for pigmentation in barley.

Taking it further

In this investigation you have conducted a monohybrid cross. What type of investigations could you conduct to demonstrate a dihybrid cross and a sex-linked cross? These are discussed later in this chapter.

KEY CONCEPTS

» A monohybrid cross is a cross between individuals that have different pairs of alleles of one gene at a specific gene locus.

Concept questions 7.3a

1 Define monohybrid cross.
2 Draw a Punnett square to represent the cross of two offspring from a purebred tall pea plant parent and a purebred small pea plant parent.
3 What would be the classical Mendelian ratio from a cross of the F_1 offspring from the cross in question 2?
4 The pattern of inheritance of the characteristic of pea plant height is described as autosomal. What does that mean?
5 Table 7.3 shows the observed ratio resulting from the crosses of thousands of pea plants for five different characteristics. Round each of these observed ratios to the nearest whole number. What ratio do you get in each case?

HOT Challenge

6 The wolf has 39 pairs of chromosomes. The domestic dog has 39 pairs of chromosomes. They are the same genus but they are classified as different species.
A mating pair, one from each species, came together and produced a fertile hybrid offspring with a set of 2*n* chromosomes.
a How many autosomal homologous pairs would be found in the hybrid?
b How many chromosomes would be found in the hybrid's somatic cells?
c How many chromosomes would be found in the hybrid's gametes?
d Through DNA analysis, it has been found that the wolf is an ancestor of the domestic dog. Interbreeding will produce fertile offspring called a wolfdog. So are they different species or not?

Predicted genetic outcomes for a monohybrid test cross

How can it be determined whether an organism that expresses a dominant trait is homozygous dominant or heterozygous at a specific gene locus? If the organism is incapable of self-fertilisation – as for most animals – a technique used by geneticists is to cross the individual whose genotype is unknown with an individual that is homozygous recessive at the locus in question. This is called a **test cross**. An example of a test cross can be shown using an animal commonly used in genetic experiments, the fruit fly *Drosophila melanogaster*.

Figure 7.17 The fruit fly *D. melanogaster* may have a long wings or b vestigial wings. Flies with vestigial wings cannot fly and instead move by running and jumping.

D. melanogaster has four pairs of chromosomes in the nuclei of its body cells and its phenotype has many different forms or variants. For instance, most individuals have red eyes but some have white eyes; most individuals have long wings, but some have small or 'vestigial' wings (Figure 7.17). The long-winged condition (*V*) is dominant to vestigial (withered) wing (*v*). If a purebred long-winged fly (*VV*) is mated with a vestigial-winged fly (*vv*), the F_1 individuals are all heterozygous (*Vv*) and have long wings. If large numbers of these F_1 flies are interbred, a mixture of long-winged and vestigial-winged flies are produced in a ratio of approximately 3 : 1 (Figure 7.18). This is a typical monohybrid autosomal cross.

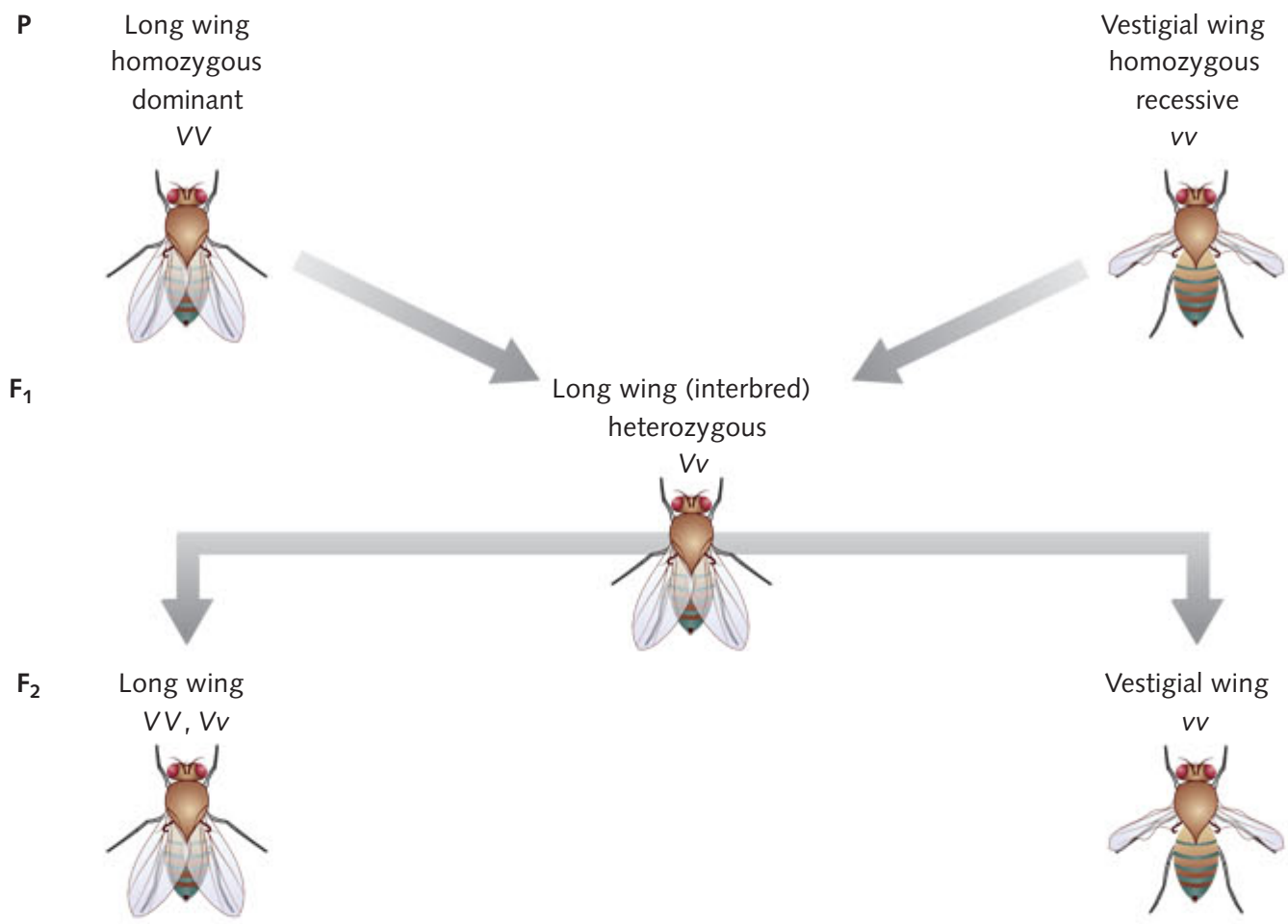


Figure 7.18 Summary of a monohybrid cross in fruit flies

To determine if an F_2 long-winged fly is homozygous dominant (*VV*) or heterozygous (*Vv*), a monohybrid test cross can be carried out. This involves crossing a long-winged fly of unknown genotype with a homozygous recessive vestigial-winged fly. If the long-winged F_2 fly has the genotype *VV*, then crossing it with a vestigial-winged fly will produce only long-winged offspring. If the long-winged F_2 fly has the genotype *Vv*, then the cross will result in approximately equal numbers of long and vestigial-winged flies. This is summarised in Figure 7.19.

Test crosses of individuals with a dominant phenotype but unknown genotype with individuals that are known to be homozygous recessive at the locus in question are a routine method of establishing the organism's genotype.

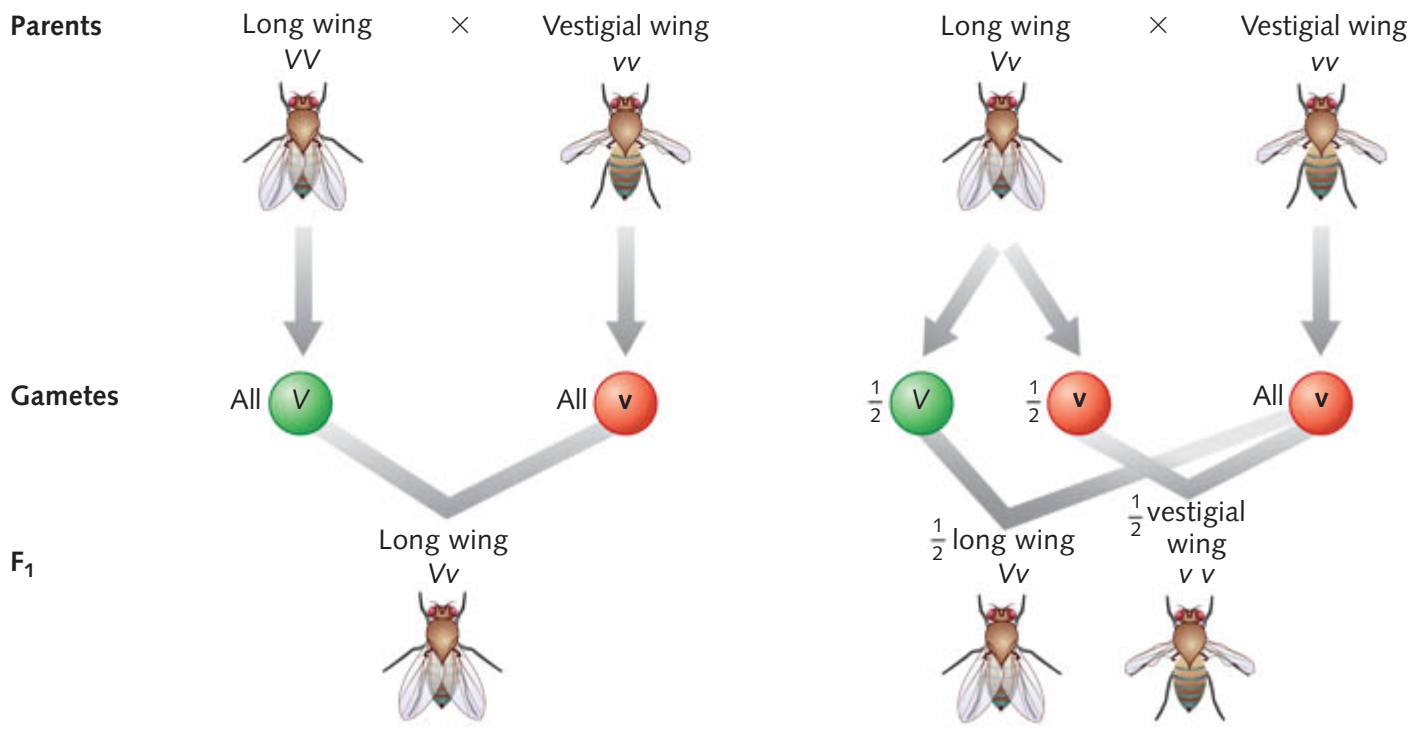


Figure 7.19 A test cross to determine whether a fruit fly is homozygous dominant or heterozygous for long wings

KEY CONCEPTS

- A test cross can be used to determine the genotype of an individual displaying a dominant phenotype.
- A test cross involves breeding an organism exhibiting the dominant trait with an organism displaying the recessive trait (homozygous recessive).

Concept questions 7.3b

1 What is the meaning of homozygous recessive?
2 What is a test cross?
3 **a** A monohybrid autosomal cross typically produces a ratio of 3 : 1. What does this mean?
b A test cross typically produces a ratio of 1 : 1 for a heterozygous genotype. What does this mean?
4 Explain how offspring may have a different genotype from either of their parents at a specific locus.

HOT Challenge

5 Characteristics of fruit flies can be described as wild type and mutant. Find out what characteristics might be grouped into each class and state what vestigial means.

Predicted genetic outcomes for sex-linked inheritance

Alamy Stock Photo/Science Photo I

Figure 7.20 Scanning electron micrograph (SEM) of X and Y chromosomes in humans

WB 7.3.2 SEX-LINKED INHERITANCE PAGE 182

In the somatic cells of humans and some other organisms, there are two types of chromosomes: autosomes or non-sex chromosomes, and sex chromosomes – in mammals, these are the X and Y chromosomes. Human male and female somatic cells contain 44 autosomes and two sex chromosomes. In female cells, there are two longer X chromosomes, each with a region of genes that determine female secondary sexual characteristics and a region of genes that contain **sex-linked genes**. Male somatic cells contain one of the longer X chromosomes and one shorter Y chromosome (Figure 7.20). A small part of the shorter Y chromosome contains some unique Y-linked genes that determine male Y-linked characteristics that only ever appear in males, such as development of male secondary characteristics. Females will have two copies of each X-linked gene because they have two X chromosomes, whereas males will only have one copy of the X-linked gene on their one X chromosome. Inheritance patterns involving genes located on the X or Y chromosomes are described as **sex-linked inheritance**.

X-linked recessive inheritance

When a recessive phenotype under investigation is determined by an allele on the X chromosome, it is said to be an **X-linked** recessive phenotype. Males who have the allele for a recessive trait on their X chromosome will always express the phenotype because they have only one X chromosome. Females will express the phenotype only when both X chromosomes have the allele concerned. A heterozygous female will be a **carrier** because she has the allele but does not express it. Consequently males show X-linked recessive phenotypes much more often than females. Red-green colour blindness and haemophilia are two recessive conditions in humans that are transmitted to offspring through X-linked inheritance.

When writing sex-linked inheritance patterns, a special type of notation is used. The letter for the allele carried on the X chromosome is written as a superscript above a letter X, indicating it is found on the X chromosome. The Y is written with no superscript because it does not carry the gene for the trait. The condition of haemophilia (*h*) is recessive to normal (*H*) so the genotype of a normal male is written

X^HY and a male with haemophilia is X^hY; a normal female could be X^HX^H or X^HX^h (carrier) and a female with haemophilia is X^hX^h. Normal females are therefore homozygous for the normal allele and do not have the disease, or they are heterozygous and a carrier. If they are homozygous for the haemophilia allele then they express the condition. A male with haemophilia would be described as hemizygous because he has one haemophilia allele on his one X chromosome; this is not masked by another allele because he only has one X chromosome. Females, on the other hand, can be carriers if they have a haemophilia allele on one X chromosome that is masked by a normal allele on their other X chromosome.

In this type of inheritance, a male with the phenotype cannot pass on the trait to his sons because they always inherit his Y chromosome only. His daughters will get the X chromosome with the affected allele, but they will only show the phenotype if they also inherit an X chromosome with the affected allele from their mother. As with autosomal recessive phenotypes, some generations may not have any members showing the phenotype.

Consider an unaffected female who is a carrier of the haemophilia allele who has a child with a normal male. This cross is shown in Figure 7.21. The outcome of a haemophiliac female is not possible in this cross because a carrier female would have to have a child with a haemophiliac male.

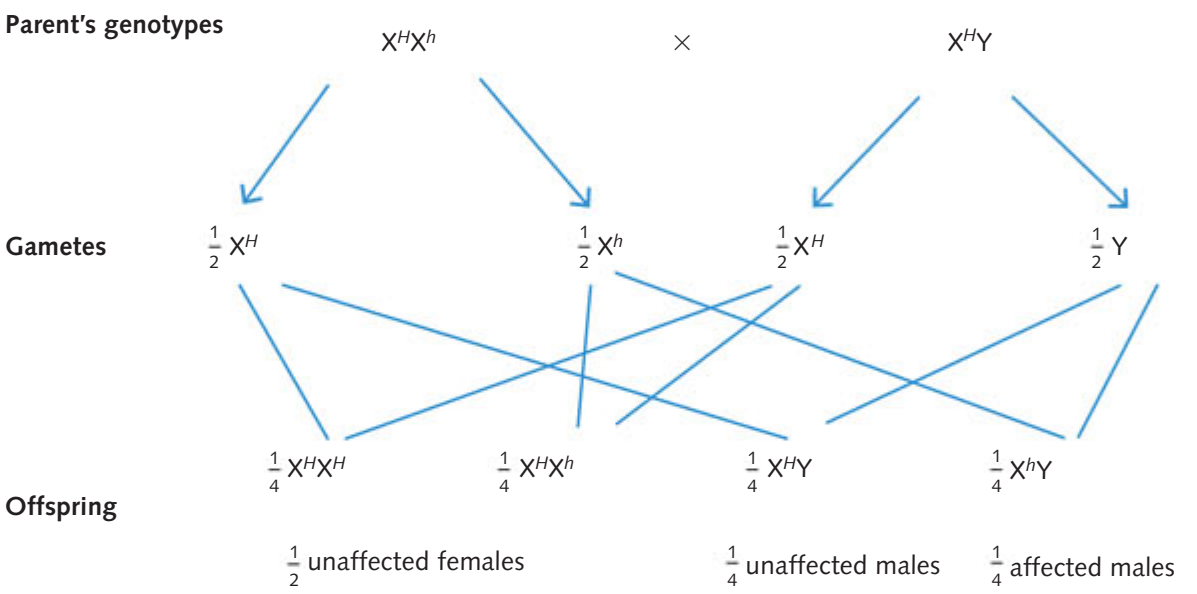


Figure 7.21 Possible outcomes if an unaffected female carrier has a child with a normal male

CONNECT

Sex determination in fruit flies is even more complex than in honeybees (Chapter 6) but for convenience it is described here as if it relies on X and Y chromosomes as in humans.

X-linked inheritance is also observed in species other than humans. In fruit flies, if a male with white eyes is crossed with a female with red eyes, all the F_1 fruit flies have red eyes, indicating that red is dominant to white. If males and females of the F_1 generation are mated, three-quarters of the F_2 fruit flies have red eyes and one-quarter have white eyes. This seems like a typical Mendelian ratio for a monohybrid cross, but there is something unusual: all the white-eyed flies are male. Alternatively, if the initial cross is between a red-eyed male and white-eyed female, all the F_1 males have white eyes and all the F_1 females have red eyes. This can be explained because the gene for eye colour is carried on the X chromosome. In the first cross between the white-eyed male and the red-eyed female, the male has only one copy of the white allele. The female is homozygous dominant for the red-eyed allele. In the F_1 generation, all the females are heterozygous for the red-eyed phenotype. The males, however, can only inherit one X chromosome from their mother, and so inherit one allele for red eyes. In the F_2 generation, all the females have at least one allele for red eyes because they inherited one of their X chromosomes from their red-eyed father. On the other hand, males inherit only one X chromosome from their heterozygous mother: half get the red allele, half get the white allele.

In the alternative cross between a red-eyed male and a white-eyed female, all the F_1 females inherit an X chromosome with an allele for the red-eyed trait from their father, who has one allele. All the F_1 males inherit their X chromosome with an allele for the white-eyed trait from their homozygous mother. Figure 7.22 summarises these crosses.

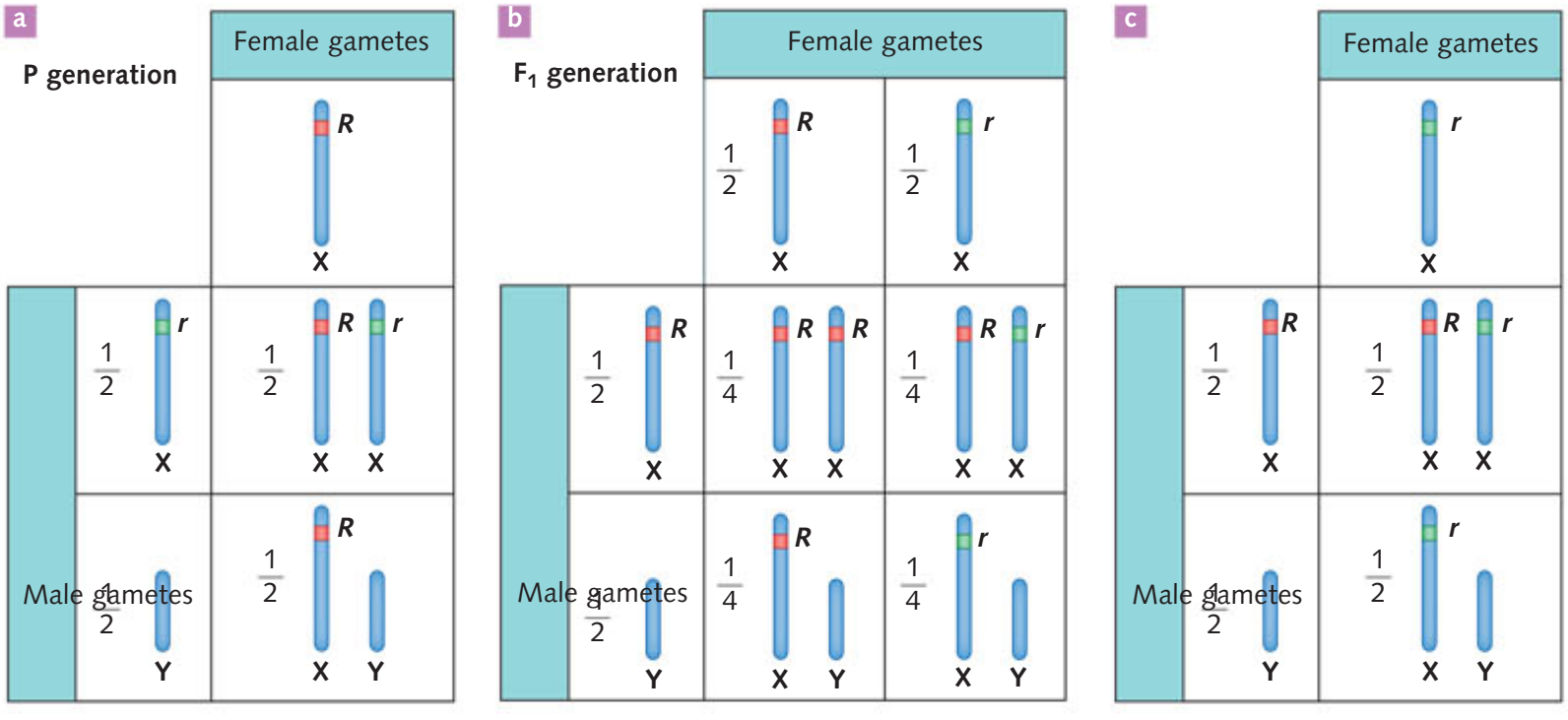


Figure 7.22 White eye colour in fruit flies is an X-linked recessive phenotype. The Punnett squares show **a** the P generation and **b** the F_1 generation of a monohybrid cross between a red-eyed male and a red-eyed female, and **c** a monohybrid cross between a red-eyed male and a white-eyed female.

X-linked dominant inheritance

X-linked dominant inheritance shows a similar pattern to X-linked recessive inheritance, except that heterozygous females will always show the phenotype and any affected individuals must have at least one parent with the phenotype. Males showing the phenotype will not pass the affected allele on to their sons (because the sons inherit their father's Y chromosome) but they will pass it on to all their daughters, who will show the phenotype. A heterozygous female is expected to pass on the allele to 50% of her offspring regardless of their sex.

For example: If the allele symbols T = show trait and t = not show trait, then:

- Unaffected females will have genotype X^tX^t
- Affected females will have genotypes X^TX^T or X^TX^t
- Affected males will have genotype X^TY and unaffected males X^tY
- Affected heterozygous females carrying one of the sex-linked dominant alleles (X^TX^t) are not called carriers because they will always express the allele for the dominant trait and it is not masked.

Y-linked inheritance

If an allele for a trait is carried on the Y chromosome, it is said to be **Y-linked**. The most conspicuous phenotype associated with genes of the Y chromosomes is male gender. 'Maleness' in humans is determined by the SRY gene carried on the Y chromosome. Other Y-linked genes are relevant to testis development and sperm production.

KEY CONCEPTS

- Sex-linked genes are found on the sex chromosomes: X-linked genes are on the X chromosome and Y-linked genes are on the Y chromosome.
- Alleles carried on the X and Y chromosomes show different inheritance patterns for males and females.
- X-linked recessive phenotypes are more common in males and Y-linked phenotypes are only expressed in males.

Concept questions 7.3c

1 Define sex-linked, X-linked and Y-linked inheritance.
2 Explain the term carrier when used in sex-linked inheritance. Explain why males cannot be carriers of an X-linked disease.
3 Explain why a father with an X-linked condition is not able to pass on the characteristic to his sons.
4 Explain why colour blindness is less common in women than in men.
5 When are X-linked disorders more common in females?

HOT Challenge

6 Studies have shown that male pattern baldness is linked to a gene on the X chromosome.
a From which parent is early-onset male pattern baldness usually inherited?
b A young man went bald in his twenties yet his father was not bald. Neither of his grandfathers were bald, nor any of his brothers or uncles. Where did his baldness come from?
c A woman was found at about the age of sixty to be going bald. Her doctor told her she was exhibiting female pattern baldness and could have inherited it from either parent. What does this tell you about female pattern baldness and early onset male pattern baldness?

7.4 Pedigree charts for autosomal and sex-linked inheritance

WB 7.4.1 PEDIGREE CHARTS PAGE 184

One way of finding out the type of pattern of inheritance of a characteristic is to follow the inheritance pattern over two or more generations. This technique is called **pedigree analysis**. Pedigree analysis of traits can easily be carried out in species such as pea plants and fruit flies by selecting organisms with chosen phenotypes and genotypes and carrying out breeding experiments. This is because their generation times are short, they can be readily interbred, and they can be kept in controlled conditions in a small area.

Humans, on the other hand, have long generation times, cannot be manipulated to carry out reproductive crosses, usually have a small number of offspring, and timing of reproduction cannot be manipulated. They live in changing environments that cannot be experimentally controlled. Due to these factors, interbreeding experiments cannot be carried out. To study patterns of inheritance in humans, geneticists collect all the available information for a particular trait from individuals in a family and from related families and use it to construct a **pedigree chart**. These charts show the inheritance of a particular trait over several generations. The greater the number of related individuals and the more pedigrees examined for the same trait, the more accurate the genetic analysis of the trait under investigation. Figure 7.23 shows examples and explanations of the symbols used in pedigree charts.

When studying the pedigree of a family, geneticists use knowledge of patterns of gene transmission to determine whether the allele for the characteristic under investigation is located on an autosome or sex chromosome and whether the trait is dominant or recessive.

Pedigree analysis can be used in a clinical setting, as it may reveal inheritance patterns that allow predictions about the transmission of genes to future children. Pedigree analysis may occasionally be affected by the presence of mutations that arise spontaneously.

Autosomal recessive inheritance

For an individual to express an autosomal recessive trait, they must carry two copies of the allele for the recessive trait. The affected individual must receive one copy of each allele from each parent. If the parents are carriers or heterozygous, they will not express the trait but will still each be able to pass on an allele for the trait. It is expected that 25% of their children will express the trait. Families usually have few children and so the sample size is too small for this pattern to be observed. If both parents are affected, all offspring will be affected. A family pedigree may have some generations where no expression of the trait occurs. Figure 7.24 shows an example of autosomal recessive inheritance for lack of skin pigmentation (albinism). Genotypes have been assigned to some individuals to help show the inheritance pattern, but these are usually omitted. Each generation is labelled from I for the original parents, II for the next

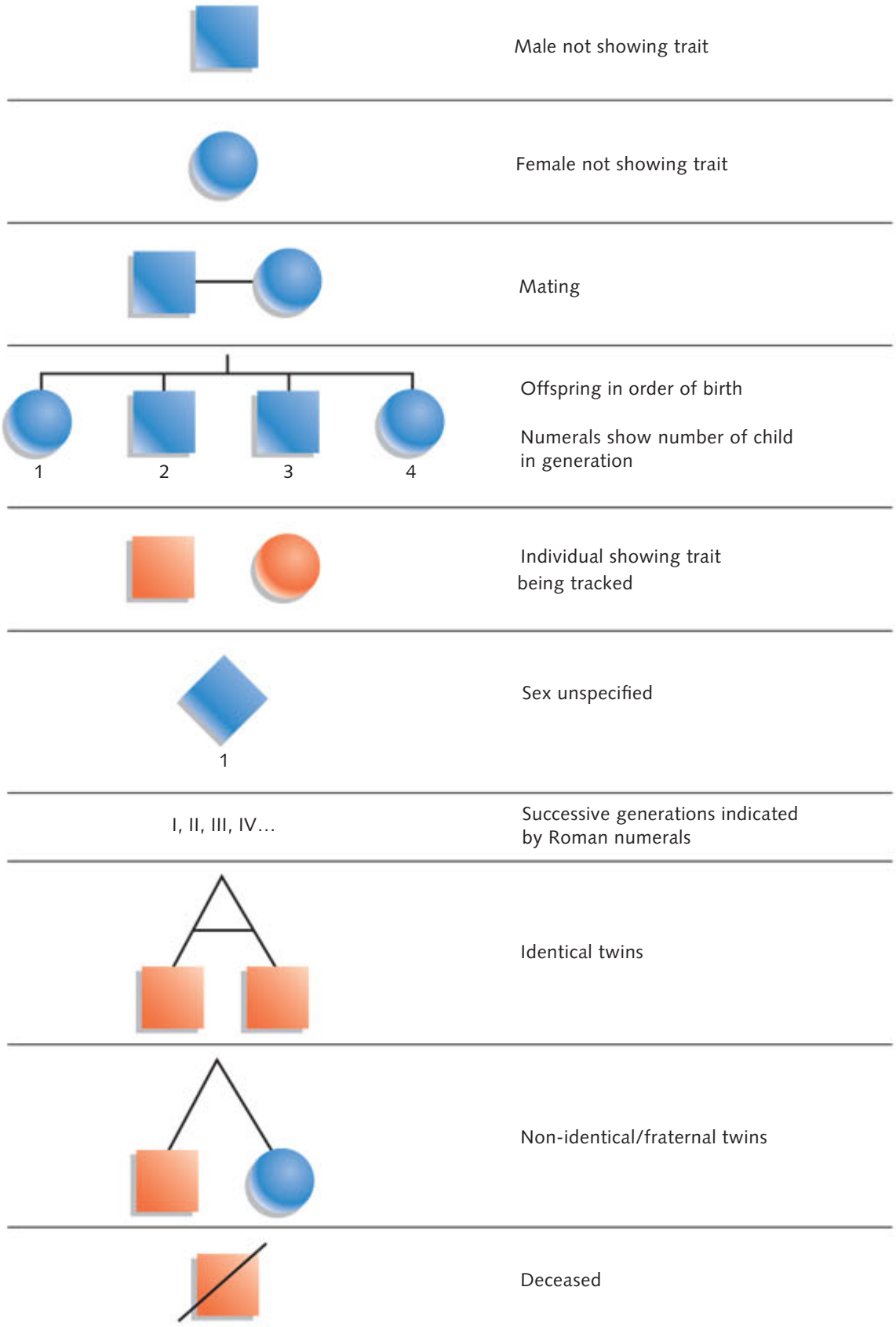


Figure 7.23 Symbols used in constructing pedigree charts

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

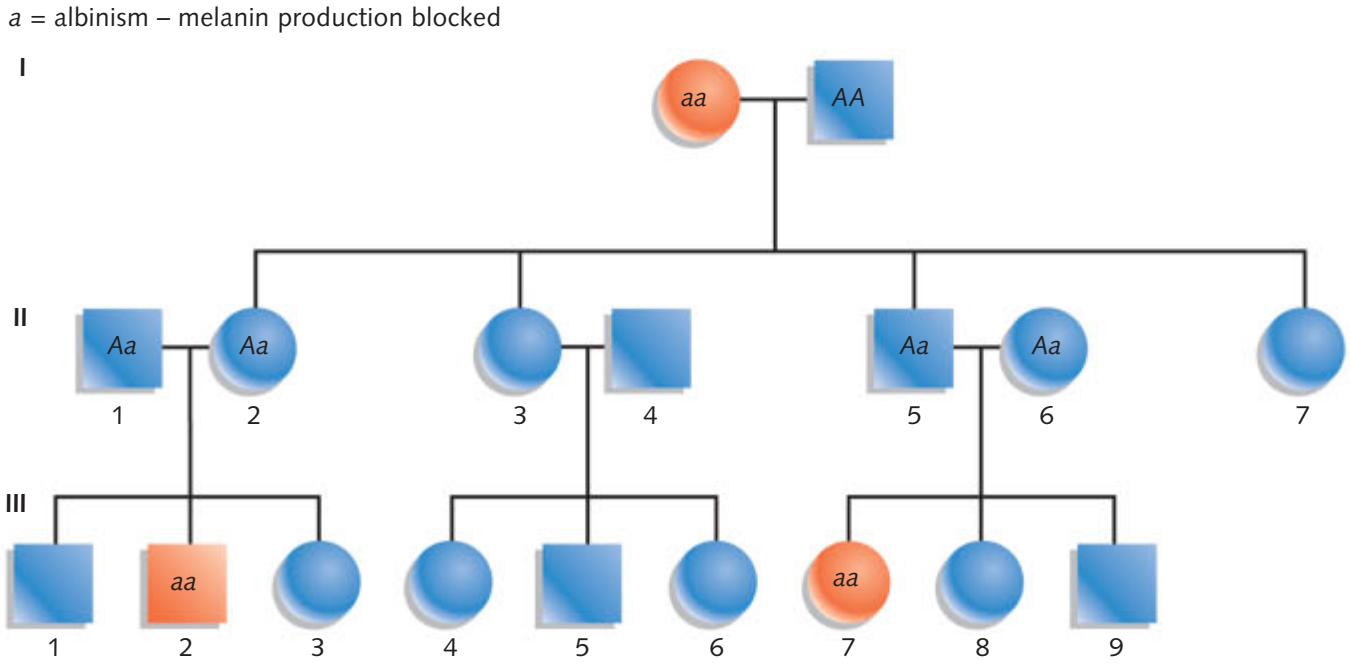


Figure 7.24 Pedigree showing individuals with the autosomal recessive trait of albinism

generation, and so on. Within each generation, the individuals are numbered 1, 2, 3, 4 and so on, whether they are offspring from the parents or have married, partnered, or been adopted into that generation. In Figure 7.24 you can see that individual 2 in generation III shows the autosomal recessive trait of albinism. This is written as III2.

The key to recognition of a pattern of inheritance that is autosomal recessive is to look for two unaffected parents that produce male and female affected offspring.

Autosomal dominant inheritance

An autosomal dominant trait is expressed when at least one copy of the allele is present in an individual's genotype. This means that any individual with the trait must have at least one parent with the trait and that it often appears in each generation. If one parent is homozygous recessive and therefore does not show the trait, and the other is heterozygous and does show the trait, then any child has a 50% chance of being heterozygous and showing the trait and a 50% chance of being homozygous recessive and not showing the trait.

Figure 7.25 shows a human pedigree of a family with achondroplasia, a form of dwarfism. This is an autosomal dominant condition that affects about 1 in 10 000 humans. Babies that are homozygous dominant for the condition are often stillborn, but heterozygotes can survive and reproduce normally.

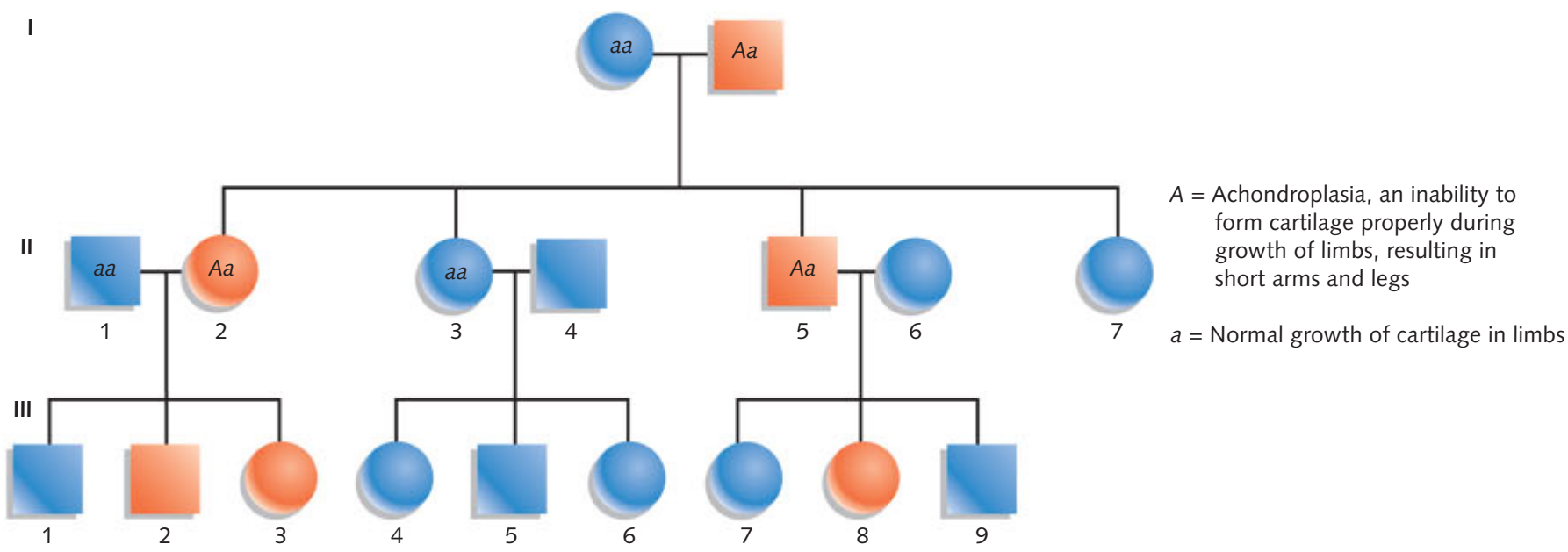


Figure 7.25 Pedigree showing individuals with achondroplasia, an autosomal dominant trait

The key to recognition of a trait that is inherited due to an autosomal dominant pattern of inheritance is to look for two affected parents that produce unaffected offspring, both males and females.

Some alleles for dominant traits cause serious genetic disorders, such as progeria, which is a rare genetic disease resulting in premature ageing. These diseases remain in populations because they can occur spontaneously due to random mutations. Other genetic diseases, such as Huntington disease, remain in the population because they do not appear until later in life, often after 40 years of age, when most people have already had children and passed on the allele for the disease.

X-linked recessive inheritance

When an allele for a recessive trait under investigation is on the X chromosome, it is said to be a sex-linked (or X-linked) recessive trait. Males who have this allele on their X chromosome will always express the trait because they only have one X chromosome, but females will only express the trait when both X chromosomes have the allele for this trait. A heterozygous female is called a carrier. This type of inheritance is usually detected in a pedigree when more males than females express the trait. Another way to detect this is in the pattern of inheritance of a male with the trait and his children. His sons cannot inherit the trait from their father because they inherit only his Y chromosome; however, his daughters will receive

the X chromosome carrying the affected allele from the father, and if they inherit another X chromosome carrying the affected allele from their mother, they will show the trait. As with autosomal recessive traits, some generations may not have any members showing the trait. Figure 7.26 illustrates a pedigree of a family with haemophilia, a recessive sex-linked disease in which the blood does not clot normally.

Figure 7.26 Pedigree showing individuals with haemophilia, a sex-linked recessive trait

The key to recognition of a trait that has an X-linked recessive pattern of inheritance is to look for more affected male offspring than female, and matings between either type of female with an unaffected male that produce affected sons only and no affected daughters.

X-linked dominant inheritance

This type of inheritance shows a similar pattern to sex-linked recessive inheritance, except that heterozygous females will always show the trait and any affected individuals must have at least one parent with the trait. Males showing the trait will not pass the affected allele on to their sons (because sons must inherit their father's Y chromosome) but they will pass it on to all their daughters, who will show the trait. A heterozygous female is expected to pass on the allele to 50% of her offspring regardless of their sex. Figure 7.27 illustrates the pedigree chart of a family with faulty enamel trait, which is when the normal protective enamel coating of teeth fails to develop.

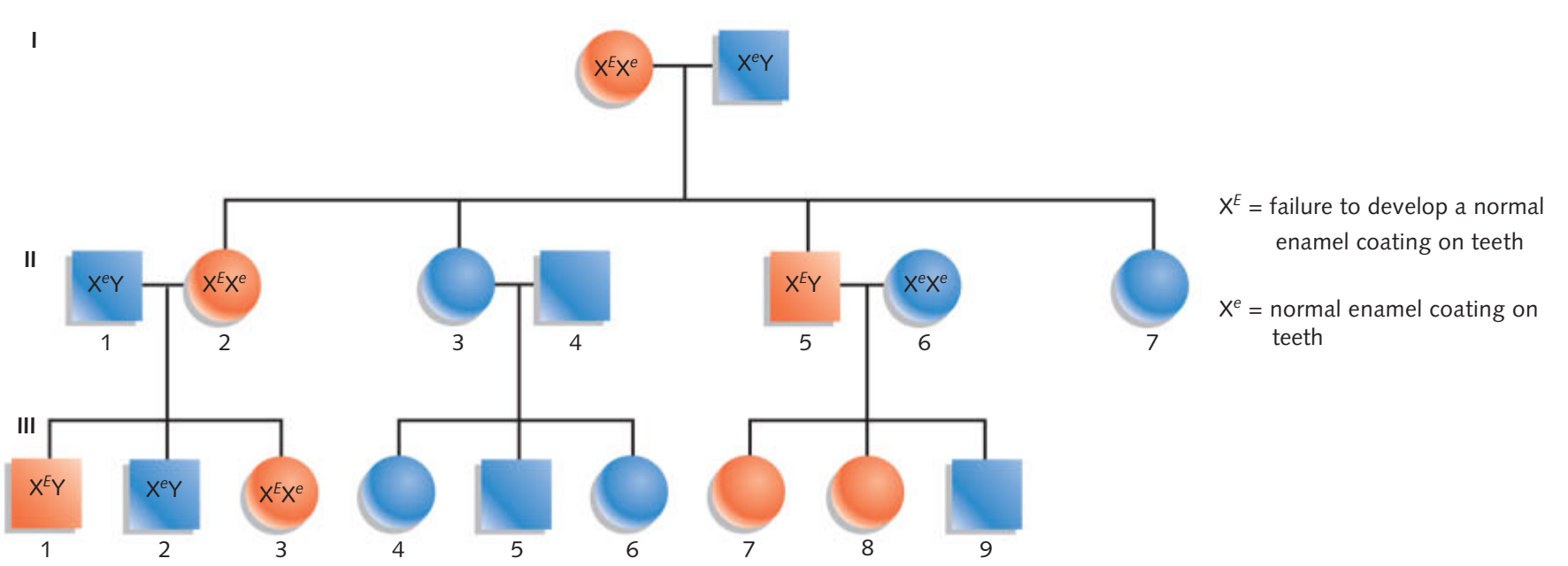


Figure 7.27 Pedigree showing individuals with the sex-linked dominant trait of abnormal teeth enamel coating

The key to recognition of an X-linked dominant pattern of inheritance is that the trait appears more frequently in females than in males, and an affected male will produce unaffected sons and all affected daughters.

KEY CONCEPTS

- Pedigree charts can be used to determine the pattern of inheritance of a particular trait in humans by studying the phenotypes of the parents and offspring over several generations.
- Autosomal recessive patterns of inheritance are shown if two unaffected parents produce male and female offspring that are affected.
- Autosomal dominant patterns of inheritance are shown if two affected parents produce male and female offspring that are not affected.
- Sex-linked inheritance is detectable by unequal phenotypic ratios between males and females.
- X-linked recessive phenotypes are more common in males than in females.
- X-linked dominant phenotypes show up in all affected females and males.
- Y-linked phenotypes are exclusively male.

Concept questions 7.4

1 How do pedigree charts assist in pedigree analysis?

2 Describe features of a pedigree chart that may indicate that a trait is inherited as:
- **a** an autosomal recessive trait
- **b** an autosomal dominant trait
- **c** an X-linked recessive trait
- **d** an X-linked dominant trait.

3 At each birth of a child, what is the chance of a male?

4 The family pedigree shown in Figure 7.28 is an example of an X-linked dominant type of inheritance.
- **a** Assign allele symbols for the faulty enamel gene and explain why you chose those symbols.
- **b** Give the genotype of a male with the faulty enamel trait, using the correct notation for sex-linkage.
- **c** List the genotypes of females with the trait. Give the genotype of an unaffected female.
- **d** Give the genotype of individual III 5 in the pedigree.
- **e** Explain whether individual III 1 inherited the allele for faulty enamel from her mother or from her father.

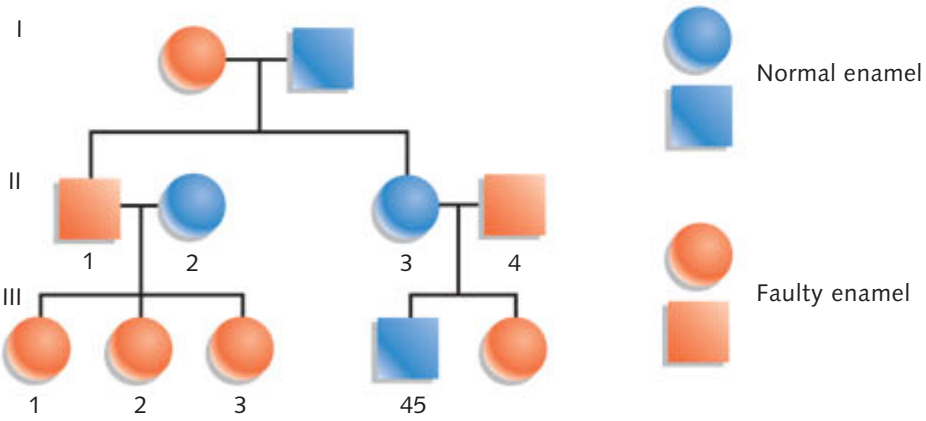


Figure 7.28 Pedigree of family with faulty enamel

HOT Challenge

5 Determine the type of inheritance shown in the pedigree chart in Figure 7.29. List all the individuals that exhibit the affected phenotype.

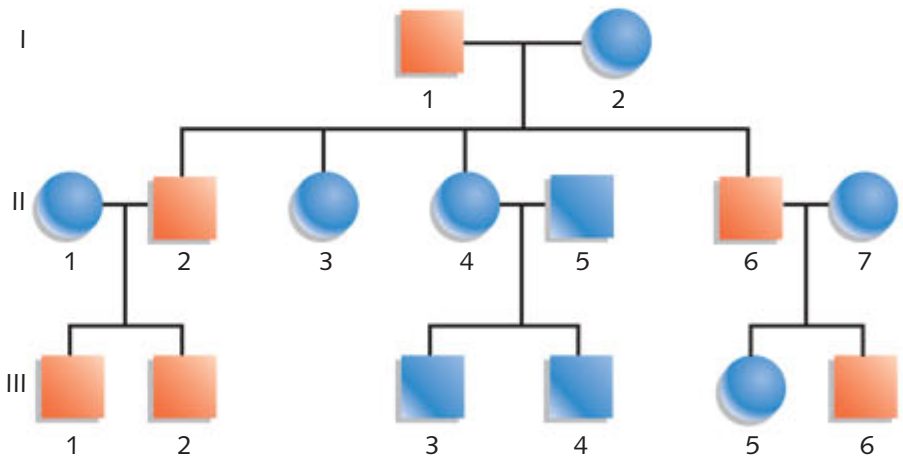


Figure 7.29 Inheritance pattern shown on a pedigree chart

7.5 Predicted genetic outcomes for two autosomal genes

WB
7.5.1 GENES THAT ASSORT INDEPENDENTLY PAGE 187

So far, we have considered only the inheritance of one pair of contrasting characteristics determined by two different alleles at a single gene locus. Mendel also studied **dihybrid inheritance**, which is the inheritance of alleles of two different genes controlling two different characteristics.

In one experiment, Mendel crossed a purebred tall pea plant possessing purple flowers with a short plant possessing white flowers (Figure 7.30). In the F_1 generation, all the plants produced were tall and had purple flowers. These were then self-pollinated. In the F_2 generation, there were four different phenotypes: tall plants with purple flowers; tall plants with white flowers; short plants with purple flowers; and short plants with white flowers. In other words, the offspring showed the two pairs of characteristics (tall, short; purple, white) combined in four possible ways. Mendel counted the different types of plants and found 96 tall purple plants, 31 tall white plants, 34 short purple plants and 11 short white plants, giving a ratio of approximately 9 : 3 : 3 :1. The cross is described as a **dihybrid cross** and is shown in Figure 7.31.

Shutterstock.com/Valery Prokhozhy Shutterst

Figure 7.30 Pea plant flowers may be **a** purple or **b** white.

Figure 7.31 Summary of Mendel's dihybrid cross

Several conclusions can be drawn from these results. First, the observation that all the F_1 plants are tall with purple flowers confirms that tall is dominant to short and purple flower is dominant to white flower. Using symbols to represent the alleles of the two genes, *T* represents the allele for tall, *t* for short, *P* for purple flowers and *p* for white flowers. Mendel always started his experiments with purebred plants, so the parent plants must be homozygous for both genes. The genotype of the tall plant with the purple flowers is, therefore, *TTPP*, and that of the short plant with white flowers is *ttpp*. The gametes produced by the parent plants are all *TP* from the pure breeding tall purple-flowered parent and all *tp* from the pure breeding short white-flowered parent. All the F_1 offspring will, therefore, have the genotype *TtPp*, heterozygous for both genes.

If the heterozygous F_1 offspring are then interbred, another conclusion can be drawn. During meiosis and gamete formation, the pairs of chromosomes separate or 'assort' independently of each other and, therefore, so do the alleles of the two gene loci found on the different chromosome pairs. If all four possible combinations of characteristics show up in the F_2 generation, the F_1 plants must produce four kinds of gamete during meiosis: *TP*, *Tp*, *tP* and *tp* (Figure 7.32).

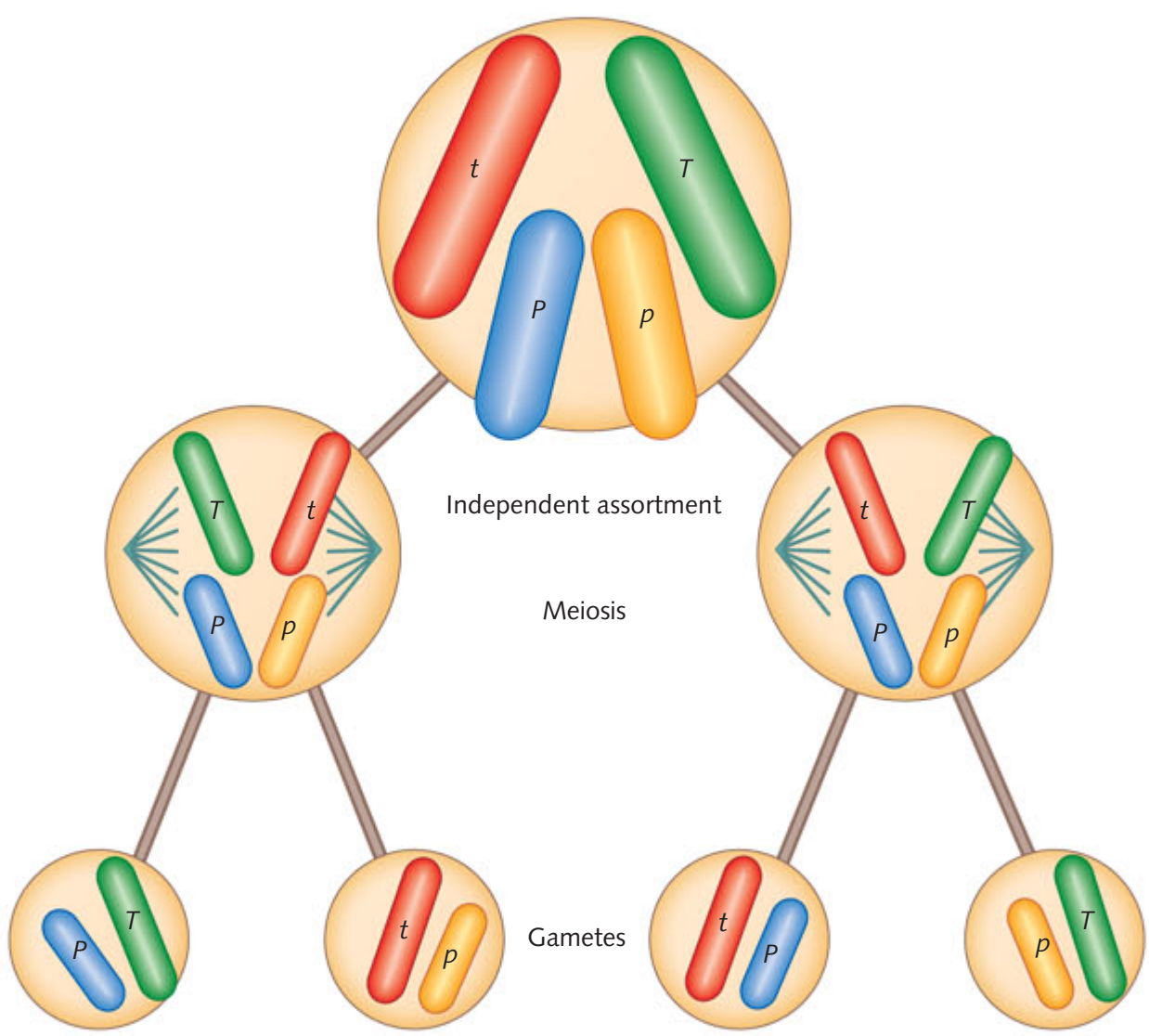
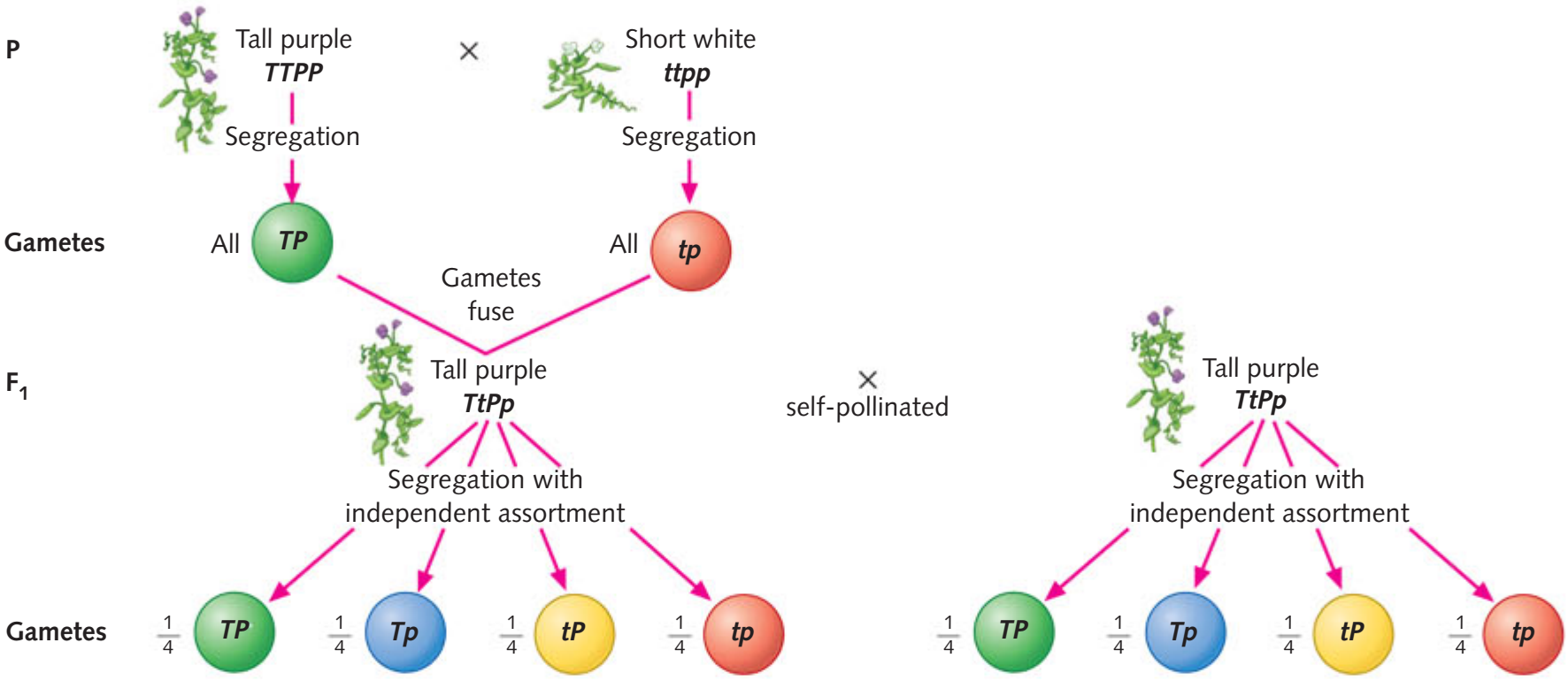


Figure 7.32 **Meiosis explains the independent assortment that Mendel found in his dihybrid crosses. The independent assortment of alleles in inheritance corresponds to the free assortment of chromosomes during meiosis.**

The Punnett square in Figure 7.33 shows the cross between two F_1 plants heterozygous at both gene loci. The four types of gametes produced by one parent are placed across the top and the four types produced by the other parent down the side. The different genotype combinations produced when the gametes fuse and the resulting phenotypes are in the boxes, together with the predicted proportion of each of the resulting 16 combinations of F_2 offspring. For a plant to be tall, its genotype must contain at least one *T* allele; to be purple-flowered, it must contain at least one *P* allele. The tabulated genotypes show that $\frac{9}{16}$ will produce tall purple-flowered plants, $\frac{3}{16}$ tall white-flowered plants, $\frac{3}{16}$ short purple-flowered plants and $\frac{1}{16}$ short

white-flowered plants. The observed 9 : 3 : 3 : 1 ratio can be accounted for if all the possible combinations occur with equal likelihood. This is the predicted ratio and is more likely to be observed in a large sample.



Punnett square to show fusion of F_1 gametes

		Female gametes: 1/4 TP	Female gametes: 1/4 Tp	Female gametes: 1/4 tP	Female gametes: 1/4 tp
Male gametes	1/4 TP	1/16 *TTPP* Tall purple	1/16 *TTPp* Tall purple	1/16 *TtPP* Tall purple	1/16 *TtPp* Tall purple
	1/4 Tp	1/16 *TTPp* Tall purple	1/16 *TTpp* Tall white	1/16 *TtPp* Tall purple	1/16 *Ttpp* Tall white
	1/4 tP	1/16 *TtPP* Tall purple	1/16 *TtPp* Tall purple	1/16 *ttPP* Short purple	1/16 *ttPp* Short purple
	1/4 tp	1/16 *TtPp* Tall purple	1/16 *Ttpp* Tall white	1/16 *ttPp* Short purple	1/16 *ttpp* Short white
F_2		9/16 Tall purple	3/16 Tall white	3/16 Short purple	1/16 Short white

Figure 7.33 **Punnett square showing the F_2 generation resulting from a parental dihybrid cross of a purebred tall pea plant with purple flowers with a short pea plant with white flowers**

The conclusion that can be drawn from a 9 : 3 : 3 : 1 ratio in the F_2 offspring is that the alleles of the two genes are transmitted independently of each other from parents to offspring and, therefore, 'assort freely'. In other words, each of the alleles of one gene may combine with each of the alleles of another gene in equal probabilities. This is known as **independent assortment**. Independent assortment requires that the two gene loci are on different chromosomes; they are not linked on the same chromosome. They are therefore called **unlinked genes**.

Online Video
Dihybrid crosses

The gene locus for the gene for flower colour is located on one pair of homologous chromosomes and the gene locus for the gene for height is on another pair of chromosomes. The alleles for height and flower colour segregate and assort independently because they are carried on separate chromosomes, which themselves segregate and assort independently in meiosis.

WORKED EXAMPLE 7.2

A purebred fruit fly that has curly wings and red eyes is crossed with a purebred fruit fly that has straight wings and purple eyes (Figure 7.34). Their offspring all have curly wings and red eyes. Two of the F_1 generation flies are crossed. If the gene loci for wing shape and eye colour are on different chromosomes and therefore independent assortment occurs, predict the phenotypes of the F_2 generation and the proportions of each phenotype.

a Assign the alleles.

b Draw the Punnett square and enter the haploid gametes.

c Determine the genotypes of all the possible offspring.

d Determine the corresponding phenotypes for the genotypes.

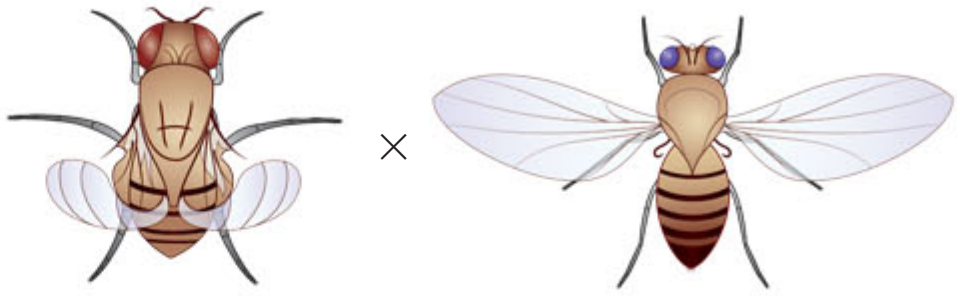


Figure 7.34 Pure breeding fruit flies with curly wings and red eyes are crossed with pure breeding fruit flies with straight wings and purple eyes.

Answer	Logic
a *C* = curly wing *c* = straight wing *R* = red eyes *r* = purple eyes	The P generation flies are pure breeding, so they are homozygous for wing shape (curly or straight) and eye colour (red or purple). It follows that all the F_1 generation must be heterozygous with respect to both wing shape and eye colour. All the F_1 generation have curly wings and red eyes. This indicates that curly wings are dominant to straight wings and red eyes are dominant to purple eyes.
b	The F_1 cross is between heterozygous fruit flies – that is, *CcRr* × *CcRr*. For each individual, half the gametes will receive the *C* allele and half will receive the *c* allele; half will receive the *R* allele and half will receive the *r* allele. The alleles for each trait (*Cc* and *Rr*) assort independently of each other, so four equally likely combinations of alleles are present in the gametes of the F_1 generation: $\frac{1}{4}CR$, $\frac{1}{4}Cr$, $\frac{1}{4}cR$ and $\frac{1}{4}cr$.

×	Female gametes: $\frac{1}{4}CR$	$\frac{1}{4}Cr$	$\frac{1}{4}cR$	$\frac{1}{4}cr$
Male gametes: $\frac{1}{4}CR$				
$\frac{1}{4}Cr$				
$\frac{1}{4}cR$				
$\frac{1}{4}cr$				

c

×		Female gametes			
		$\frac{1}{4}$ *CR*	$\frac{1}{4}$ *Cr*	$\frac{1}{4}$ *cR*	$\frac{1}{4}$ *cr*
Male gametes	$\frac{1}{4}$ *CR*	$\frac{1}{16}$ *CCRR*	$\frac{1}{16}$ *CCRr*	$\frac{1}{16}$ *CcRR*	$\frac{1}{16}$ *CcRr*
	$\frac{1}{4}$ *Cr*	$\frac{1}{16}$ *CCRr*	$\frac{1}{16}$ *CCrr*	$\frac{1}{16}$ *CcRr*	$\frac{1}{16}$ *Ccrr*
	$\frac{1}{4}$ *cR*	$\frac{1}{16}$ *CcRR*	$\frac{1}{16}$ *CcRr*	$\frac{1}{16}$ *ccRR*	$\frac{1}{16}$ *ccRr*
	$\frac{1}{4}$ *cr*	$\frac{1}{16}$ *CcRr*	$\frac{1}{16}$ *Ccrr*	$\frac{1}{16}$ *ccRr*	$\frac{1}{16}$ *ccrr*

As with the monohybrid cross, each square is filled with the product of the intersecting female and male gametes. For example, $\frac{1}{16}$ *CCRR* is entered into the first vacant square, which represents the product of $\frac{1}{4}$ *CR* (female) and $\frac{1}{4}$ *CR* (male). The next vacant square to the right is filled with $\frac{1}{16}$ *CCRr*, which is the product of $\frac{1}{4}$ *Cr* (female) and $\frac{1}{4}$ *CR* (male). Continue working through until all 16 squares are filled.

d

×		Female gametes			
		$\frac{1}{4}$ *CR*	$\frac{1}{4}$ *Cr*	$\frac{1}{4}$ *cR*	$\frac{1}{4}$ *cr*
Male gametes	$\frac{1}{4}$ *CR*	$\frac{1}{16}$ *CCRR*	$\frac{1}{16}$ *CCRr*	$\frac{1}{16}$ *CcRR*	$\frac{1}{16}$ *CcRr*
	$\frac{1}{4}$ *Cr*	$\frac{1}{16}$ *CCRr*	$\frac{1}{16}$ *CCrr*	$\frac{1}{16}$ *CcRr*	$\frac{1}{16}$ *Ccrr*
	$\frac{1}{4}$ *cR*	$\frac{1}{16}$ *CcRR*	$\frac{1}{16}$ *CcRr*	$\frac{1}{16}$ *ccRR*	$\frac{1}{16}$ *ccRr*
	$\frac{1}{4}$ *cr*	$\frac{1}{16}$ *CcRr*	$\frac{1}{16}$ *Ccrr*	$\frac{1}{16}$ *ccRr*	$\frac{1}{16}$ *ccrr*

Nine of the 16 squares show offspring with at least one *C* and one *R* allele, and these offspring will have both dominant phenotypes, curly wings and red eyes. Three of the 16 squares show offspring with at least one *C* allele for curly wing shape and two *rr* alleles for purple eye colour. Three of the 16 squares show offspring with two *cc* alleles for straight wings and at least one *R* allele for red eyes. Just one of the 16 squares shows offspring with the genotype *ccrr* for both recessive phenotypes, straight wings and purple eyes.

The dihybrid cross gives a 9 : 3 : 3 : 1 ratio of fruit flies with curly wings, red eyes : curly wings, purple eyes : straight wings, red eyes : straight wings, purple eyes.

Try these yourself

1 A purebred fruit fly that has curly wings and long legs is crossed with a purebred fruit fly that has straight wings and short legs. Their offspring all have curly wings and long legs. Two of the F_1 generation flies are crossed. If the gene loci for wing shape and leg length are on different chromosomes and therefore the alleles of the two genes assort independently, predict the phenotypes of the F_2 generation and the proportions of each phenotype.

2 A purebred pea plant bearing yellow, wrinkled peas was crossed with a purebred pea plant bearing green, round peas. All the F_1 offspring have yellow, round peas. If the gene loci for pea colour and shape of seed are unlinked and two of the F_1 pea plants are crossed, predict the possible combinations of pea phenotypes with respect to colour and shape and the proportions in which they are likely to occur.

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INVESTIGATION 7.2

A dihybrid cross in maize

The popular edible grain corn (*Zea mays*), also known as maize, is a member of the grass family (Poaceae). There are dozens of varieties of domesticated corn (Figure 7.35).

Corn is a useful organism for investigating patterns of inheritance because the offspring of the same parents are represented as kernels on a single cob. This means that examining a single cob provides data on several hundred offspring of the same parents. Each kernel is made up of an embryo surrounded by nutritive tissue and an outer covering (Figure 7.36).

Kernel colour is determined by the presence or absence of a pigment called anthocyanin: when the pigment is present the kernels are purple or 'coloured'; when it is absent the kernels appear yellow or 'colourless'.

Kernel shape may be described as smooth if the kernels retain water or wrinkled if they dry out and collapse The difference between the two is largely due to the ratio of sugar to starch in the contents of the endosperm. An endosperm high in sugar dries out quickly, causing the kernels to collapse.

In this investigation, you will examine these traits of corn kernels (colour and shape) to determine their inheritance patterns over three generations.

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Figure 7.35 Some examples of different corn varieties

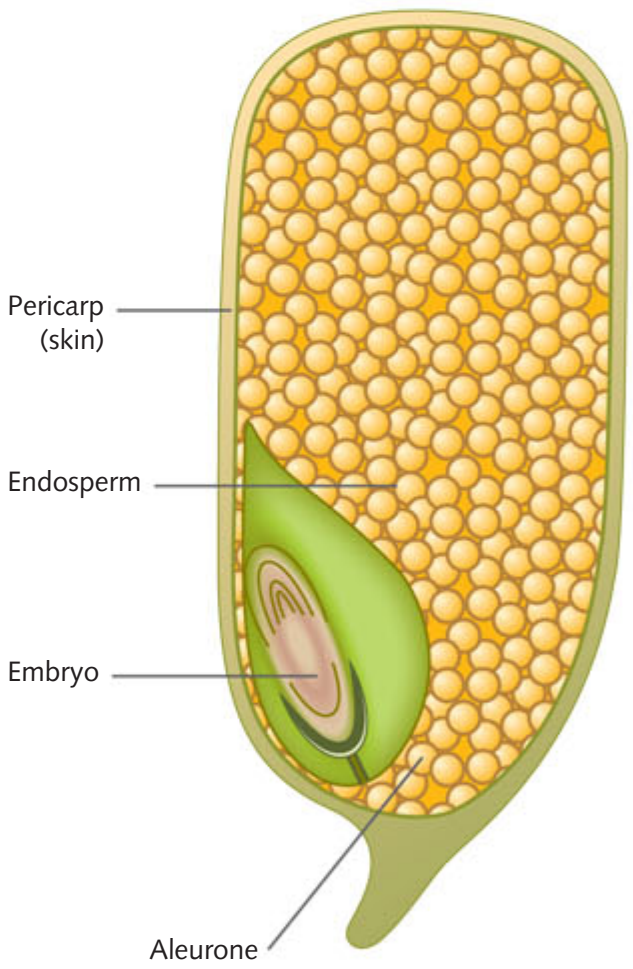


Figure 7.36 The structure of a corn kernel

Aim

To predict the phenotypic ratios of F_2 offspring arising from a dihybrid cross in *Zea mays* (corn) and compare the prediction against observed data.

Materials

» Dihybrid maize model, boxed (produced by Carolina Biological Supply Company, sourced locally through Australian suppliers)

Note: Alleles are assigned in the model. Ideally, these should be removed or obscured so that alleles are assigned during the investigation.

» Maize ear: segregation for dihybrid cross (Carolina Biological Supply Company)

» Pins

Method

Part A: Predict the outcome of the dihybrid cross

A cross was set up between two purebred corn plants (P) to produce an F_1 generation. Representatives of the F_1 generation were subsequently self-pollinated to give the F_2 generation. A model of the two crosses is shown in the boxed model.

1 Examine the model and determine the dominant and recessive phenotypes for the two independently assorting characteristics in corn: colour and shape.

2 Copy Table 7.5 into your logbook. Assign alleles corresponding to each of the dominant and recessive phenotypes and enter them into Table 7.5.

3 Copy Table 7.6 into your logbook and complete the first Punnett square to show the genotype(s) of the F_1 generation kernels.
4 Copy Table 7.7 into your logbook and complete the second Punnett square to show the predicted genotype(s) of the F_2 generation corn kernels.
5 Use the genotype in Table 7.7 to determine the corresponding phenotype of each possible zygote formed. List these possible phenotypes under Table 7.7 in your results section.
6 Copy Table 7.8 into your logbook. Use the phenotype data from your list to calculate the ratio of the predicted phenotypes of the corn kernels and record your results in Table 7.8.

Part B: Gather experimental data and compare with predicted ratios

You are presented with the maize ear from the F_2 generation.

1 Identify the four different phenotypes with respect to kernel shape and kernel colour. Copy Table 7.9 into your logbook and record the phenotypes in the top row.
2 Select and mark five columns of kernels with a pin (at the flat end of the cob). Count the number of kernels of each phenotype for each row and enter the data into Table 7.9.
3 Calculate the total number of kernels for each phenotype and enter these into the Totals row of Table 7.9.
4 Identify which of the phenotypes in Table 7.9 is represented by the smallest total number of individuals. Divide the total number of each phenotype by the smallest total number and round off to the nearest whole number. Enter these values in the Simplified ratio row of the table to generate a ratio for the observed phenotypes.

Results

Copy and complete each of the tables, following the instructions given in the method. Add extra rows as required.

Table 7.5 Corn kernel phenotypes and their corresponding alleles

Characteristic	Colour		Shape	
Phenotypes	Dominant phenotype	Recessive phenotype	Dominant phenotype	Recessive phenotype

Table 7.6 Punnett square representing the cross between two purebred P corn plants to give the F_1 generation

		Female gamete
Male gamete		

Table 7.7 Punnett square representing the cross between F_1 corn plants to give the F_2 generation

		Female gametes			
Male gametes					

Possible phenotypes:

Table 7.8 Ratio of expected phenotypes for the F_2 corn kernels

Phenotype				
Ratio				

Table 7.9 Observed data for F_2 generation corn

	Phenotype 1:	Phenotype 2:	Phenotype 3:	Phenotype 4:
Column 1 Number of kernels				
Column 2 Number of kernels				
Column 3 Number of kernels				
Column 4 Number of kernels				
Column 5 Number of kernels				
Totals				
Simplified ratio				

Results

1 How many different genotypes are represented in your Punnett square (Table 7.7)?
2 How many different phenotypes are represented (Table 7.8)?

Discussion

1 Compare your expected and observed phenotypic ratios. Explain any discrepancies between the two ratios.
2 What could be done to improve the accuracy of the observed phenotypic ratio?
3 Consider the coloured smooth corn kernels of the F_2 generation. What kind of cross could be done to determine their genotypes?
4 Discuss how corn from the F_2 generation could be crossed to regenerate purebred lines of coloured smooth and colourless wrinkled corn.

Conclusion

Draw a conclusion that is consistent with your observations, data and analysis.

KEY CONCEPTS

- Inheritance for two unlinked autosomal genes can be studied with a dihybrid cross.
- In a dihybrid cross involving two unlinked genes, if one parent is homozygous dominant for both traits and the other is homozygous recessive for both traits, the F_1 offspring are heterozygous for both traits and express the dominant phenotypes. In a cross between the F_1 individuals, the F_2 offspring are predicted to show four combinations of phenotypes: dominant–dominant, dominant–recessive, recessive–dominant, recessive–recessive, in the ratio of 9 : 3 : 3 : 1.
- In the inheritance of two unlinked genes, the two copies of genes segregate during the production of gametes so that offspring acquire one allele from each parent. Alleles of a gene separate independently from alleles of another gene. Hence, the inheritance pattern of one trait will not affect the inheritance pattern of the other.

Concept questions 7.5a

1 Define dihybrid cross.
2 What is independent assortment? Explain the arrangement of the two gene loci that would result in independent assortment. What term is used to describe these two gene loci?
3 Explain the origin of the 9:3:3:1 phenotypic ratio in a dihybrid cross by giving the genotypes of the parents, F_1 and F_2, and proportions of each type. (Hint: First allocate allele symbols.)
4 What is meant by unlinked genes? Why does the 9:3:3:1 ratio only work if the two genes being investigated in a dihybrid cross are unlinked?
5 If *AaBb* is crossed with a*abb*, what proportion of the offspring would be expected to be *aabb*?

HOT Challenge

6 Whenever the allele combination of aaBB is present, a red colour is produced in the progeny.
   a In a cross of AaBB × aaBb, how many red offspring would you expect out of 320? (Hint: get the gametes correct first.)
   b What are the genotype ratios?

Dihybrid crosses involving linked genes

WB 7.5.2 LINKED GENES PAGE 189

Mendel's predicted outcomes of dihybrid crosses were based on the study of genes that were located on different chromosomes. The same expected results are not obtained if the two gene loci are located on the same chromosome. Genes that are close together and located on the same chromosome are called **linked genes** or a **linkage group**. Linked genes are usually inherited together and do not show independent assortment.

The concept of linkage can be shown by examining two characteristics of the fruit fly *Drosophila melanogaster*. Wing shape has two phenotypes with normal long wings (*V*) dominant to vestigial wings (*v*); body width has two phenotypes with broad abdomen (*A*) dominant to narrow abdomen (*a*). If these genes are linked and the two gene loci are close together on the same chromosome, the predicted outcome from crossing a purebred long-winged fly with a broad abdomen (*VVAA*) with a purebred short-winged fly with a narrow abdomen (*vvaa*) would be all F_1 offspring that are long-winged with a broad abdomen (*VvAa*). Because the alleles of the two gene loci stay together during meiosis, only two types of gametes would be produced from the F_1 flies during meiosis, so they would only produce two types of gametes (*VA* and *va*). A Punnett square for interbreeding the F_1 flies would have two gametes across the top from one parent and two types down the side from the other parent. In a large sample, the F_2 offspring would be predicted to be three-quarters long-winged with a broad abdomen and one-quarter short-winged with a narrow abdomen. This is shown in Figure 7.37. Notice that genotypes for linked genes are written in a special way: a fly with normal wings and broad abdomen can produce gametes with both these alleles. This gamete is written as $\underline{VA}$. A gamete containing both recessive alleles is written as $\underline{va}$. F_1 offspring would have the genotype $\frac{VA}{va}$.

Test crosses and dihybrid ratios

As already explained, a test cross can be used to determine if an organism that expresses the dominant phenotype is homozygous or heterozygous for the alleles of the gene. Test crosses can also be used to determine if two gene loci are linked, close together and inherited together, or not linked and located on different pairs of homologous chromosomes.

If an F_1 tall plant with purple flowers heterozygous for both characteristics (*TtPp*) that produces four types of gametes (*TP*, *Tp*, *tP*, *tp*) is crossed with a short plant with white flowers (*ttpp*) that would produce only one type of gamete (*tp*), four types of offspring could be produced in equal numbers: tall purple, tall white, short purple, short white. Mendel carried out this experiment and obtained 47 tall purple, 40 tall white, 38 short purple and 41 short white plants. This is very close to the expected ratio of 1:1:1:1. This is shown in Figure 7.38.

It is now understood that the ratio of 1 : 1 : 1 : 1 will only be obtained in a test cross if the two gene loci are on different homologous chromosomes and are inherited independently.

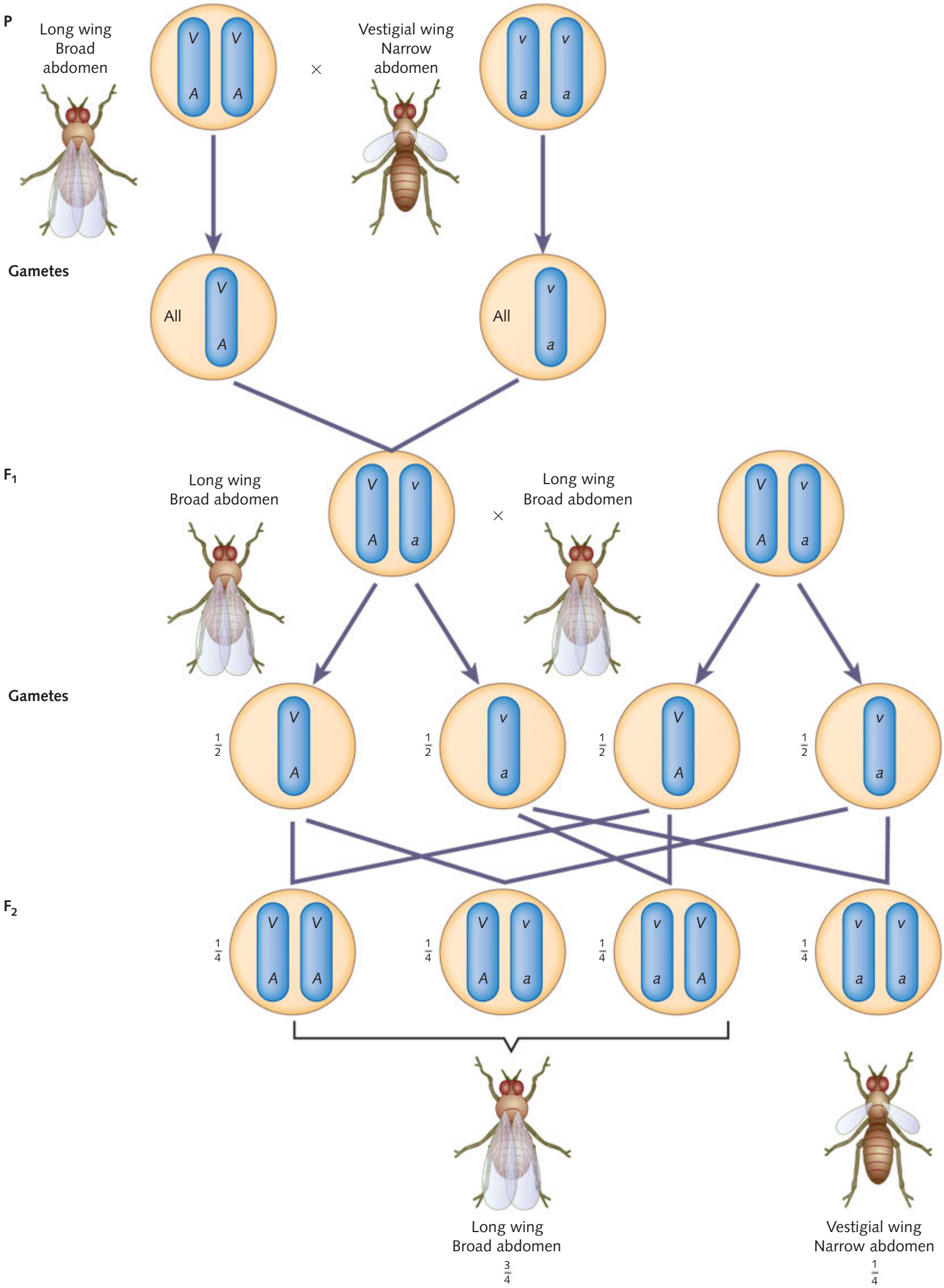


Figure 7.37 **The genes for wing length and abdomen width are located close together on the same chromosome and are called linked genes. They are inherited together and do not show independent assortment.**

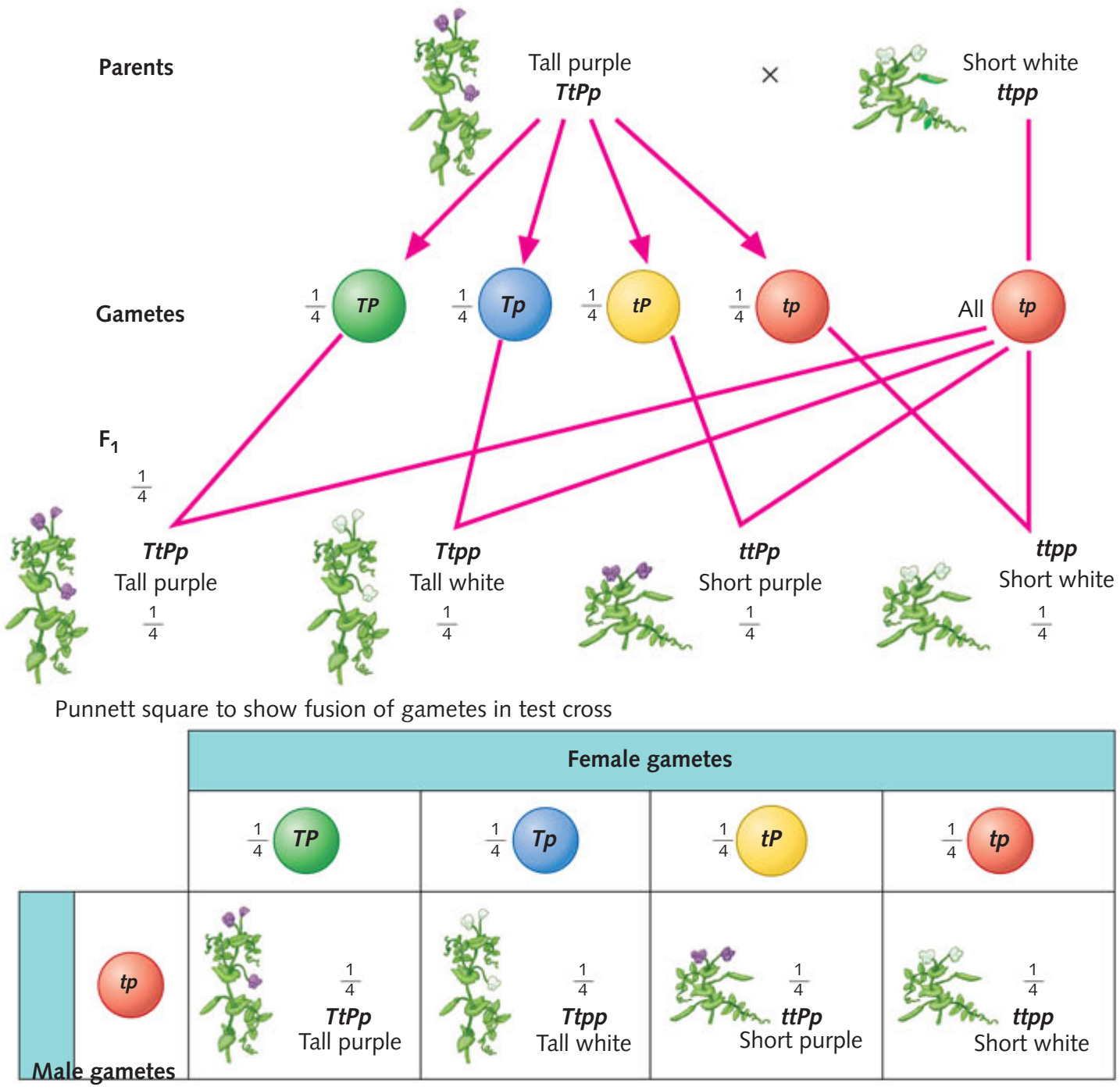


Figure 7.38 In a test cross of a pea plant that is heterozygous for both height and flower colour with a homozygous recessive plant, four possible types of offspring may result as the two gene loci are unlinked.

Crossing over produces new combinations of alleles in the gametes

Genes on the same chromosome do not always stay linked together. Sometimes one chromatid of each chromosome of a homologous pair exchange sections during prophase I of meiosis, a process called crossing over and recombination. Figure 7.39 illustrates this with a pair of hypothetical homologous chromosomes with genes *EF* and *ef*. Crossing over between linked genes results in new combinations of genes in the gametes that are not found in either parent, called **recombinant gametes** (Figure 7.40) and ultimately resulting in

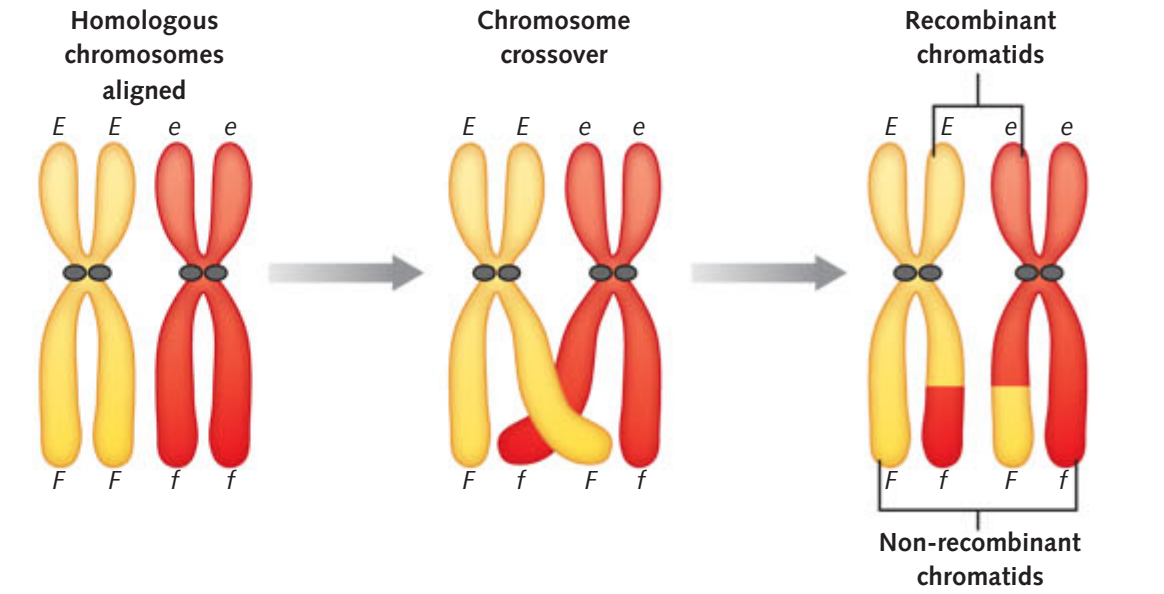


Figure 7.39 Crossing over occurs in prophase I of meiosis. It swaps over a linkage group, resulting in new combinations of alleles in the gamete.

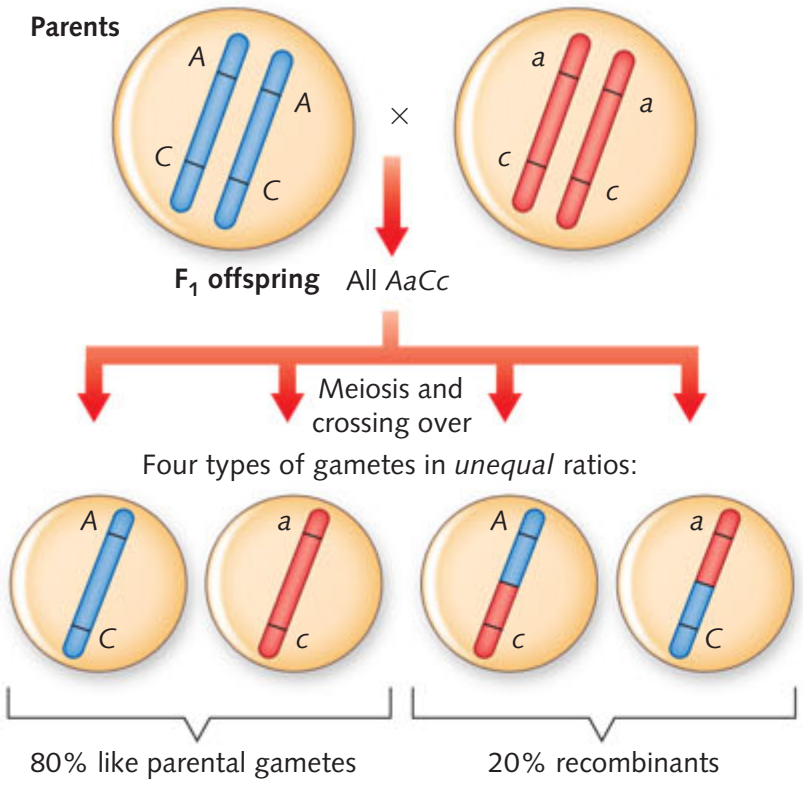


Figure 7.40 Crossing over results in recombinant offspring.

recombinant offspring. The further apart the linked genes, the more likely crossing over and the formation of recombinant gametes and therefore recombinant offspring.

A test cross between an organism heterozygous for two gene loci and an organism homozygous for both loci, where the two gene loci are linked on the same chromosome but further apart, will result in crossing over and a certain percentage of recombinant gametes and therefore recombinant offspring. The ratio predicted in the offspring of such a cross will be 1 parental : few recombinant : few recombinant : 1 parental. The further apart the two gene loci, the greater the chance of crossing over and therefore the greater the number of recombinant offspring.

KEY CONCEPTS

- Genes linked on the same chromosome are inherited together and do not show independent assortment.
- A test cross can be performed between an organism heterozygous for two gene loci and an organism homozygous recessive for the same two gene loci, to determine whether the two gene loci are linked and further apart on the same chromosome, resulting in crossing over producing some recombinant offspring and the predicted ratio of 1 :few : few : 1, compared to when the two gene loci are not linked and are on different chromosomes, resulting in a predicted ratio of 1 : 1 : 1 : 1.
- Crosses involving linked genes usually produce a small proportion of offspring with new combinations of alleles (recombinants) in addition to the parental combinations. This can be explained by crossing over and recombination during meiosis.

Concept questions 7.5b

1 Explain what is meant when genes are described as linked genes or said to belong to a linkage group.

2 State the phenotypic ratios in a dihybrid test cross between an organism heterozygous for two gene loci and an organism homozygous for the same two gene loci, if the two loci are:
   a located on different chromosomes, unlinked genes
   b What differences in ratios would you expect between linked and unlinked genes?

3 Do genes on the same chromosome always stay linked together? If not, what can happen?

4 The genotype $\frac{vA}{vA}$ refers to characteristics as shown in Figure 7.37 (p. 294).
   a What is the phenotype for this genotype?
   b Are these gene loci found on different chromosomes? Explain.

5 Explain how recombinant offspring occur.

HOT Challenge

6 Figure 7.41 represents a replicated pair of homologous chromosomes, during meiosis. State the gametes that would result in relation to this chromosome if crossing over occurred at X.

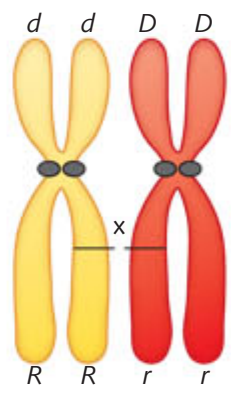
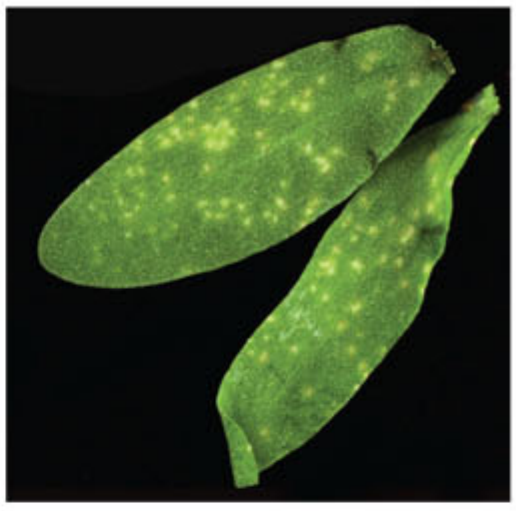


Figure 7.41 Homologous chromosomes during meiosis

BRANCHING OUT

The gene-for-gene concept

The gene-for-gene concept was first recognised and demonstrated by the American plant pathologist Harold Flor, who published his findings in 1971 in the *Annual Review of Phytopathology*. His studies focused on the commercially important flax plant *Linum usitatissimum* and a fungal rust pathogen that attacked the flax plant, called linseed rust or *Melampsora lini*. Figure 7.42 shows the effect that this rust pathogen has on the flax plant.



CSIRO scie

Figure 7.42 Flax plant leaf infected with linseed rust

Flor showed that the inheritance of both resistance to the rust pathogen in the host plant and the rust pathogen's ability to cause disease are controlled by pairs of matching genes, one pair in the flax plant and one pair in the rust pathogen. Each pair of genes follows the laws of Mendelian inheritance. The plant gene is called the resistance gene and is designated with the letter *R* (alleles *R* and *r*). The pathogen gene is the avirulence (lack of virulence) gene and is designated with the letter *A* (alleles *A* and *a*). Flax plants produce a specific receptor that is produced by the expression of the *R* allele. The rust fungus pathogen produces a specific protein that is produced by the expression of the *A* allele. Certain combinations of these alleles of these genes will produce either resistance to the disease or susceptibility to the disease as shown in Table 7.10.

Table 7.10 Patterns of disease susceptibility

		Pathogen genotype		
		AA	*Aa*	*aa*
Host genotype	*RR*	No disease	No disease	Disease
	Rr	No disease	No disease	Disease
	rr	Disease	Disease	Disease

R = produces receptor to protein

r = does not produce receptor to protein

A = produces protein product

a = does not produce protein product

Figure 7.43 shows the mechanism behind the inheritance. In Figure 7.43a, the pathogen genotype is *AA*, meaning that the pathogen is able to produce the protein. The host flax plant genotype is *RR*, meaning that the flax plant cell's produce a receptor to detect the pathogen protein. When the receptor of the flax plant recognises the protein of the pathogen, a defence reaction is triggered and the disease cannot progress. In Figure 7.41b, the pathogen genotype is *aa*, so no protein is produced. Therefore, even though the flax cell has a receptor, no binding occurs to trigger the defence mechanism, so the flax plant is infected by the rust fungus.

Questions

1 Construct a table to show all the genotype combinations possible for each of the flax cell/pathogen combinations shown in Figure 7.43 a–d. In each case, state whether the rust disease will progress in the flax plant and why.

2 If a flax plant that is homozygous recessive for resistance to the rust disease comes in contact with a rust pathogen that is heterozygous for the production of the protein, will the plant succumb to the rust disease? Provide an explanation for your answer.

3 Predict the proportion of offspring from a cross between two heterozygous flax parents that would be resistant to *Aa*-type pathogen.

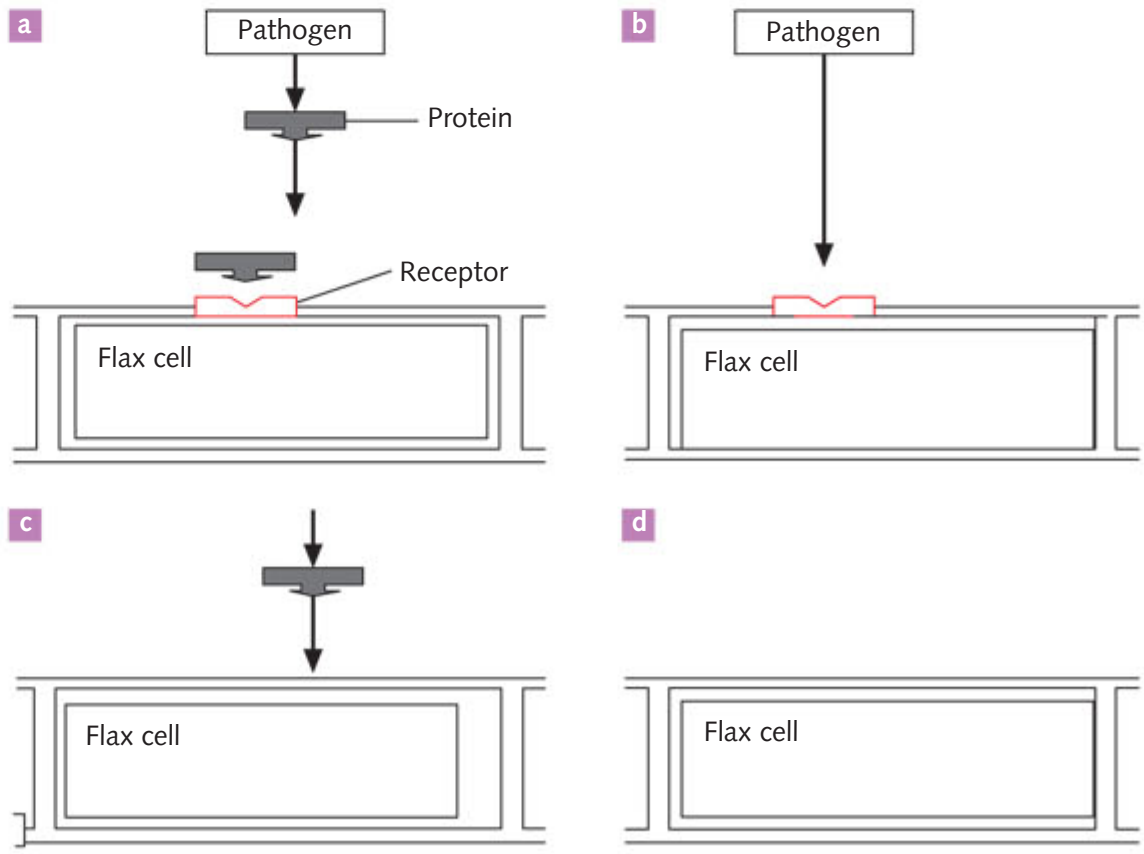


Figure 7.43 The different combinations (a–d) of protein and receptor possible in the host and pathogen

Online Key Concepts
Chapter 7 summary of key concepts

7 Summary of key concepts

7.1 Patterns of inheritance

KEY CONCEPTS

p. 261

- Gregor Mendel's study of peas established the principles of heredity.
- Crosses of pure breeding tall and short pea plants (P) produced offspring (F_1) which were all tall.
- Interbreeding the F_1 plants produced tall and short offspring (F_2) in the approximate ratio of 3 : 1.
- Punnett squares are a convenient way to represent crosses and predict the resulting genotypes and phenotypes and their proportions.
- Observed phenotypic ratios for any cross may vary from those predicted by a Punnett square. This is due to random assortment of alleles on chromosomes during meiosis and the fertilisation of random gametes.

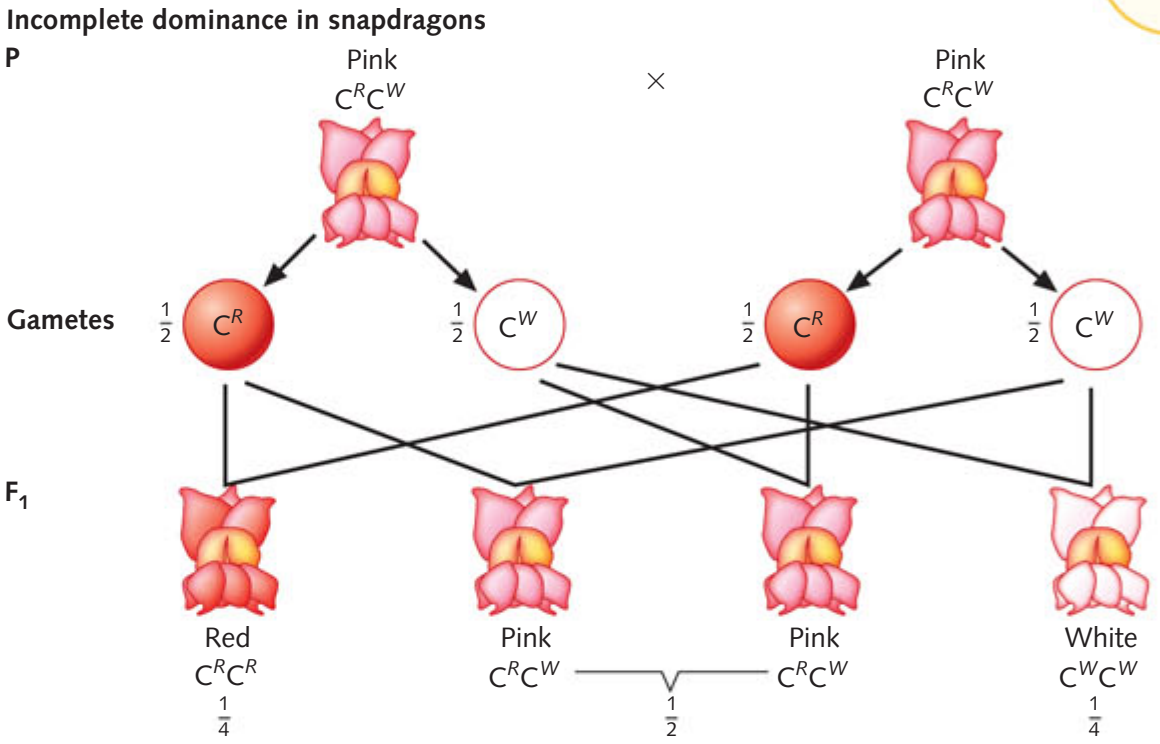


Figure 7.9 **Crossing snapdragons with pink flowers results in a predicted phenotypic ratio of approximately 1 red : 2 pink : 1 white.**

- Alleles are alternative or different forms of the same gene. Many genes have two alleles; some genes have more than two alleles. Alleles are found at a gene locus on a chromosome. In inheritance involving sexual reproduction, one allele is found on a chromosome that came from one parent gamete and the other allele is found on the homologous chromosome of the pair and came from the other parent gamete.
- The combination of alleles an organism has for a particular gene is its genotype. The two alleles may be identical (homozygous) or different (heterozygous).
- A trait is a characteristic of an organism; for example, eye colour.
- A dominant trait is expressed in both homozygous and heterozygous conditions.
- A recessive trait is expressed only in a homozygous condition.
- The way a genotype is expressed is termed its phenotype; for example, blue eyes.
- The combination of alleles inherited by an organism from its parents is one factor that determines its phenotype.
- Incomplete dominance or partial dominance refers to a situation when one allele does not mask the effect of the other allele completely and the heterozygous phenotype is intermediate or a blend between the homozygous parental phenotypes.
- When both alleles in a genotype are fully expressed in the phenotype of the heterozygote, such traits are said to be codominant.

7.2 Genetic material, environmental factors and epigenetic factors

KEY CONCEPTS

p. 269

- The phenotypic expression of genes can be influenced by environmental factors such as light, temperature and various chemicals.
- Epigenetic mechanisms such as DNA methylation and histone modification can also alter the phenotype by altering expression of the genes without changing the genetic sequence of the DNA.

Figure 7.12 The Himalayan rabbit is normally white with black hair only on its long ears, nose, tail and lower leg limbs.

7.3 Patterns of inheritance

KEY CONCEPTS

p. 271

- A monohybrid cross is a cross between individuals that have different pairs of alleles of one gene at a specific gene locus.
- A test cross can be used to determine the genotype of an individual displaying a dominant phenotype.
- A test cross involves breeding an organism exhibiting the dominant trait with an organisms displaying the recessive trait (homozygous recessive).
- Sex-linked genes are found on the sex chromosomes: X-linked genes are on the X chromosome and Y-linked genes are on the Y chromosome.
- Alleles carried on the X and Y chromosomes show different inheritance patterns for males and females.
- X-linked recessive phenotypes are more common in males and Y-linked phenotypes are only expressed in males.

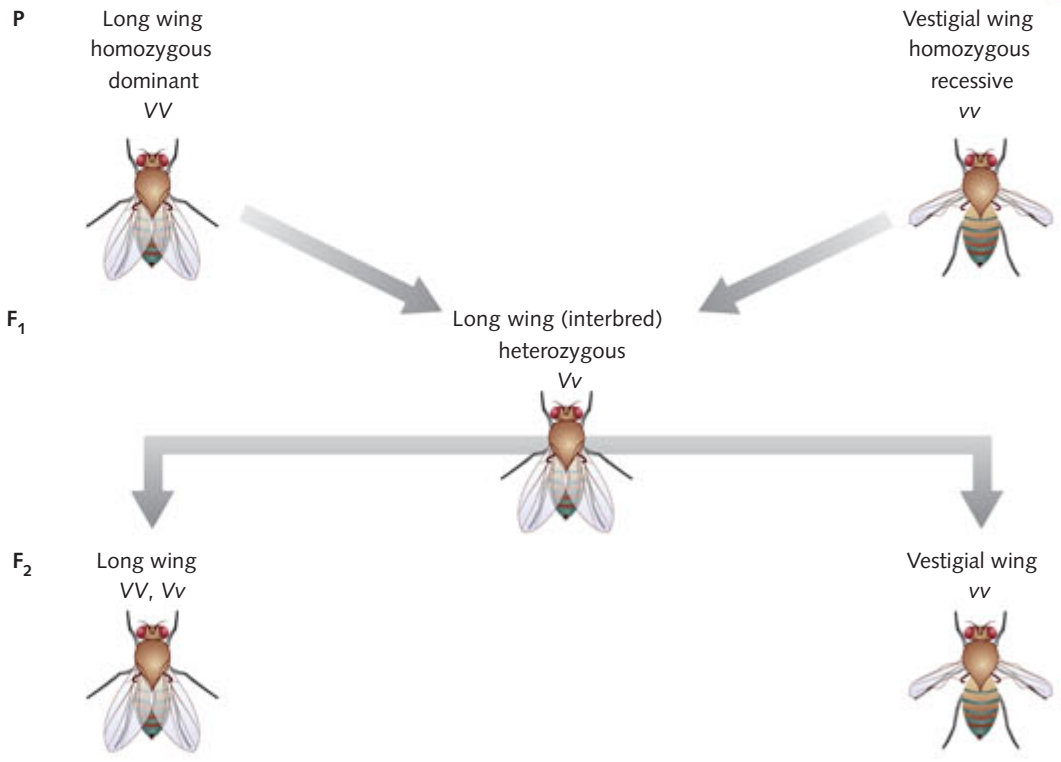


Figure 7.18 Summary of a monohybrid cross in fruit flies

7.4 Pedigree charts for autosomal and sex-linked inheritance

KEY CONCEPTS

p. 280

- Pedigree charts can be used to determine the pattern of inheritance of a particular trait in humans by studying the phenotypes of the parents and offspring over several generations.
- Autosomal recessive patterns of inheritance are shown if two unaffected parents produce male and female offspring that are affected.
- Autosomal dominant patterns of inheritance are shown if two affected parents produce male and female offspring that are not affected.
- Sex-linked inheritance is detectable by unequal phenotypic ratios between males and females.
- X-linked recessive phenotypes are more common in males than in females.
- X-linked dominant phenotypes show up in all affected females and males.
- Y-linked phenotypes are exclusively male.

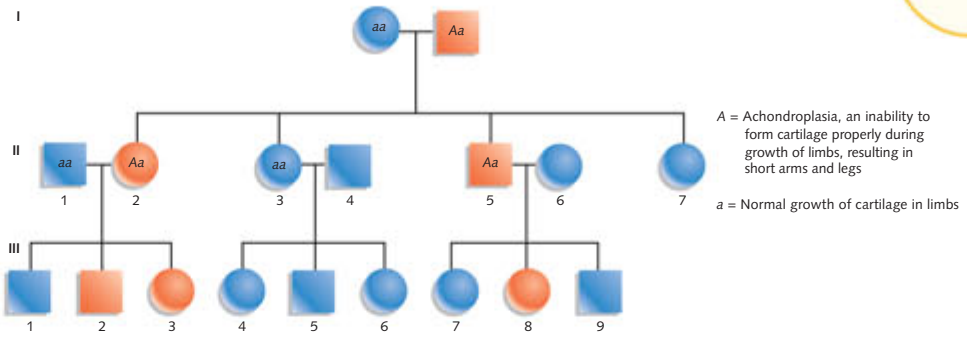


Figure 7.25 Pedigree showing individuals with achondroplasia, an autosomal dominant trait

7.5 Predicted genetic outcomes for two autosomal genes

KEY CONCEPTS

p. 285

- Inheritance for two unlinked autosomal genes can be studied with a dihybrid cross.
- In a dihybrid cross involving two unlinked genes, if one parent is homozygous dominant for both traits and the other is homozygous recessive for both traits, the F_1 offspring are heterozygous for both traits and express the dominant phenotypes. In a cross between the F_1 individuals, the F_2 offspring are predicted to show four combinations of phenotypes: dominant–dominant, dominant–recessive, recessive–dominant, recessive–recessive, in the ratio of 9:3:3:1
- In the inheritance of two unlinked genes, the two copies of genes segregate during the production of gametes so that offspring acquire one allele from each parent. Alleles of a gene separate independently from alleles of another gene. Hence, the inheritance pattern of one trait will not affect the inheritance pattern of the other.
- Genes linked on the same chromosome are inherited together and do not show independent assortment.
- A test cross can be performed between an organism heterozygous for two gene loci and an organism homozygous recessive for the same two gene loci, to determine whether the two gene loci are linked and further apart on the same chromosome, resulting in crossing over producing some recombinant offspring and the predicted ratio of 1 : few : few : 1, compared to when the two gene loci are not linked and are on different chromosomes, resulting in a predicted ratio of 1:1:1:1.
- Crosses involving linked genes usually produce a small proportion of offspring with new combinations of alleles (recombinants) in addition to the parental combinations. This can be explained by crossing over and recombination during meiosis.

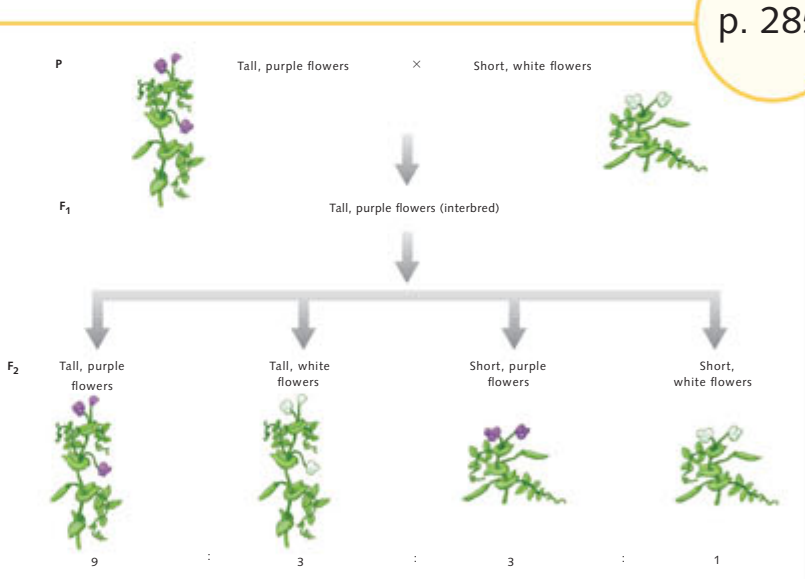


Figure 7.31 Summary of Mendel's dihybrid cross

7.6.1
KEY TERMS
PAGE 190

7 Chapter glossary

autosomal gene a gene located on an autosome or non-sex chromosomes

carrier a heterozygous organism carrying an allele for a recessive phenotype that may transmit the allele for the recessive phenotype to its offspring

codominant describes a phenotype in which both alleles in the genotype are fully expressed in the heterozygote

dihybrid cross a cross between two organisms for two different traits that involves two genes located at two different gene loci on the same or different chromosomes

dihybrid inheritance inheritance of two pairs of contrasting characteristics which involve the alleles of two different genes at two different gene loci

DNA methylation the attachment of a methyl group to nucleotides or histone proteins in the DNA molecule, thus altering the structure of the DNA molecule but not the DNA sequence

dominant describes a phenotype that requires only one copy of the allele for a dominant trait in an individual for it to be expressed

epigenetics the study of chemical modifications resulting in DNA structural changes that cause changes in the expression of genes but not changes in the DNA sequence

first filial generation (F_1) the first generation of offspring produced from a cross between two pure breeding parents (P) with different phenotypes for the same trait

genotype a specific combination of alleles for a locus belonging to an individual or cell

heterozygous a genotype with two different alleles for a single gene locus

homozygous a genotype with two identical alleles for a single gene locus

incomplete dominance the state in which a heterozygous individual has a phenotype that is intermediate or a blend between those of the corresponding homozygous individuals; also known as partial dominance

independent assortment when alleles of gene pairs redistribute independently into different combinations in gametes during meiosis

inheritance the genetic acquisition of characteristics by offspring from their parents

linkage group a segment of genes close together on the same chromosome that are inherited together

linked genes genes that are inherited together because they are located close together on the same chromosome

Mendelian genetics an explanation of patterns of inheritance based on the discoveries of Gregor Mendel and his statistical analysis and breeding experiments on pea plants

monohybrid cross a cross between two organisms for one trait involving the alleles of one gene located at one specific locus on a chromosome

parental generation (P) two organisms that represent the start of a breeding experiment; their offspring are the F_1 generation

partial dominance *see* incomplete dominance

pedigree analysis a way of finding out the pattern of inheritance of the alleles of a gene for a specific characteristic by following the inheritance pattern over several generations

pedigree chart a chart that uses accepted symbols and shows the inheritance of a particular trait over several generations

phenotype the characteristics expressed in an organism determined by their genotype and influenced by factors in their environment and epigenetic factors

Punnett square a grid used to graphically predict the outcome of a cross or breeding experiment

purebred refers to an organism that has identical alleles for a gene (homozygous) and produces offspring with the same phenotype as the parent over many generations (true breeding)

pure breeding describes a line of organisms that, when crossed with each other, always produce offspring with the same phenotype

recessive describes a phenotype that requires two copies of the allele of the gene for it to be expressed

recombinant gametes new combinations of genes in the gametes that are not found in either parent, resulting from crossing over between linked genes

recombinant offspring offspring with combinations of alleles that are not found in either parent and result from crossing over and recombination of segments of chromatids

second filial generation (F_2) offspring of the F_1 generation; the second generation produced from a cross between two homozygous parents (P)

sex-linked gene a gene located on either the X or the Y chromosome

sex-linked inheritance the inheritance pattern shown by a gene located on a sex chromosome

test cross a cross using an organism with a recessive phenotype to determine the genotype of an organism with a dominant phenotype or to determine if two gene loci are linked closely on the same chromosome or are present on different chromosomes

trait a heritable characteristic; phenotype

unlinked genes *see* independent assortment

X-linked related to a gene located on the X chromosome

Y-linked related to a gene located on the Y chromosome

WB
7.6.2
PRACTICE EXAM QUESTIONS
PAGE 192

7 Chapter review

Remembering

1 Describe the relationship between the following terms.
   a Gene and allele
   b Genotype and gene
   c Genotype and phenotype

2 Match each term in the first column with a description in the second column. Each item can only be used once.

Heterozygous	Two different alleles are both fully expressed in the phenotype.
Homozygous	The phenotype is intermediate between each of those determined by two different alleles.
Recessive	Two copies of the same allele are present for a particular gene locus.
Dominant	Only one copy of the gene is required for the phenotype to be expressed.
Codominant	Two different alleles are present for a particular gene locus.
Partially dominant	Two copies of the allele are required for the phenotype to be observed.

3 Explain why it is not possible to produce a pure breeding pink snapdragon.

4 Explain why genetic analysis of traits is much harder to carry out in humans than in organisms such as pea plants.

5 Define epigenetics and provide one example.

Understanding

6 Explain what pure breeding means. Why was it important for Gregor Mendel to use purebred plants in his experiments?

7 Explain how organisms with the same genotype can have different phenotypes, and how organisms with the same phenotypes can have different genotypes.

8 Distinguish between the effects on phenotype of random assortment of alleles of a gene and of linked genes. Explain what accounts for these differences.

9 Draw a diagram to show crossing over of genetic material between a pair of chromosomes. Label two pairs of genes on each chromosome, depicting the alleles as being heterozygous for each gene.

10 Consider two genes, *D* and *R*. A homozygous recessive male mates with a homozygous dominant female. What ratio would you expect in the F_2 if the *D* and *R* genes were:
   a unlinked
   b linked.

Applying

11 If you were carrying out breeding experiments with a group of organisms that are heterozygous for a particular gene that has one dominant and one recessive allele:
   a How many different phenotypes of offspring would there be? Identify them and give their expected ratios.
   b How many different genotypes of offspring would there be? Identify them and give their expected ratios.

12 Cystic fibrosis is inherited as an autosomal recessive trait, as shown in Figure 7.44.
- a Decide how many genotypes are possible for individual III 3, and identify them.
- b Identify whether individual II 4 is homozygous or heterozygous for this trait. Explain your answer.
- c Compare and comment on the genotypes for cystic fibrosis of individuals II2 and II3.

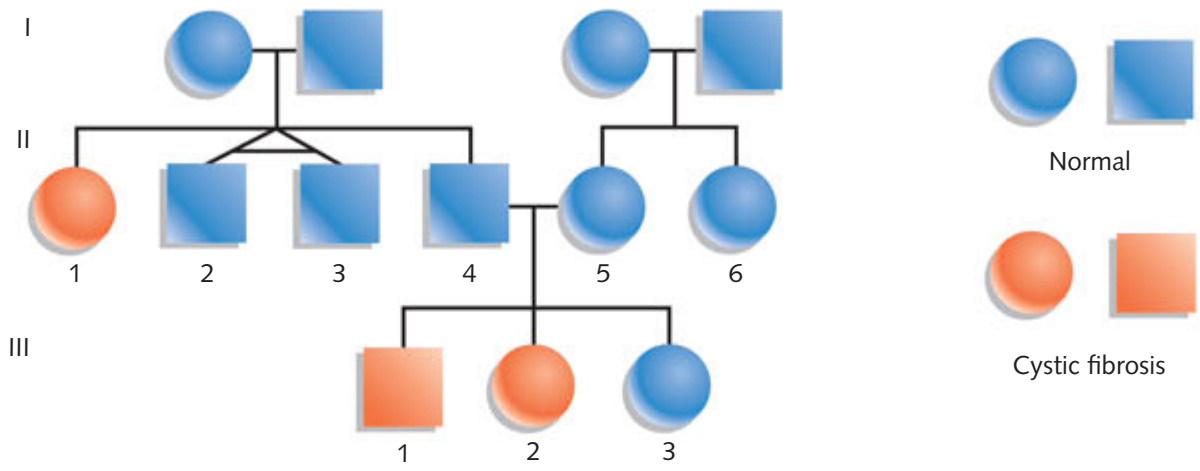


Figure 7.44 Pedigree of a family with cystic fibrosis

13 Describe and explain the occurrence of phenotypes that are:
- a X-linked recessive
- b X-linked dominant
- c Y-linked.

14 Xolo is a miniature breed of hairless dog. The hairless phenotype is dominant to hairy.
- a Assign the allele symbols for hairless and hairy and use a Punnett square to demonstrate the expected phenotypes for a litter of four pups born to two heterozygous Xolo parents.
- b If the same parents had a subsequent litter of nine pups, how many of these pups would you expect to be hairless?

15 Two purebred rabbits are mated: a doe (female) with grey fur and black eyes is mated with a buck (male) with white fur and red eyes. The litter contains only offspring with grey fur and black eyes.
- a Assign the alleles and show the genotypes of the P and F_1 individuals.
- b Draw a Punnett square to show a cross between individuals of the F_1 generation.
- c Predict the ratio of phenotypes with respect to fur and eye colour in the F_2 generation.

16 A breeder of guinea pigs needs to find out whether one of her brown guinea pigs is heterozygous or homozygous for hair colour. Albino (white) guinea pigs have the genotype *aa*. Guinea pigs that are not albinos have the genotype *AA* or *Aa*. How would she go about doing this?

17 Ichthyosis is the name given to a number of inherited conditions characterised by scaly skin. One form of the condition affects around 1 in 6000 males but female cases are almost unknown.
- a Suggest what might account for the differences in occurrence of this form of ichthyosis among males and females.
- b Name which parent an affected male would have inherited the condition from.
- c Predict the probability of the affected male passing the responsible gene on to his sons. Explain your reasoning.

18 A Himalayan rabbit is placed in a room which is kept at a constant 4°C.
- a What colour fur would you expect this rabbit to have after one week?
- b If the same rabbit was then transferred to another room that was kept constant at 30°C, what would you expect to happen to its fur colour?
- c Explain why this is happening to the fur colour of the rabbit.

19 Two grey rats are mated. Half the offspring are grey, one-quarter are white and one-quarter are black.
- a Assign the allele symbols for coat colour.
- b Describe the genotypes of the parents and the offspring.
- c Name the type of dominance shown.

20 In mice, coat colour is determined by an autosomal gene, and pink coat colour is dominant to brown. Dwarfism is caused by an X-linked recessive allele. If a brown female dwarf mouse mates with a pure breeding pink male of normal size, predict the phenotypic ratios in each gender in the F_1 and F_2 generations.

21 In cherry tomatoes, a tall vine is dominant to a dwarf vine, round-shaped fruit is dominant to pear-shaped fruit. If you crossed a pure breeding tall, round-fruited plant with a short plant with pear-shaped fruit, predict what you would expect to be the appearance of the F_1 generation. Assuming that the genes controlling these two characteristics are inherited independently, predict the possible combinations of genes in the gametes of the F_1 generation.

22 A particular gene in cats is crucial for normal development. An allele of this gene – Manx (*M*) – causes the spine of cats to develop abnormally. In the homozygous form (*MM*), cats die when they are still embryos. In the heterozygous form (*Mm*), cats are born with no tails. Suppose that two *Mm* cats mate.

- a Predict the probability of their kittens having tails.
- b Predict the probability of their kittens lacking a tail.
- c Explain how lethal alleles can remain in a population.

23 Explain why test crosses are important to commercial breeders.

Analysing

24 The snapdragon (*Antirrhinummajus*) can show a condition called 'aurea' in which the leaves appear a golden colour instead of green. A pair of aurea snapdragons with golden leaves was crossed and they produced 101 offspring, 67 with golden leaves and 34 with green leaves. Draw a Punnett square for the cross and use the data to explain how the ratio among F_2 offspring could have arisen.

25 A test cross of fruit flies with curly wings and red eyes produces offspring with red eyes, half of which have curly wings, half straight wings. Identify the genotype of the original red-eyed fruit fly with curly wings, and provide evidence to support your conclusion.

26 A male purebred fruit fly with a brown body is crossed with a female purebred fruit fly with a yellow body. All the male offspring have yellow bodies, while all the female offspring have brown bodies.

- a Explain where the gene is located.
- b Predict the proportions of the phenotypes in the offspring produced by crossing the F_1 fruit flies.

Evaluating

27 Discuss the benefits and limitations of studying Mendelian inheritance patterns in humans.

28 Explain why each of the following statements is false.

- a Offspring resulting from self-fertilisation are genetically identical.
- b In a monohybrid cross $Bb \times Bb$, there is a 25% chance of a child being *bb*. If the first child is *bb*, there is less of a chance that the second child will be *bb*.

Creating

29 Draw four different pedigrees showing examples in which the only possible mode of inheritance can be:

- a autosomal dominant inheritance
- b autosomal recessive inheritance
- c sex-linked dominant inheritance
- d sex-linked recessive inheritance.

Unit 2 Area of Study 1 review

Multiple choice

Question 1 ©VCAA 2005 E2 Q2 ADAPTED MEDIUM

The diploid number in a male red kangaroo is 16. It is reasonable to conclude that, in the red kangaroo:

A a nerve cell will contain 8 chromosomes.
B at the end of meiosis there will be 8 chromosomes per cell.
C during mitosis the chromosome number will halve.
D a zygote will have 8 chromosomes.

Questions 2 and 3 refer to this information.

Two genes and their alleles in tomatoes are shown below.

Plant height	*D* tall	Fruit shape	*P* spherical
	d dwarf		*p* pear-shaped

Question 2 ©VCAA 2005 E2 Q10 ADAPTED HARD

The genes for plant height and fruit shape are linked. This means that:

A the genes assort independently.
B the genes are close together on the same chromosome.
C the alleles are incompletely dominant.
D the traits show continuous variation.

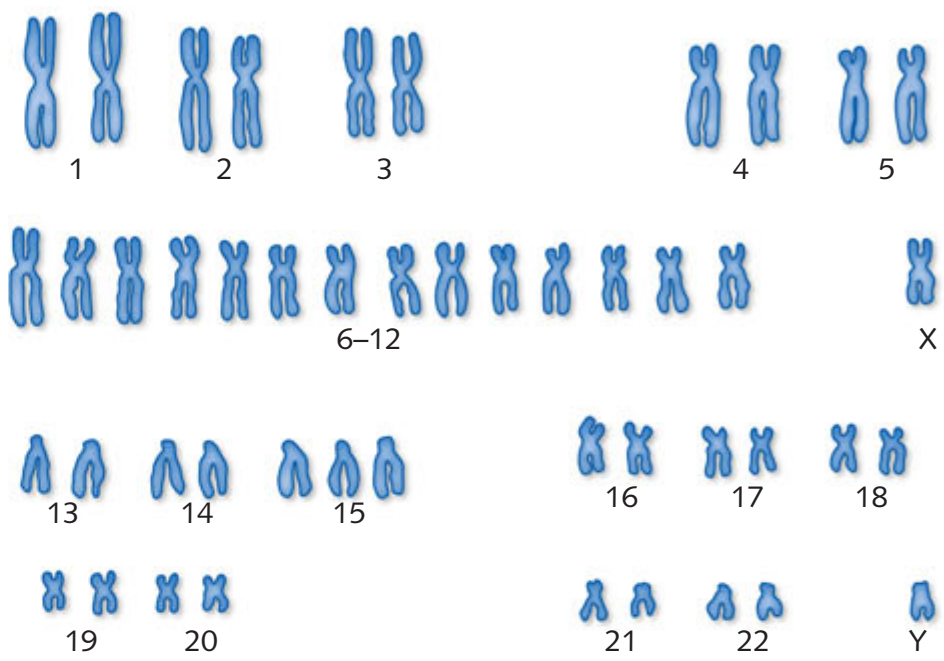
Question 3 ©VCAA 2005 E2 A Q11 ADAPTED HARD

A test cross was carried out on a tall plant with spherical fruit. What is the genotype of the plant it was crossed with?

A $\frac{DP}{dp}$
B $\frac{dp}{dp}$
C $\frac{dd}{pp}$
D $\frac{Dp}{Dp}$

Question 4 ©VCAA 2010 E2 Q10 ADAPTED MEDIUM

The following karyotype is from a human.



The number of autosomes shown in the karyotype is:

A 22
B 44
C 23
D 45

Question 5 The ABO blood group has four possible phenotypes: A, B, AB and O. The AB phenotype is a heterozygote, in which an allele for the A antigen and an allele for the B antigen are fully expressed. This is an example of:

A codominance.
B incomplete dominance.
C polygenic inheritance.
D continuous inheritance.

Question 6 ©VCAA 2009 E2 Q5 ADAPTED HARD

The gene locus in cats that controls tabby coat patterns has three alternative alleles. This results in how many possible genotypes?

A 3
B 4
C 5
D 6

Question 7 ©VCAA 2003 E1 Q22 ADAPTED MEDIUM

Cuttings were taken from a hydrangea plant and grown. Some plants had pink flowers and some had blue flowers. It would be reasonable to conclude that:

A the difference in flower colours was due to environmental factors.
B this is an example of incomplete dominance.
C this is an example of codominance.
D the genes for blue flowers and pink flowers are linked.

Question 8 ©VCAA 2013 Q23 ADAPTED MEDIUM

Cystic fibrosis is an autosomal recessive trait that affects many parts of the body, particularly the lungs and other organs.

Parents who show none of the characteristics of cystic fibrosis have an affected child. The chance that their next child will also be affected is:

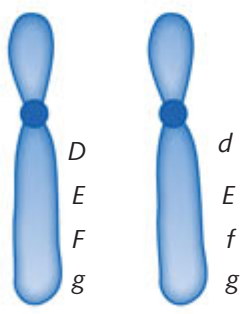
A three in four.
B one in four.
C one in two.
D zero.

Question 9 During gamete formation, homologous chromosomes pair and then separate. This process is known as independent assortment. It results in:

A new alleles being formed.
B gametes with new combinations of parental chromosomes being formed.
C gametes with different numbers of chromosomes being formed.
D chromosomes breaking and exchanging material with other chromosomes.

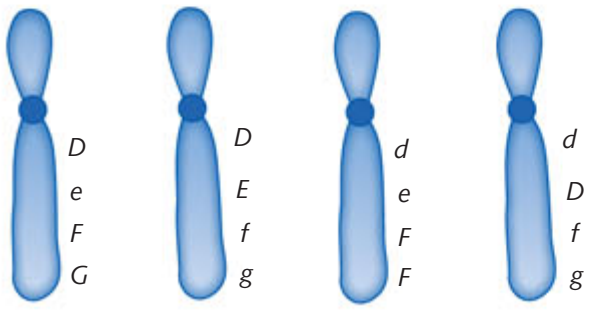
Question 10 ©VCAA 2009 E2 Q4 ADAPTED EASY

A pair of homologous chromosomes involved in normal meiosis in an ovary carries the alleles shown.



Chromosomes detected in eggs produced would include:

A B C D



Question 11 The hair colour of Australian shepherd dogs is under genetic control. The colour of the hair found inside the ears, on the legs and under the tail is under the control of a gene that has the following alleles.

A^W white
a^S sable colour

White is dominant to sable. White and sable phenotype would be produced in equal numbers in a cross of:

A a homozygous white dog and a sable dog.
B two sable dogs.
C heterozygous white dog and a sable dog.
D two heterozygous white dogs.

Question 12 ©VCAA 2006 E2 SEC. B Q1 ADAPTED

A plant has two phenotypes: blue flowers or yellow flowers. A flower supplier wants to determine which colour is the dominant phenotype and performed the following crosses:

Cross	Parents	Offspring
1	Yellow × Yellow	All yellow
2	Blue × Blue	All blue
3	Yellow × Blue	$\frac{1}{2}$ yellow and $\frac{1}{2}$ blue
4	Blue × Blue	$\frac{1}{4}$ yellow and $\frac{3}{4}$ blue

Which cross on its own allows you to conclude which is the dominant phenotype?

A 1
B 2
C 3
D 4

Question 13 The human genome is:

A the genes and non-coding DNA in a cell.
B all the genes in a set of chromosomes.
C comprised mostly of coding DNA.
D the same as the genome of a fruit fly.

Question 14 An individual who has Down syndrome will have a karyotype that shows three number 21 chromosomes instead of the usual two. This syndrome is due to:

A non-disjunction of homologous pairs at anaphase II.
B non-disjunction of chromatids at anaphase I.
C non-disjunction of chromatids at anaphase II.
D DNA replicating between meiosis I and meiosis II.

Question 15 ©VCAA 2004 E2 Q3 ADAPTED **HARD**

Two genes in watermelons have the alternate alleles shown below.

Gene 1	*S* spots	Gene 2	*B* bitter fruit
	s solid colour		*b* sweet fruit

The two genes assort independently.

Two plants, both heterozygous at each gene locus, were crossed and 1600 seeds were collected. When plants were grown from these seeds, it would be reasonable to expect that about:

A 1600 of the plants produced spotted, bitter fruit.
B 900 of the plants produced solid-coloured bitter fruit.
C 300 of the plants produced solid-coloured sweet fruit.
D 300 of the plants produced spotted, sweet fruit.

Question 16 Homologous chromosomes carry:

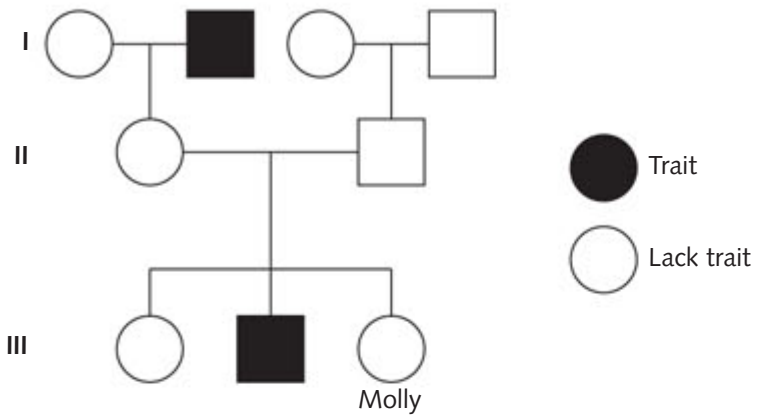
A the same alleles of the same gene at the same gene loci.
B the same alleles.
C the same genes at the same gene loci.
D only two genes.

Short answer

Question 1

©VCAA 2010 E2 SEC. B Q1 ADAPTED

Consider the following pedigree.



a What is the mode of inheritance of the trait?

(1 mark)

b What is the chance that Molly is heterozygous for the trait? Show your working out, including the genotype of Molly's parents.

(3 marks)

c What term do we use to describe Molly's mother in relation to this trait?

(1 mark)

Question 2

©VCAA 2011 E2 SEC. B Q2 ADAPTED

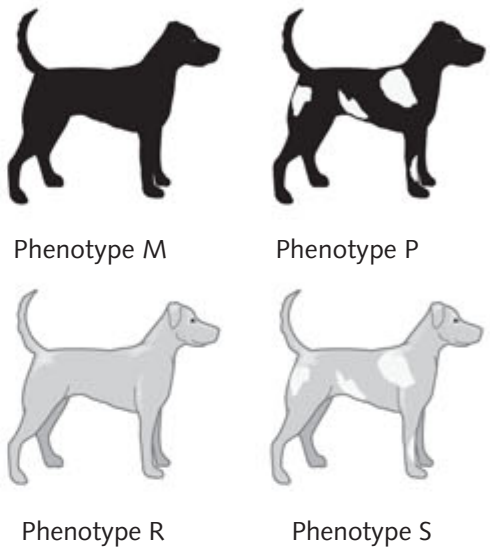
©VCAA 2009 E2 SEC. B Q2 ADAPTED

In dogs, two gene loci have the following alleles.

Gene 1 *B* black coat colour *b* grey coat colour

Gene 2 *T* no white on coat *t* white areas on coat

Two dogs, dog F and dog G, were mated. The litter of four pups that resulted had the following phenotypes.



a Explain whether all pups with phenotype R would have the same genotype.

(2 marks)

It has been suggested that dog M is heterozygous at both loci.

b What cross would you carry out to support this statement? Show the results of this cross that support the claim.

(2 marks)

c Could the results of your cross enable you to decide if the genes were on the same or different chromosomes?

(2 marks)

d A litter usually has only six pups. Therefore, would you be confident in making a prediction that the genes were linked or not based on one litter?

(2 marks)

Reproductive strategies

8

By the end of this chapter you will have covered the following material.

Key knowledge

Reproductive strategies

» biological advantages and disadvantages of asexual reproduction pp. 313–320

» biological advantages of sexual reproduction in terms of genetic diversity of offspring pp. 320–323

» the process and application of reproductive cloning technologies pp. 323–328

Key science skills

Plan and conduct investigations

» work independently and collaboratively as appropriate and within identified research constraints, adapting or extending processes as required and recording such modifications pp. 315–316

Comply with safety and ethical guidelines

» demonstrate safe laboratory practices when planning and conducting investigations by using risk assessments that are informed by safety data sheets (SDS), and accounting for risks pp. 315–316

» apply relevant occupational health and safety guidelines while undertaking practical investigations pp. 315–316

» demonstrate ethical conduct when undertaking and reporting investigations pp. 315–316

Generate, collate and record data

» systematically generate and record primary data, and collate secondary data, appropriate to the investigation, including use of databases and reputable online data sources pp. 315–316

» record and summarise both qualitative and quantitative data, including use of a logbook as an authentication of generated or collated data pp. 315–316

» organise and present data in useful and meaningful ways, including schematic diagrams, flow charts, tables, bar charts and line graphs pp. 315–316

Analyse, evaluate and communicate scientific ideas

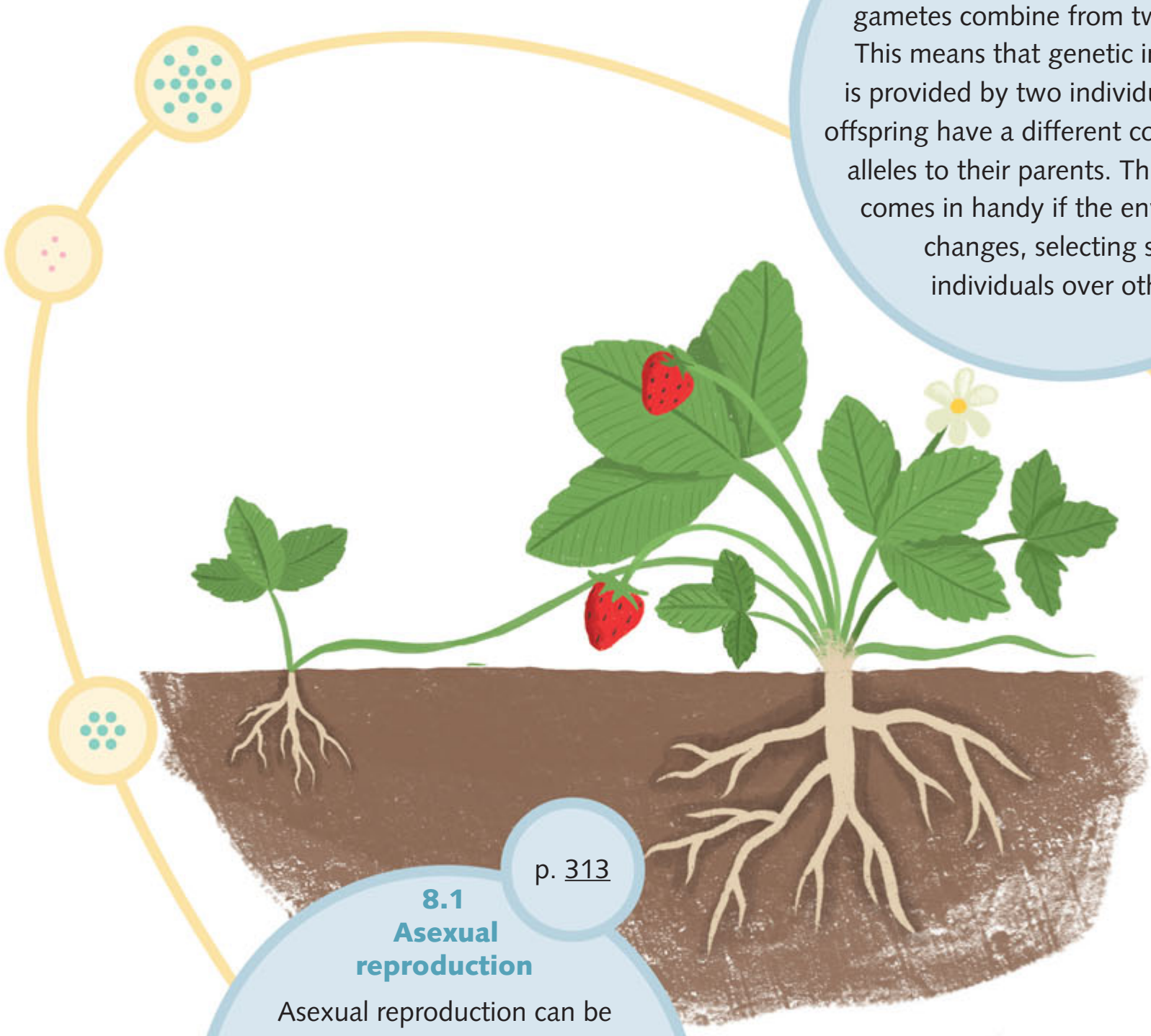
» use appropriate biological terminology, representations and conventions, including standard abbreviations, graphing conventions and units of measurement pp. 315–316

» discuss relevant biological information, ideas, concepts, theories and models and the connections between them pp. 315–316

Online Chapter Map
Chapter 8 map

8 Reproductive strategies

Different organisms have different ways that they produce the next generation. Some of these ways are good for the continuation of the species, other ways are not so good. It all depends on where you live!



8.2 Sexual reproduction p. 320

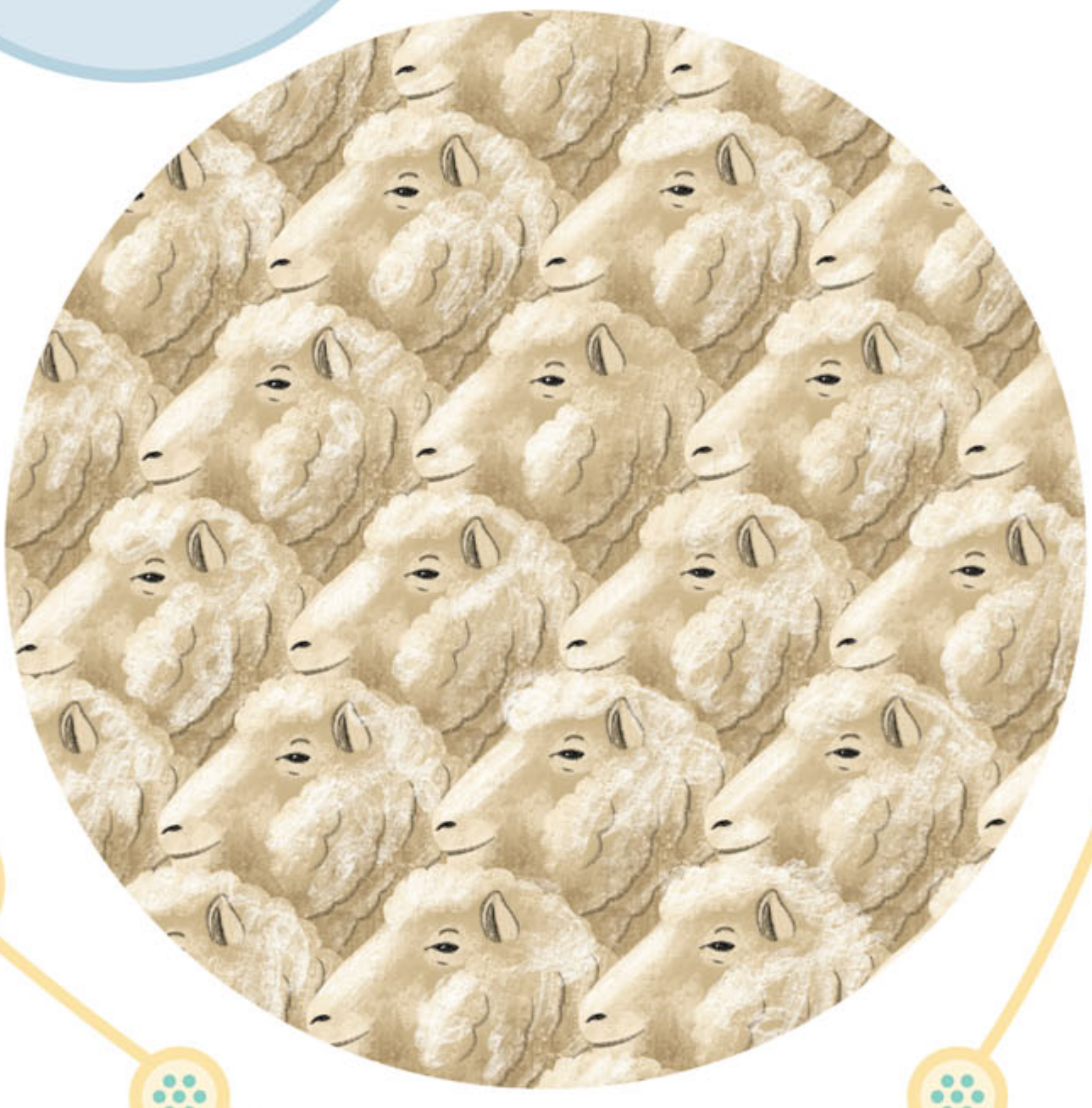
Sexual reproduction is when gametes combine from two parents. This means that genetic information is provided by two individuals and the offspring have a different combination of alleles to their parents. This variability comes in handy if the environment changes, selecting some individuals over others.

8.1 Asexual reproduction p. 313

Asexual reproduction can be as easy as one cell splitting into two cells, or more complicated, involving mitosis in eukaryotic cells. The offspring are always genetically identical to their parent. This is not a problem, so long as the environment does not change.

8.3 Cloning p. 323

Cloning is making an exact genetic replica of one organism. Nature has been doing this for ages, but only now have humans worked it out. Splitting an embryo in two or transferring the nucleus of a cell from one animal into the egg cell of another are cloning processes. Lots of bioethics here!



Asexual reproduction, like cloning, produces exact genetic copies of organisms, which suits stable environments. Sexual reproduction mixes up the DNA from different parents to produce offspring that are different from each parent and from each other. This variability in genetic makeup is advantageous in a changing environment.

To access resources below, visit www.nelsonnet.com.au

Online Chapter Map:
- Chapter 8 map (p. 310)

Online Key Terms:
- Chapter 8 flashcards (p. 312)

Weblinks:
- Advantages and disadvantages of asexual and sexual reproduction (p. 322)
- Reproductive cloning technology (p. 325)

Online Worksheets:
- Advantages and disadvantages of asexual and sexual reproduction (p. 322)
- Reproductive cloning technology (p. 325)

Online Key Concepts:
- Chapter 8 summary of key concepts (p. 330)

Know your key terms

Online Key Terms
Chapter 8 Flashcards

asexual reproduction
biodiversity
budding
clone
cloning
fragmentation
grafting
monoculture
parthenogenesis
spore
vegetative propagation

Remember

This chapter will build on the following concepts that you will have already met. Take the time to refresh these concepts before you start this chapter.

WB REMEMBER PAGE 196

1 Mitosis is the orderly division of the nucleus in eukaryotic cells to produce two identical nuclei.
2 Meiosis is the orderly division of the nucleus in eukaryotic cells to produce daughter nuclei containing half the number of chromosomes of the parent nuclei.
3 Haploid refers to one set of chromosomes in a cell such as in a gamete; diploid refers to two sets of chromosomes in a cell such as in a zygote.
4 Fertilisation occurs when two haploid gametes join to make a diploid zygote.

There are many tourist destinations in Victoria. The Yarra Valley in the outer east of Melbourne is particularly attractive to tourists interested in fine food and wine. If you drive through the area, you will find roadside stalls selling different fruits and berries, including locally grown strawberries (Figure 8.1).

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Figure 8.1 Strawberry fields in the Yarra Valley area of Victoria

If you were to grow strawberries in your garden, you would observe 'runners' coming from the plants. These are offshoots of the parent plant. At intervals along the runner, nodes appear. From each node, a daughter plant or 'plantlet' can develop, complete with roots and leaves. Each of these plantlets forms a new individual plant with the same genetic make-up as all the others. In this way, one strawberry plant can cover a large area with genetically identical offspring.

The strawberry plant also produces flowers that are pollinated by insects. Strawberries will only develop when the flowers are pollinated. These strawberries contain seeds that are all genetically different from the parent plants. These seeds are then dispersed by animals that eat the strawberries.

Strawberry plants are unusual in that they reproduce both asexually (producing offspring with the same DNA as their parents) in the plantlets that form from runners, and sexually (combining DNA from two different parents) in plants that arise from the seeds of strawberries.

8.1 Asexual reproduction

When strawberry plants send out runners, new cells are produced by the process of mitosis. Mitosis ensures that the two cells formed have exactly the same DNA as the dividing parent cell. Reproduction by mitosis can also be described as **asexual reproduction**. Organisms produced by asexual reproduction are exactly the same genetically as their parent.

Asexual reproduction occurs in both prokaryotic and eukaryotic organisms, both unicellular and multicellular. All cells produced by asexual reproduction are genetically identical to the cell or cells of the parent.

Asexual reproduction can occur by a number of different methods:

» fission
» budding
» vegetative reproduction
» spore formation
» fragmentation
» parthenogenesis.

Fission

CONNECT

Further details about mitosis and binary fission are provided in Chapter 2.

Amoebae are single-celled eukaryotic organisms (they possess a nucleus and other membrane-bound organelles). These organisms reproduce by fission, which includes the division of a parent nucleus by mitosis and then division of the cytoplasm to produce two new daughter cells. Figure 8.2 shows the process in action in an amoeba.

The rate of multiplication by fission can be extraordinary. For example, under suitable environmental conditions, cells can divide every 20 minutes. This means that in a 24-hour period a single cell can lead to a population in excess of 4^{21} (or 4 billion trillion) cells. This number of cells is achievable because the increase in cell division is exponential. For example, from one amoeba dividing every 20 minutes, eight amoeba will be present at the end of the first hour, 512 amoeba will be present after 3 hours, and by the end of the day the number of amoeba produced is almost overwhelming. This does not actually happen because there are other population controls on amoebae such as space, food and build-up of toxic wastes.

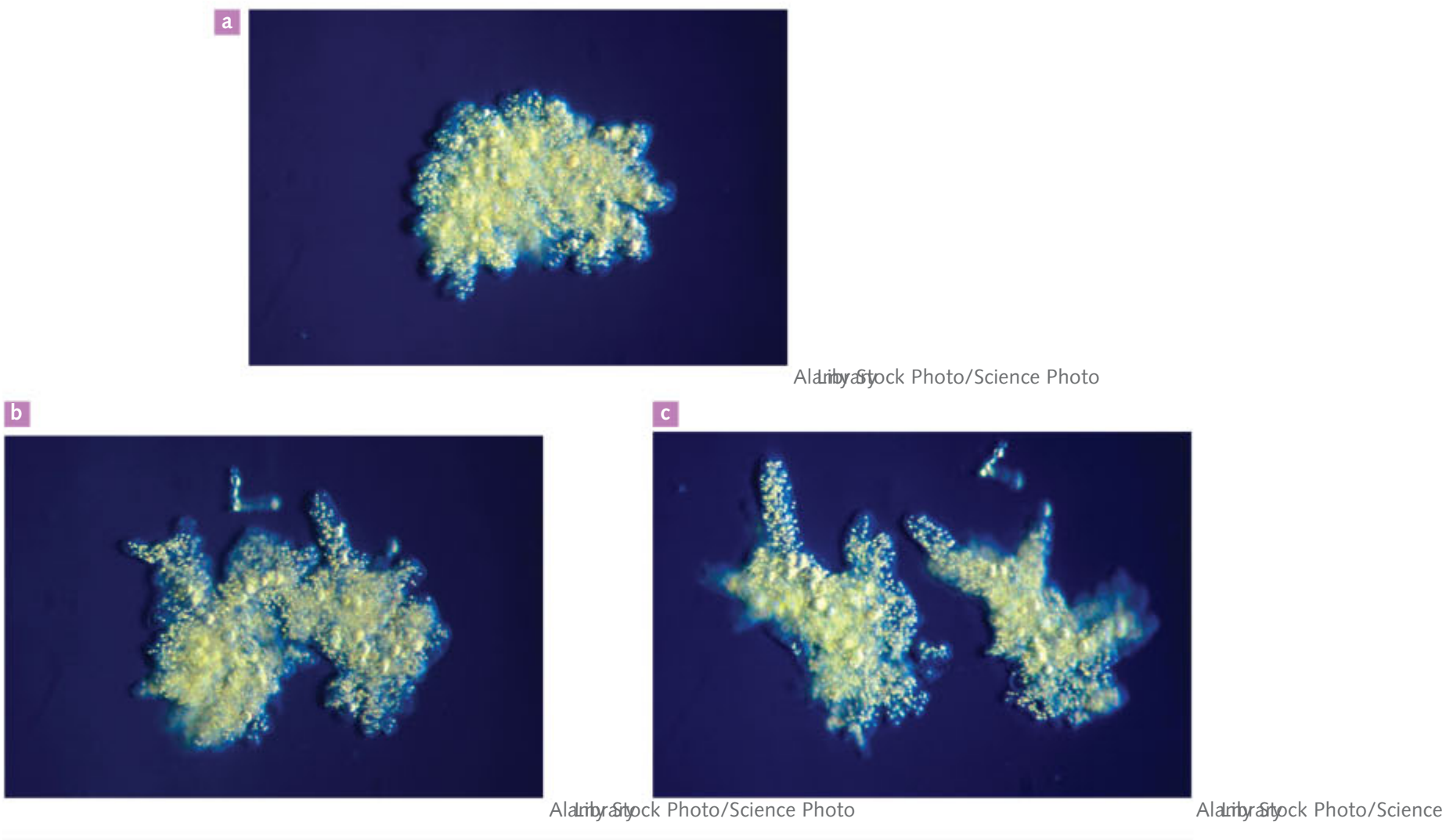

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Figure 8.2a The parent amoeba **b** Cell division begins. **c** Two new daughter cells

Budding

Hydra is a multicellular animal in the phylum Cnidaria and Class Hydrazoa. It is found in freshwater environments, which are sometimes turbulent. Occasionally, the *Hydra* may experience injuries that seemingly amputate parts of its body. *Hydra* have the unusual ability to regenerate parts of their body and give rise to a complete organism. The process *Hydra* undergoes is one of **budding**, which involves the development of a new organism or parts of an organism from an outgrowth of the parent organism (Figure 8.3a). The new organism may detach from the parent and grow to adult size. If the new individual remains attached to the parent, a branching colony is formed. This form of reproduction also occurs in yeast cells (Figure 8.3b), some flatworms and several of the annelid (worm) groups.

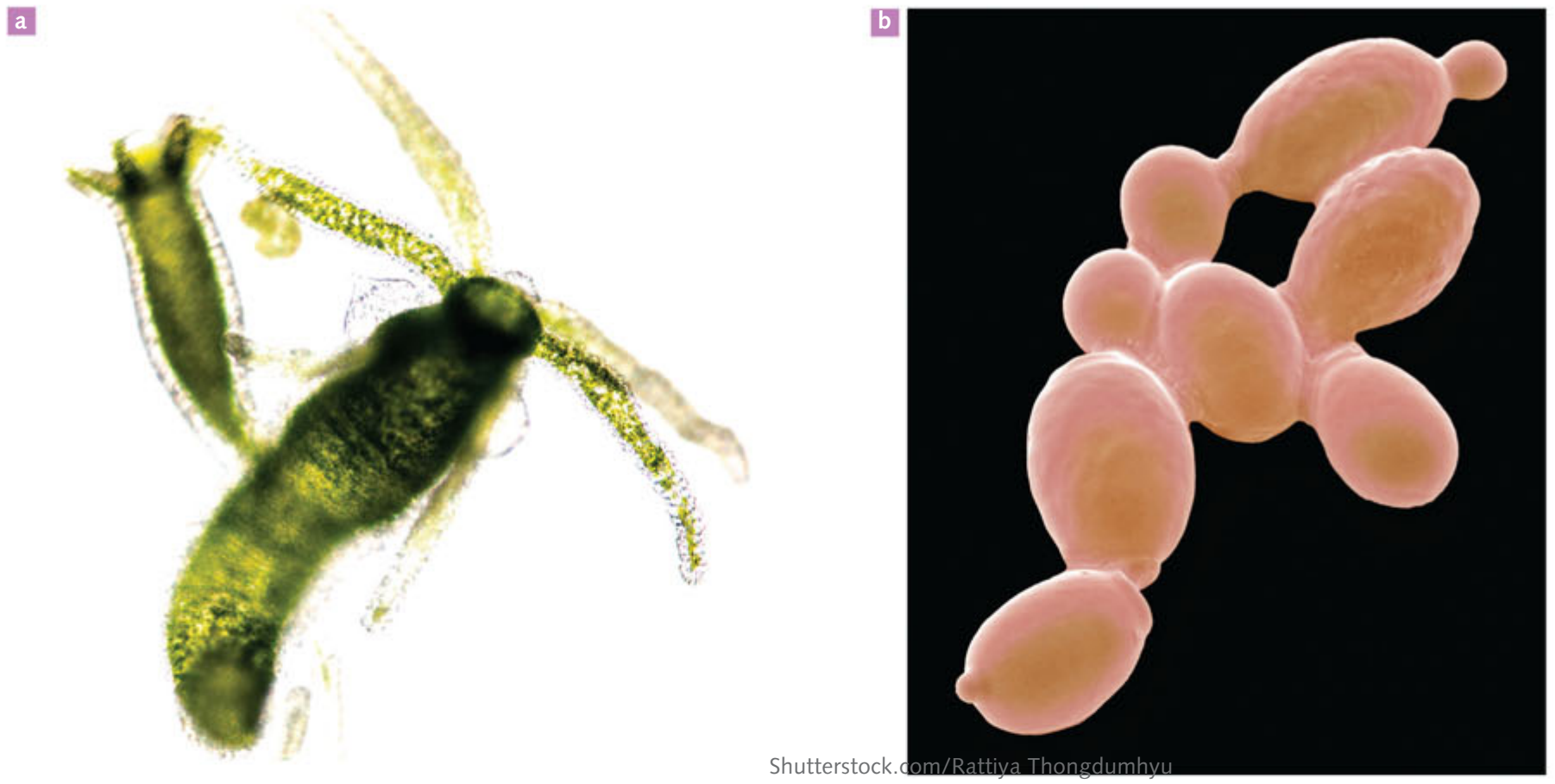

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Figure 8.3a In *Hydra,* a new individual forms from the outgrowths of the parent by producing a bud that branches from the side of the body. **b** Budding in yeast, where new individuals remain attached to the parent body

SOUTHERN Biological Stress tested by Southern Biological

INVESTIGATION 8.1

Asexual reproduction in *Hydra*

The name *Hydra* commonly refers to cnidarians (jellyfish) in the class Hydrazoa. They are small, multicellular, freshwater animals, usually less than a centimetre long. They have a hollow, cylindrical body with a mouth surrounded by six to ten tentacles. They move either by gliding like a snail, or by somersaulting slowly. Hydra can reproduce sexually or asexually, depending on environmental conditions.

Yeast (*Saccharomyces cerevisiae*) is a single-celled member of the kingdom Fungi and reproduces asexually by budding. Yeast has long been used to ferment the sugars of rice, wheat, barley and corn, in producing alcoholic beverages, and in the baking industry to expand, or raise, dough.

Aim

To observe asexual reproduction in *Hydra* and yeast

Materials

Each student will require:

- *Hydra*
- Half a teaspoon of fresh yeast mixed in 100 mL of warm water with a teaspoon of molasses (let stand for 15 minutes)
- Pasteur pipettes or eye droppers
- Microscope
- Microscope slides
- Coverslips

What are the risks in doing this investigation?	How can you manage these risks to stay safe?
If you drop the microscope it could damage yourself or the lenses.	Carry the microscope with both hands.
A glass slide could break and cut you.	Clean up any broken glass using protective gloves and put glass into a safety container.

Method

Hydra

1 Use a pipette to capture a *Hydra*. Sometimes they stick to the walls of the container. Use the pipette to gently prise one off.
2 Lay out four microscope slides. Place a few drops at each end of each slide until the *Hydra* comes out of the pipette. Do not place a coverslip on top.
3 Choose the slide with the *Hydra* on it and observe under low power. You may find another *Hydra* growing on the parent like a branch on a tree, or that the *Hydra* changes shape.
4 If you need to add water for some reason, use only the water that the *Hydra* came in, as water from the tap may be chemically too different for them to survive.
5 Make a labelled drawing in your logbook that includes tentacles, mouth and bud.

Yeast

6 Draw up some yeast solution using a clean pipette.
7 Place it on a clean microscope slide and place a coverslip on top.
8 Observe under low power and then high power of the microscope.
9 Locate some yeast cells that are budding and draw them in your logbook.

Discussion

1 Explain the advantages for *Hydra* of reproducing asexually.
2 Explain the advantages for *Hydra* of reproducing sexually.
3 Suggest the genetic make-up of the bud compared to its parent and explain why you made this suggestion.
4 When a *Hydra* is cut into pieces, each piece can grow into a complete individual. Describe how the genetic composition of such *Hydra* compare to the original reproducing organism.
5 Describe how budding in yeast is different from that in *Hydra*. Describe how it is similar.

Taking it further

1 Use a time-lapse camera to capture the process of budding in both *Hydra* and yeast.
2 Some chemicals can make the stinging cells of *Hydra* fire off. Find out what chemicals can do this and examine the stinging cells under high magnification.
3 Make a list of other organisms that reproduce in a similar way to yeast and *Hydra.*
4 Plan and carry out an experiment to determine the best conditions for yeast reproduction. Try varying the amounts of yeast, molasses, temperature or time. Suggest why varying each of these factors alters the rate of reproduction in yeast.

Vegetative propagation

WB
8.1.1 VEGETATIVE PROPAGATION PAGE 197

You may have tried cutting the top off a carrot or pineapple and putting it in a saucer of water. You will find that after a few days roots begin to appear. Have you ever tried putting a piece of a garden plant into soil so a new plant will grow?

The new plants produced are genetically identical to the parent plant – they are **clones** of the parent plant. This is a form of asexual reproduction known as **vegetative propagation** and is seen only in

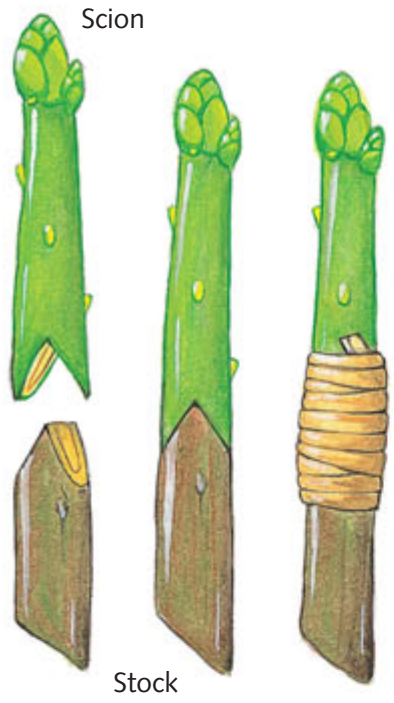

Figure 8.4 Grafting techniques are used by growers to reproduce desirable qualities in their plants.

Alamy Stock Photo/ Kevin Ebi

Figure 8.5 New plants arise from the upper side of the old leaves of the piggyback plant, a member of the saxifrage family, a perennial herbaceous plant native to North America.

plants. Vegetative propagation involves part of a plant body becoming detached and developing into a new individual.

Vegetative propagation can be performed artificially, and one technique is known as **grafting** (Figure 8.4). With this method, a piece of stem of one plant is attached to the stem and roots of another. The actively dividing tissues of the different plants join at the graft site and unite, giving rise to normal vascular tissue. The plant to which the part of another plant is attached in grafting is called the stock and the piece of stem that is attached to it is the scion. Grafting as a method of propagation is commercially important to growers of fruit trees and roses because it enables the reliable production of plants with desirable qualities as well as strong roots.

The runners produced in strawberry plants are another example of vegetative propagation. This form of reproduction is also seen in the piggyback plant (*Tolmiea menziesii*), from the saxifrage family. Figure 8.5 shows this happening.

Spore formation

In desert conditions, survival and reproduction of plants is often difficult and reproduction opportunities are confined to a short period of time. Some plants conserve energy and water by producing **spores** – hardy, self-contained capsules that contain the DNA instructions required to produce a new plant when conditions are suitable.

Spores are single-celled structures formed by cell division in a parent organism. Spores detach from the parent organism and develop into new individuals. Prokaryotes, protists, fungi and many plants, such as ferns and club mosses, can produce spores. Spores are generally mass-produced, small and light, and are easily dispersed by wind, water or animals. Each spore may be surrounded by a thick, resistant wall, which helps it survive dormant for long periods of unfavourable environmental conditions such as drought and extremes of temperature. Spores found in the tombs of the Egyptian pharaohs have germinated to grow into new plants. Figure 8.6 shows the spores from Lycopodium.

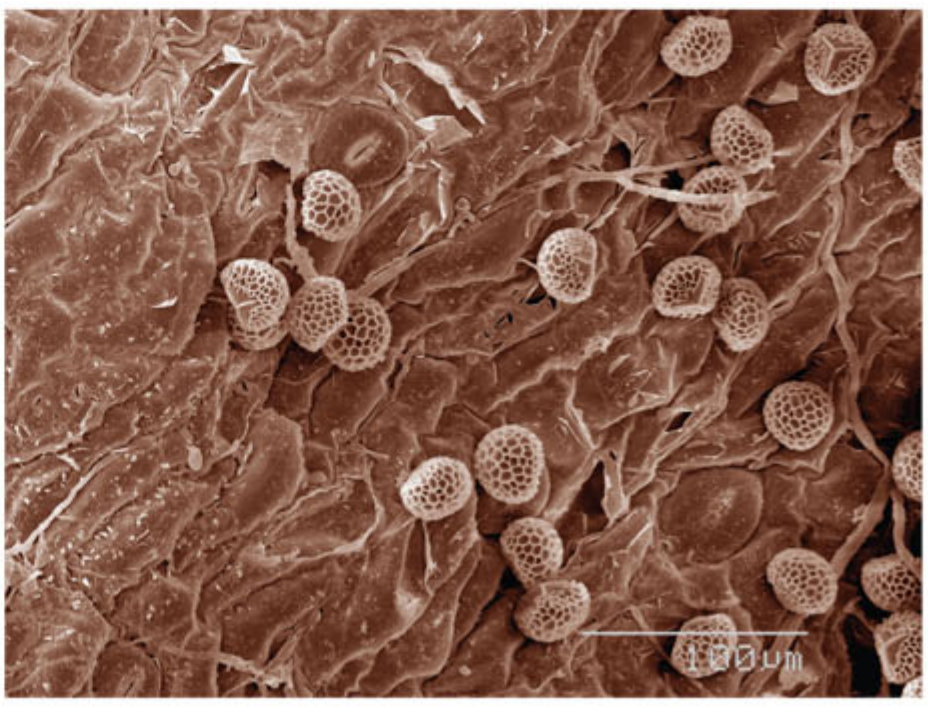

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Figure 8.6 Spores of *Lycopodium.*

Fragmentation

Sea stars, flatworms, sponges and corals are able to reproduce by a process called **fragmentation**. This process occurs when an organism, usually from the Animal Kingdom, is divided into parts and then each part is able to regenerate the missing parts of the organism. This ensures survival of each organism (and the species) through means of asexual reproduction.

Unfortunately, there are instances where this process has not worked well in terms of the health of the ecosystem in which these organisms are found. The crown of thorns sea star is a predator that occurs naturally on the Great Barrier Reef. Occasionally its numbers increase hugely, possibly due to fluctuations in the numbers of its own predators, changes in ocean currents and nutrient supply and run-off from agricultural lands. During those booms it has devoured large patches of the corals. A healthy reef has the capacity to recover, but the Great Barrier Reef has struggled because it is under stress from climate change, ocean acidification and pollution. Another voracious predatory sea star, the Northern Pacific sea star, has been accidentally introduced to Port Phillip Bay, Victoria, probably in ballast water from freighters. A number of strategies have been implemented to slow down the progress of both species, but ill-judged attempts that involved chopping up the animals had the opposite effect (Figure 8.7). Rather than alleviating the problem, it made things worse because most of the pieces gave rise to complete new organisms.

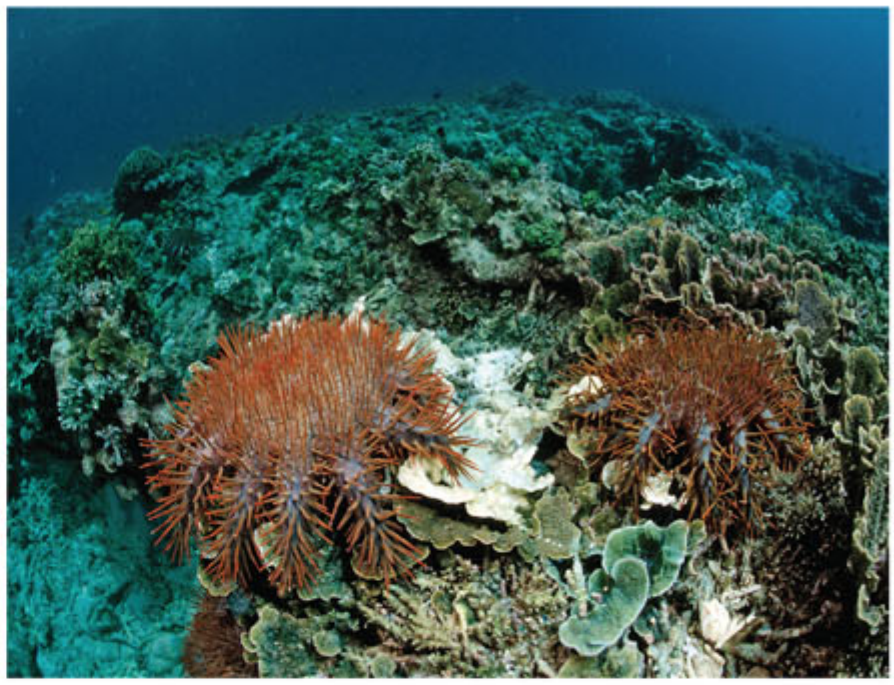

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Figure 8.7 Strategies to control crown of thorns starfish on the Great Barrier Reef are constrained by their ability to reproduce asexually by fragmentation.

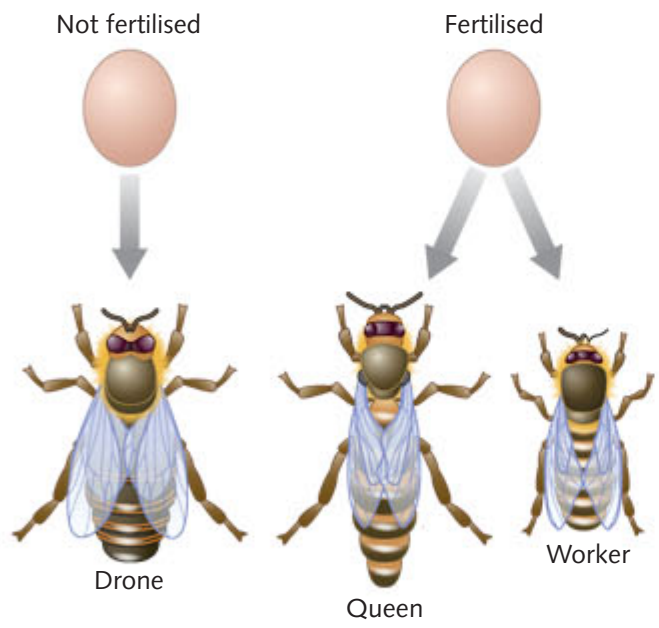

Figure 8.8 Parthenogenesis in bees

Parthenogenesis

When animals lay eggs, the eggs will often develop into genetically diverse individuals because the egg is a result of fertilisation. In some instances, however, unfertilised eggs are able to develop into mature individuals. This is an example of **parthenogenesis**. The egg (female gamete formed through meiosis, Chapter 6 p. 241.) is commonly a haploid cell that is able to develop and give rise to haploid males in species such as bees, nematodes and some plants. Females may lay eggs that have not been fertilised but go on to develop into complete organisms as the eggs divide by mitosis and the cells differentiate. In bees, the unfertilised eggs all develop into male bees (drones), and fertilised eggs develop into female: worker bees or a new queen bee (Figure 8.8). In a species of grasshopper, *Warramaba virgo*, all individuals are female. Because the individual formed in these instances is the result of development from a gamete, the process involved does not fit neatly into the classification of asexual reproduction.

Biological advantages of asexual reproduction

Asexual reproduction enables the exploitation of an ideal habitat. For example, a single spore from a fungus lands on a patch of damp soil beneath a pine plantation. If these are the best conditions for growth of that species of fungus, it is advantageous for the fungus to reproduce quickly and maximise the number of offspring (Figure 8.9). In plants, a crop with identical features will thrive in a suitable situation.

Considering the characteristics of asexual reproduction, it is possible to understand its biological advantages.

- Asexual reproduction involves only one parent; a mate is not required. Consequently, there is no need to spend time and energy searching for a suitable mate. Energy is also saved because there is no need to develop special mechanisms to combine sex cells (egg and sperm) and allow fertilisation (fusion of sex cells). Instead, the available energy can be used to produce numerous offspring. This is important when an organism colonises a new area where suitable mates might not be available. It is also important if organisms are confined to one particular place and are unable to look for a mate – an example is the fungus found growing in a pine plantation, or a roundworm living in your gut.
- All the offspring are genetically identical to the parent. If an individual has the genetic makeup that makes it adapted to an area, then it is reproduced exactly many times to form many new individuals with that particular gene pattern. The offspring are equally well adapted to their environment because of the success of their parents.
- A large number of offspring are reproduced rapidly and efficiently. This enables offspring to spread and colonise an area quickly and to take advantage of favourable environmental conditions. This is particularly advantageous in stable environments with very little change.

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Figure 8.9 The fruiting bodies of a fungus. Fungi can take advantage of ideal conditions to grow lots of individuals quickly.

Biological disadvantages of asexual reproduction

Because asexual reproduction does not produce variation between organisms, this can leave populations susceptible to extinction when the environment changes such as when all individuals in the population are susceptible to infection.

- Offspring are genetically identical. If environmental conditions change, there is very little variation, other than mutations (which are random, unpredictable events), to allow for adaptation to the changed conditions. Whole communities of genetically identical individuals may not survive these changes. An asexually reproducing species runs the risk of suddenly disappearing because of a catastrophe that affects all organisms of the species.
- Mutations are no guarantee of survival or genetic diversity. Mutations may be neutral, providing no advantage or disadvantage to the organism, fatal, disadvantageous or advantageous. If there is a genetic mutation in the parent cell that causes harmful effects, it impacts negatively on the survival ability of the offspring. This could be deadly to all these individuals.
- A large number of offspring are reproduced rapidly. This may be a disadvantage if the offspring are close together and have to compete for limited resources.

WB
8.1.2 BIOLOGICAL ADVANTAGES AND DISADVANTAGES OF ASEXUAL REPRODUCTION PAGE 199

KEY CONCEPTS

- Asexual reproduction occurs when cells or organisms reproduce by binary fission (in prokaryotic cells and some eukaryotic cells) and mitosis (in eukaryotic cells).
- Organisms reproduced by asexual reproduction are exactly the same, genetically speaking, as their parents.
- Asexual methods of reproduction include fission, budding, vegetative reproduction and spore formation.
- Advantages of reproducing asexually include: not needing to spend time and energy seeking a receptive mate; capacity to produce a large number of offspring quickly; and offspring being genetically identical, allowing them to be well adapted to a favourable environment.
- Disadvantages of reproducing asexually include: very little genetic variation, which leaves a population susceptible to infection or environmental changes; and increased competition for limited resources.

Concept questions 8.1

1 Prepare and complete a table describing four methods of asexual reproduction. Your table will have three columns, headed Name of method, Description of method and Example.

2 Ferns and mosses usually reproduce by producing spores. State three benefits of this type of reproduction.

3 List reasons why asexual reproduction is advantageous for some species.

4 Discuss the conditions under which asexual reproduction may be disadvantageous.

5 Describe an environment where organisms that reproduce asexually are likely to be found.

6 **a** Fertilisation is not necessary in parthenogeneis. Explain why.

b Environments do not remain stable forever. Why would this be an issue with organisms that reproduce asexually?

HOT Challenge

7 Komodo dragons, *Varanus komodoensis*, have the very rare ability to produce offspring through a process called facultative parthenogenesis. This means Komodo dragons are an example of a species that can produce offspring through both sexual reproduction and parthenogenesis. Research what conditions lead to each type of reproduction.

8.2 Sexual reproduction

There may seem to be little in common between butterflies, wandering albatrosses and Sturt's desert pea (Figure 8.10). One starts life as a caterpillar before changing form into a butterfly, one travels the world and pairs for life, the other grows in dirt and produces beautiful pea-like flowers. However, they all use the same method of reproduction.

a

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b

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c

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Figure 8.10 a Butterflies, **b** wandering albatrosses and **c** Sturt's desert pea have more in common than you may think.

All these organisms reproduce by sexual reproduction. The same basic process occurs in all of them: two parents contribute genetic information to produce unique offspring. Two cells – the sex cells or gametes – unite in the process of fertilisation. Any form of reproduction in which offspring result from the union or fusion of two cells is sexual reproduction.

While asexual reproduction ensures that an ideal environment is exploited quickly, sexual reproduction incorporates a 'shuffling' of the genetic material (DNA) from one generation to the next. This shuffling results in genetic variation, which makes it more likely that, given an environmental change, at least some members of the species will have the genetic material that enables them to survive to continue the lineage.

So how does this initial shuffling occur? Each parent is unique in his or her genetic make-up and, in the production of each gamete, a random selection of half their genetic material is included in the cell. Therefore, each gamete contains a unique random selection of parental DNA. When gametes combine during fertilisation, this is also random, and provides another opportunity for creating diversity (Figure 8.11). For example, two siblings will each have a different selection of DNA from their mother and of DNA from their father, resulting in different features despite having the same parents. Combining two sex cells from each of the individual parents ensures that a unique combination of DNA is created within each offspring.

CONNECT

Refer to Chapter 6 to revise gamete formation and meiosis.

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Figure 8.11 Genetic variation in dogs as the one species

Fertilisation

In the process of fertilisation, male and female haploid sex cells fuse to produce a diploid zygote. Two gametes from different individuals (usually one male and one female) of the same species combine to produce the new individual of that species. This new individual will have a different combination of DNA from that of either parent. Reproduction by sexual means therefore ensures variation among the offspring and between the offspring and their parents.

The zygote formed is a cell with double the amount of DNA of the gamete. Remember that meiosis halves the amount of DNA in a cell and fertilisation restores the amount of DNA in a cell to the required amount for that species. For example, human gametes produced by meiosis contain 23 chromosomes. Fertilisation restores the number of chromosomes to 46 (23 + 23 = 46), the chromosome number in somatic cells. Different species have different numbers of chromosomes.

WB 8.2.1 FERTILISATION PAGE 203

Chromosomes and variation

During meiosis, when homologous chromosomes move independently to different daughter cells, gametes with many different combinations of parental chromosomes are possible. The number of possible combinations that can occur is 2^n, where n is the number of haploid chromosomes. Humans have 2^{23} possible combinations, which is almost 10 million.

When homologous chromosomes separate and recombine in the first division of meiosis, pieces of chromosomes sometimes break off and exchange positions with their homologous pair in a process known as crossing over. This can lead to further variations in the offspring.

Although all these processes mentioned above produce variations in characteristics in sexually reproducing organisms, they do not generate new DNA. Existing DNA is merely reshuffled through different combinations. New DNA only arises through mutation.

CONNECT

Refer to page 295 for further discussion on crossing over.

WB

8.2.2 BIOLOGICAL ADVANTAGES AND DISADVANTAGES OF SEXUAL REPRODUCTION
PAGE 204

Biological advantages of sexual reproduction

Sexually reproducing individuals may expend considerable time and energy locating mates, exchanging genetic material and, in some species, caring for young. Only half of a parent's genetic material is transferred to each offspring, and males produce many sperm cells, many of which, or even none, may fertilise an egg. With these disadvantages, why did sexual reproduction evolve?

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Figure 8.12 Sexual reproduction leads to variation among individuals. No two zebras have the same stripe pattern.

The greatest advantage of sexual reproduction is the fact that the offspring vary from one another and from their parents (Figure 8.12). This is very important in a changing environment, because some of the new organisms may turn out to be better adapted to the new conditions due to their different genetic make-up.

When a mutation arises in one individual, it can spread to offspring through sexual reproduction. Mutations can be lost during the random genetic recombinations (crossing over and fertilisation) that occur as members of the population reproduce, or they can survive in the population and may later confer an advantage for survival to the individuals that carry them. When individuals carrying an advantageous mutation have a better chance of surviving and reproducing in a changed environment, the frequency of individuals in the population that carry the mutation increases in later generations. This is the basis of evolution through natural selection.

CONNECT

Evolution and natural selection are discussed further in Unit 4 of VCE Biology.

Consider entering a lottery where a certain combination of numbers wins the prize. A person is much more likely to win the big prize if they enter many different combinations than if they enter the same set of numbers many times. Similarly, if individuals in a population have many unique genetic combinations there is a greater chance that at least some of their offspring will survive in an unpredictably variable environment.

Another advantage of sexual reproduction is associated with limited resources in an environment. If offspring have slightly different resource requirements because of their genetic make-up, then there will be less competition between them.

The Red Queen hypothesis proposes that coevolution exists between species, particularly between hosts and parasites. It can be likened to an evolutionary arms race, where prey and predator evolve together, responding to pressures that each puts on the other. For example, rabbits may evade predation by foxes by running faster. Foxes need to improve their speed of running to catch their prey. The only way that a species involved in competition can maintain its position in the ecosystem relative to the others is by improving its form and function. For the Red Queen hypothesis to apply, there needs to be some genetic mixing of genes, such as occurs in sexual reproduction, to enable the random fluctuations and mutations that allow new characteristics to appear. This principle was proposed by the evolutionary biologist Leigh Van Valen (1973), and is named after the observation to Alice by the Red Queen in Lewis Carroll's *Through the Looking Glass* that 'Now, here, you see, it takes all the running you can do, to keep in the same place'.

n.

Weblink
Advantages and disadvantages of asexual and sexual reproduction

Online Worksheet
Advantages and disadvantages of asexual and sexual reproduction

KEY CONCEPTS

- Cells formed by meiosis are called gametes.
- Many different combinations of parental chromosomes are possible in gametes.
- Chromosomes are randomly shuffled during meiosis and fertilisation.
- Fertilisation ensures that the zygote that results from two haploid gametes joining together is diploid; a diploid zygote has one set of chromosomes from each parent.
- The greatest advantage of sexual reproduction is that offspring all vary from one another and from their parents. In a changing environment, there is a greater chance that some of the offspring carry the genetic combinations that make them better suited to the new conditions and, therefore, better able to survive and reproduce.

Concept questions 8.2

1 Contrast sexual and asexual reproduction.
2 Describe three events that contribute to genetic variation among offspring produced by sexual reproduction.
3 Calculate the number of possible chromosome combinations in the gametes of an organism with a diploid number of eight chromosomes.
4 Explain why sexual reproduction might be advantageous to a species living in a changeable environment.
5 What is the benefit of sexual reproduction occurring via meiosis as opposed to mitosis?
6 What are the disadvantages of sexual reproduction?

HOT Challenge

7 Canola is an economically important crop in Australia. It is grown across large areas of land in New South Wales, South Australia and Victoria and is used primarily to make canola oil. The Australian canola crop is slowly losing genetic diversity through inbreeding. Explain why this could be a problem for Australian canola farmers and what can be done to mitigate the problem.

8.3 Cloning

When studying the various modes of reproduction that exist in the natural world, one must also consider the reproduction of organisms or parts of organisms with human intervention. Within the laboratory, scientists spend many hours imitating what occurs naturally in an attempt to exploit natural processes for human gain. When a farmer comes across a variety of crop that grows well on their farm, they will want to plant the same variety again for their next season. Many crops can only be grown from seed, but some important crops are reproduced via **cloning**.

Throughout human history, cloning had been practised even before the process was named. A clone is an organism of identical genotype to its parent. It is produced by asexual reproduction. When farmers ploughed crops such as potatoes back into the soil to generate next year's crop from the pieces left in the ground, they were producing their crops by cloning.

Early cloning almost exclusively involved plants. As biotechnology processes were further studied and refined, new reproductive cloning techniques have been devised.

Cloning plants

As we discussed earlier in relation to asexual reproduction of plants (p. 316), a number of methods can result in the production of a genetically identical organism. Undertaking this task in the laboratory appears relatively straightforward. Cells from a desired plant are sampled and placed in a sterile growth medium such as agar; various plant growth regulators stimulating the cells to undergo mitosis are introduced, resulting in the formation of a callus. The callus will then go on to develop roots and shoots and the resulting plantlets are separated and grown in their own pots (Figure 8.13). The original cells were taken from diploid cells and then treated to grow, thus forming clones of the original cells.

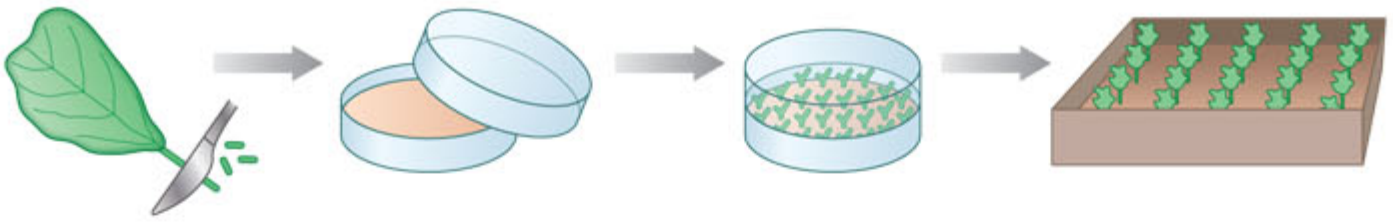


Figure 8.13 The steps in cloning a plant from a parent plant using diploid cells

Figure 8.14 Wollemi pine (*Wollemia nobilis*)

Cloning can be used to conserve rare or endangered plant species. The Wollemi pine (Figure 8.14), a plant thought to be extinct and only known previously from fossil records, has been saved through cloning. A small number of the pines were discovered in 1994 in the Wollemi National Park in the Blue Mountains in New South Wales. Ancestors of the Wollemi Pine go back to the mid-Cretaceous, and possibly even the early Cretaceous, period some 110 million years ago. All the Wollemi pine plants currently for sale around the world are clones of the original trees found in the wild. In the bushfires of the summer of 2019–2020, targeted efforts by firefighters preserved the wild population of pines in the Blue Mountains.

The cloning of plants by plant tissue culture technologies has had a huge impact on the horticultural industry. Using these techniques, cells are grown in sterile conditions on a culture medium supplying all the nutrients needed. Micropropagation is the method used to produce clones of a plant, often scaled up to mass production.

The advantages of plant cell, tissue and organ culture technologies include more rapid production of plants, taking weeks instead of months or years. Very little space is required compared to planting in fields, and the plants can be produced all year round.

Because cloning produces the same genetics in the offspring as in the parent, the most desirable characteristics in a plant can be maintained in a predictable way. Maintaining desirable characteristics can increase crop yield and quality while reducing the incidence of crop failure.

There are, however, negative consequences of mass growth of cloned or genetically similar crops or plantations. The Irish potato famine of the 1840s is an example of problems that can arise from planting crops that lack genetic diversity. Cultivation of whole fields of genetically identical potatoes left the entire crop vulnerable to disease infestation by a fungus called *Phytophthora infestans*. The disease outbreak led to a famine in which approximately one million people died and one million more emigrated from Ireland.

Modern agricultural practice often results in a reduction in the number of crop species and varieties. Crops are grown over a wide area for a large number of consecutive years. This allows large harvests with minimal labour. When only one species of organism is grown, such as a wheat field, **biodiversity** is reduced. This type of farming, resulting in a **monoculture** (a colony of genetically identical individuals of the same species), often requires extensive use of fertilisers along with pesticides and herbicides to reduce the natural tendency of the community to diversify. Another downside of this practice is the spread of disease and susceptibility to changing environmental conditions. Cultivated plants grown in genetically homogeneous monocultures do not possess the necessary ecological defence mechanisms to tolerate the impact of pest outbreaks.

As a result of reduced biodiversity in monocultures, the natural enemies of pests are no longer present. If pest outbreaks occur, the populations of beneficial insects are missing, and if weather conditions favourable to the pest happen simultaneously the effect on the crop can be catastrophic.

Cloning animals

You may have heard of Dolly the sheep. Dolly, born in July 1996, was the first mammal recorded to have been produced without the fertilisation of an egg with a sperm. Rather, she was the result of transferring the nucleus of an adult sheep's mammary gland cell into an egg cell via what is known now as nuclear transfer. Her birth was not planned: the researcher, Ian Wilmut, and his team were attempting to clone foetal cells and were using adult cells as a control when they produced the embryo that became Dolly. Wilmut was able to demonstrate that a clone could be created by using DNA from one diploid cell and inserting it into a recipient egg cell, which could then grow into a complete organism.

Nuclear transfer

As in the production of Dolly the sheep, nuclear transfer involves removing mature donor somatic cells from a mature animal and a recipient egg cell from another mature animal of the same species (Figure 8.15). The donor cells are cultured in a nutrient medium before becoming inactive, and the nucleus of the recipient egg cell is removed.

Weblink
Reproductive cloning technology

Online Worksheet
Reproductive cloning technology

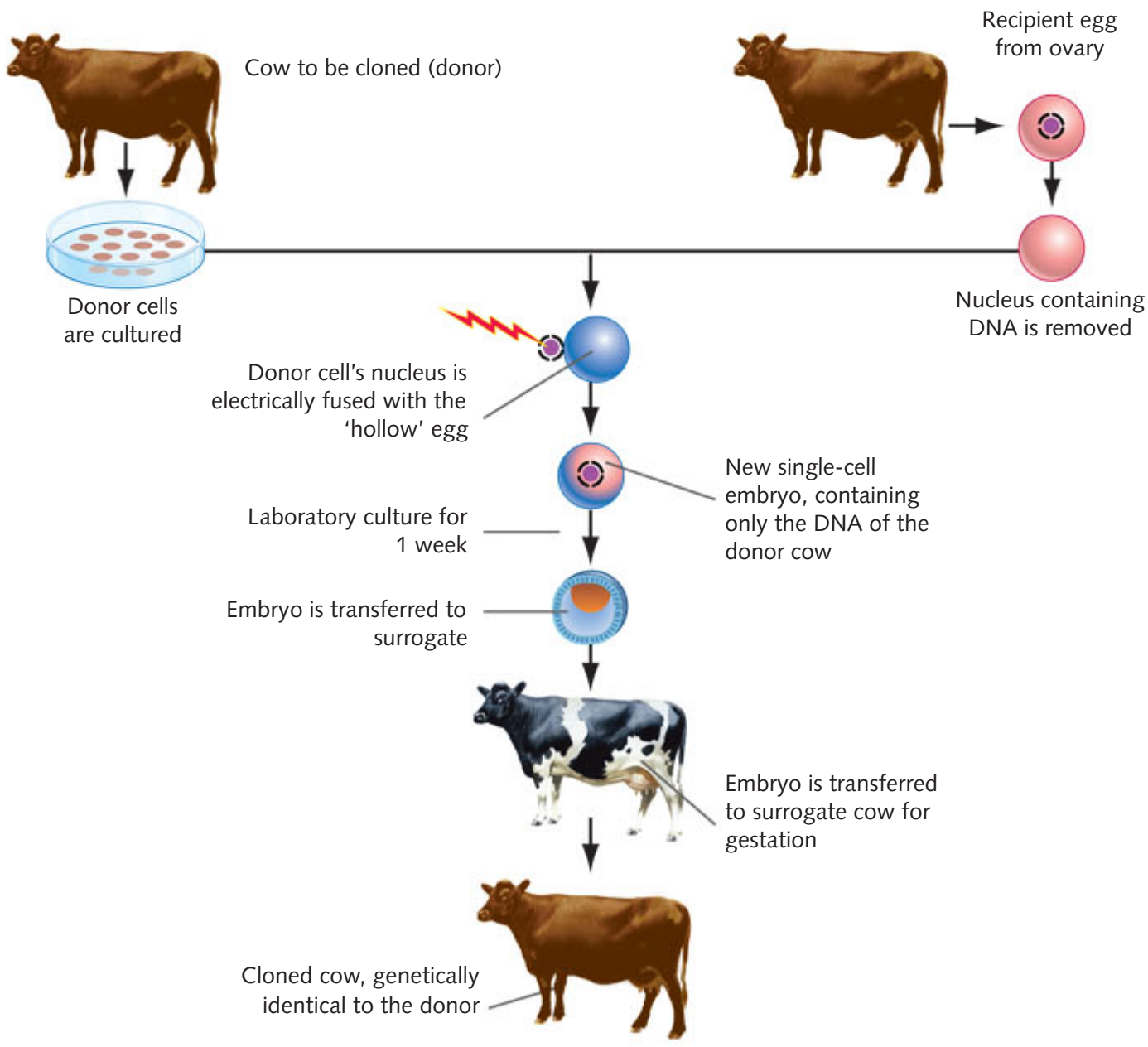


Figure 8.15 Cloning by nuclear transfer to produce a calf

The donor cell, with the intact nucleus, is fused with the 'hollow' egg by an electrical impulse. The new single-celled embryo is cultured for about a week, then cell division is activated and the developing blastocyst is surgically implanted into the surrogate mother. The offspring is genetically identical to the nucleus donor.

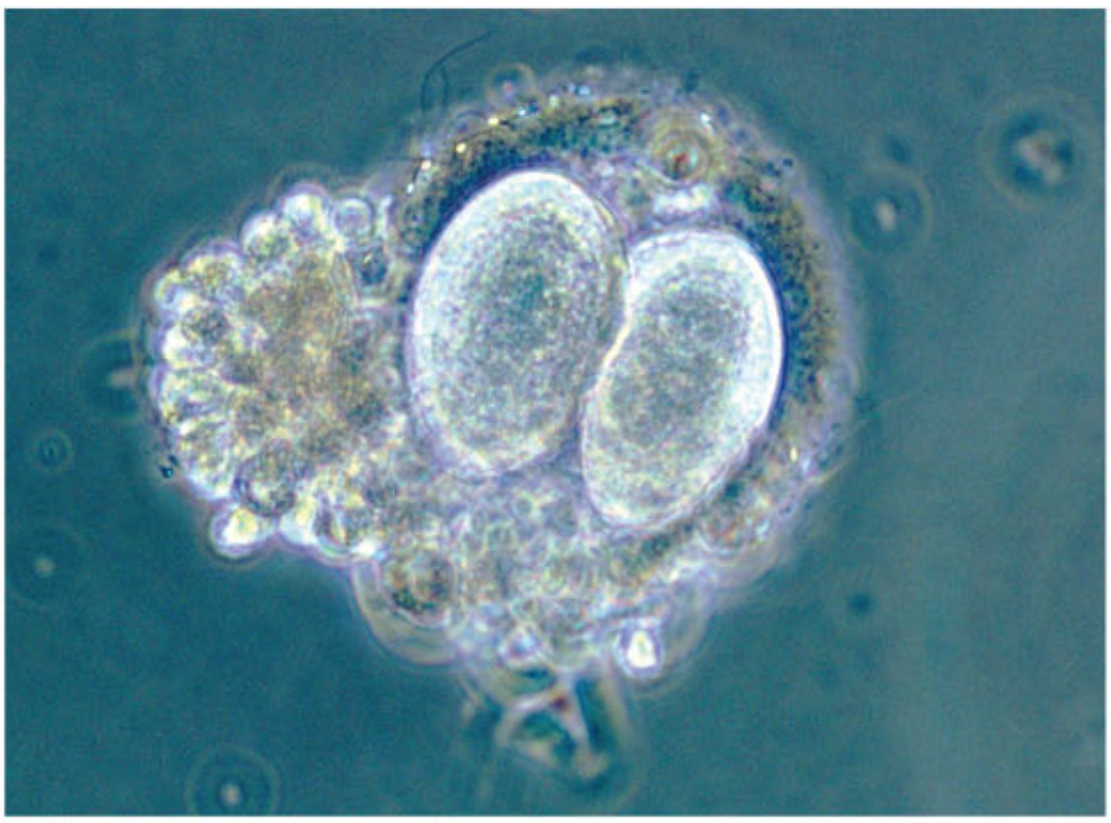
WB
8.3.1 CLONING
PAGE 205

The birth of Dolly was conclusive evidence that a mammal could be produced from another adult mammal; however, research has moved away from cloning mature animals. There have been attempts over the years to clone pets and talk of trying to reproduce members of extinct species such as the thylacine (Tasmanian tiger) or woolly mammoth. These ideas hit problems because the DNA was so degraded it could not be repaired by the machinery in the egg cell.

Cloning using nuclear transfer has not proceeded without some controversy. The success rate in terms of live births is low and many of the offspring suffer from deformities. For these and other reasons, the scientific world is almost universally opposed on ethical grounds to experimenting with reproductive cloning of humans.

Embryo splitting

Embryo splitting is a method now widely used for cloning animals for commercial reasons. In this process, egg cells are removed from the donor female and fertilised in vitro (that is, in tissue culture) by sperm from the male. After the fertilised egg has divided, the coat around the two cells that promotes cell division is removed and the two cells are separated (Figure 8.16). Each cell is then given an artificial coating that promotes cell division. Embryos that have just begun to differentiate, called blastocysts, are implanted into surrogate mothers. The individuals are genetically identical; they are like identical twins but in different surrogate mothers.



Alamy Stock Photo/Science Photo Library

Figure 8.16 Embryo splitting in process

Application of cloning in agriculture and horticulture

Animal cloning, like other types of cloning, is used to increase the number of breeding animals with naturally occurring desirable traits. This allows for the rapid spread of these characteristics through the herd (Figure 8.17). The cloning of farm animals for food production is common practice in a number of countries.

Getty Images/Star Tribune

Figure 8.17 **Cloning produces individuals that are genetically identical.**
These two heifers have resulted from cloning.

In the European Union (EU), a draft directive on cloning of animals aims to ban temporarily the use of the cloning technique on EU farmed animals. The draft directive allows cloning for purposes such as research and conservation of rare breeds and endangered species, or for use in the production of pharmaceuticals and medical devices, where the technique can be justified. The United States declared that cloned animals were identical to non-cloned animals and has encouraged the use of these techniques to ensure the quality of livestock for domestic use and international trade.

Keen gardeners are aware of the ability of plant cuttings to grow and regenerate into mature plants with all the many different types of cells needed for the plant to function independently. The brand new plant is a genetic replica of its parent – it is a clone of the parent. Gardeners may consider regenerating plants by cloning rather than using seeds from the parent plant when the parent plant has a desirable characteristic they want to keep. If the new plant was grown from a seed of the parent plant, the genetic material would not be an exact replica and the desirable characteristic may not appear in the offspring.

As far back as the beginnings of agriculture, humans have been 'cloning' plants from cuttings and by other methods. Cultivated olive trees originated about 6000 years ago in Asia Minor. Somewhere between 5000 and 3800 BP, olive trees were introduced to Egypt from Syria. There are many records of clonal propagation of these trees.

Today, many economically important plants are commonly grown using cloning techniques, including vegetable crops such as the potato, fruit crops such as bananas, strawberries and dates, and even woody species such as pines and grapes.

KEY CONCEPTS

- Cloning can be accomplished using either embryo splitting or nuclear transfer, and results in the production of an individual genetically identical to the DNA donor.
- Animal cloning is used to increase the number of breeding animals with naturally occurring desirable traits.
- Cloning can be used to conserve rare and endangered plant species.
- Mass production of plants often uses the method of micropropagation.

Concept questions 8.3

1 Define cloning.
2 Distinguish between cloning using biotechnology and cloning through processes such as fragmentation and vegetative propagation.
3 Explain how embryo splitting is different from nuclear transfer.
4 List two advantages and two disadvantages of using cloning in agriculture.
5 What are some of the ethical considerations in cloning?

HOT Challenge

6 In general, people are comfortable with cloning plant species but not animal species. Why is this?

BRANCHING OUT

Cloning monkeys for use as human proxies in research

Researchers at the Institute of Neuroscience in China have cloned macaque monkeys to produce genetically identical monkey models that can be used as human proxies to conduct research into human diseases (Figure 8.18). The more genetically identical the monkey models are the better results can be gained from the research, and in this case there is

Getty Images/AFP/STR

Figure 8.18 Macaque monkey models standing in for human subjects

no genetic variability between the monkeys. These models could be used for research, for example, if half the monkey models were given a drug to treat anxiety and the other half were given a placebo (or sugar pill). No other variables would be at play other than the independent variable of the drug.

One of the arguments for using monkey models is that ethics committees at research institutes would not allow researchers to perform this type of experiment on humans. Therefore, proxies need to be used in place of humans, but the proxies need to be biologically close to humans so the results can be generalised across humans. Great apes, chimpanzees, monkeys and orangutans are closely related to humans, all being primates.

In this research the monkeys are being used as a commodity. The monkeys cease to be an animal and become a thing. This way it is easier to stop thinking about their welfare. They can be used and discarded; they are disposable.

Cloning is a highly invasive process and many attempts are usually made for each live birth. This team started with 325 cloned embryos of which 65 were implanted to produce 5 live monkeys. The process cost US$500 000.

Some people argue that monkeys have the same moral status as humans. Moral status is defined as having characteristics such as sentience, consciousness, personhood, rationality and higher order reasoning. Some countries, including New Zealand, Sweden and the United Kingdom, recognise the moral status of primates and have legislated against their use as human proxies in research.

Questions

1 Identify two issues about the use of monkeys as human proxies.
2 Discuss one of these identified issues in terms of:
   a non-maleficence – harm resulting from a course of action should not be disproportionate to the benefits
   b respect – all living things have an intrinsic value and should be protected where possible.
3 Find out what the Australian Government's position is on the use of primates in medical research.

Chapter 8 summary of key concepts

8 Summary of key concepts

8.1 Asexual reproduction

KEY CONCEPTS

p. 313

- Asexual reproduction occurs when cells or organisms reproduce by binary fission (in prokaryotic cells and some eukaryotic cells) and mitosis (in eukaryotic cells).
- Organisms reproduced by asexual reproduction are exactly the same, genetically speaking, as their parents.
- Asexual methods of reproduction include fission, budding, vegetative reproduction and spore formation.
- Advantages of reproducing asexually include: not needing to spend time and energy seeking a receptive mate; capacity to produce a large number of offspring quickly; and offspring being genetically identical, allowing them to be well adapted to a favourable environment.
- Disadvantages of reproducing asexually include: very little genetic variation, which leaves a population susceptible to infection or environmental changes; and increased competition for limited resources.

a

Shutterstock.com/Ratthiya Thongdumhyu

Figure 8.3a In *Hydra*, a new individual forms from the outgrowths of the parent by producing a bud that branches from the side of the body.

8.2 Sexual reproduction

KEY CONCEPTS

p. 320

- Cells formed by meiosis are called gametes.
- Many different combinations of parental chromosomes are possible in gametes.
- Chromosomes are randomly shuffled during meiosis and fertilisation.
- Fertilisation ensures that the zygote that results from two haploid gametes joining together is diploid; a diploid zygote has one set of chromosomes from each parent.
- The greatest advantage of sexual reproduction is that offspring all vary from one another and from their parents. In a changing environment, there is a greater chance that some of the offspring carry the genetic combinations that make them better suited to the new conditions and, therefore, better able to survive and reproduce.

Getty Images Plus/iStoc

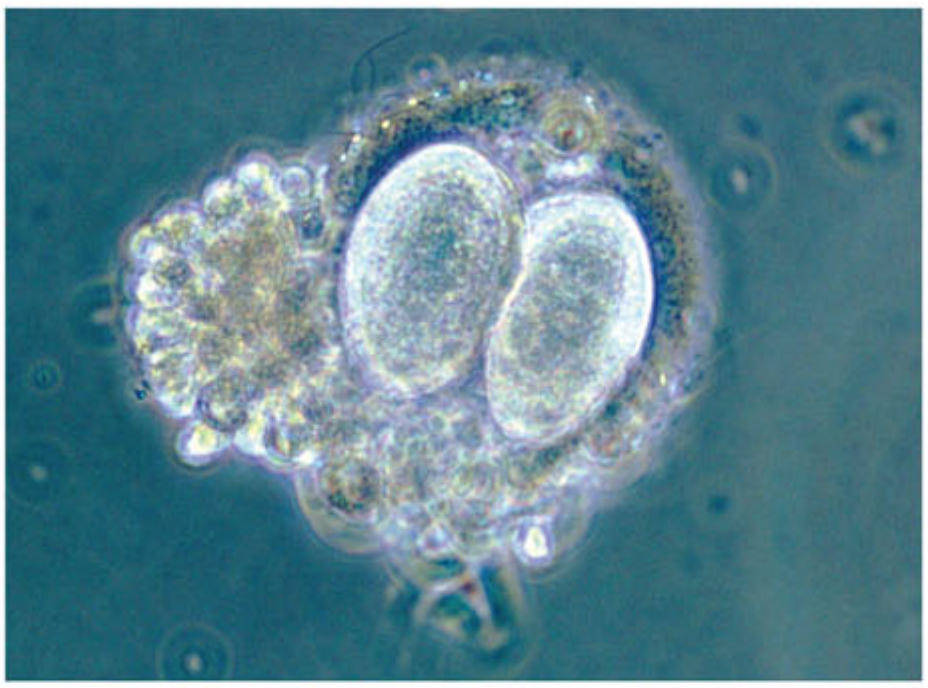
Figure 8.11 Genetic variation in dogs as the one species

8.3 Cloning

KEY CONCEPTS

p. 323

- Cloning can be accomplished using either embryo splitting or nuclear transfer, and results in the production of an individual genetically identical to the DNA donor.
- Animal cloning is used to increase the number of breeding animals with naturally occurring desirable traits.
- Cloning can be used to conserve rare and endangered plant species.
- Mass production of plants often uses the method of micropropagation.



Alamy Stock Photo/Science Photo Library

Figure 8.16 Embryo splitting in process

WB
8.4.1 KEY TERMS
PAGE 208

8 Chapter glossary

asexual reproduction a form of reproduction in which offspring are produced from a single parent

biodiversity the full range of different biological entities in a particular area or region; it can be described at various levels, including the range of different species, genetic diversity, or the diversity of ecosystems present in a large area

budding the development of a new organism from an outgrowth of the parent organism

clone cells, tissue or an organism genetically identical to another organism or its cells

cloning the process of producing a cell, a tissue or an organism genetically identical to cells of another organism

fragmentation division of a parent organism into pieces, with each piece then giving rise to a complete organism

grafting the process of artificially attaching part of one plant to another plant

monoculture the agricultural practice of growing a single crop or plant species over a wide area for a large number of consecutive years

parthenogenesis a form of asexual reproduction where growth and development into a complete organism occurs from an unfertilised egg

spore a reproductive body able to withstand harsh environmental conditions

vegetative propagation growing a new plant from a fragment of a parent plant

8.4.2
PRACTICE TEST
QUESTIONS
PAGE 209

8 Chapter review

Remembering

1 Define asexual reproduction and provide three examples of asexual reproduction techniques in different organisms.

2 List three differences between spores and gametes.

Understanding

3 Explain how sexual reproduction is different from asexual reproduction.

4 State two advantages and two disadvantages of asexual reproduction.

5 Decide whether this statement is true or false. Provide a reason for your choice. 'Cloning is a new technique that is being used to create offspring that are identical to their parents.'

6 State three ways that the action of chromosomes contributes to variability in offspring that have been produced sexually.

7 Explain why organisms produced by asexual reproduction are referred to as clones.

8 Consider the natural environment of *Hydra*. Why would budding be an advantageous way to reproduce in this environment?

9 How many daughter cells are produced at each division when a bacterium reproduces asexually?

10 Which reproductive strategy results in genetically unique individuals?

11 Explain why cutting up crown of thorns starfish was not a sensible control strategy.

Applying

12 Suppose you have a cut on your finger that becomes infected with one bacterial cell. Explain why the number of bacteria in the cut increases so rapidly.

13 Strawberry plants can reproduce both asexually and sexually. Discuss the advantages that strawberry plants would gain from reproducing by these two methods.

14 A large number of fungal spores land on some damp ground underneath a tree. State three advantages and three disadvantages for those spores if they were to germinate there.

Analysing

15 Organisms that reproduce asexually through budding rarely have a large number of different cell types. Suggest reasons why.

16 Explain why children of the same parents do not inherit identical chromosomes (except for identical twins).

17 Consider the plant shown in Figure 8.19.

- **a** Name the type of reproduction in this plant.
- **b** Explain how new plants form.
- **c** Discuss the likely genetic make-up of new plants.
- **d** Name a commercially grown plant that is propagated in this way.

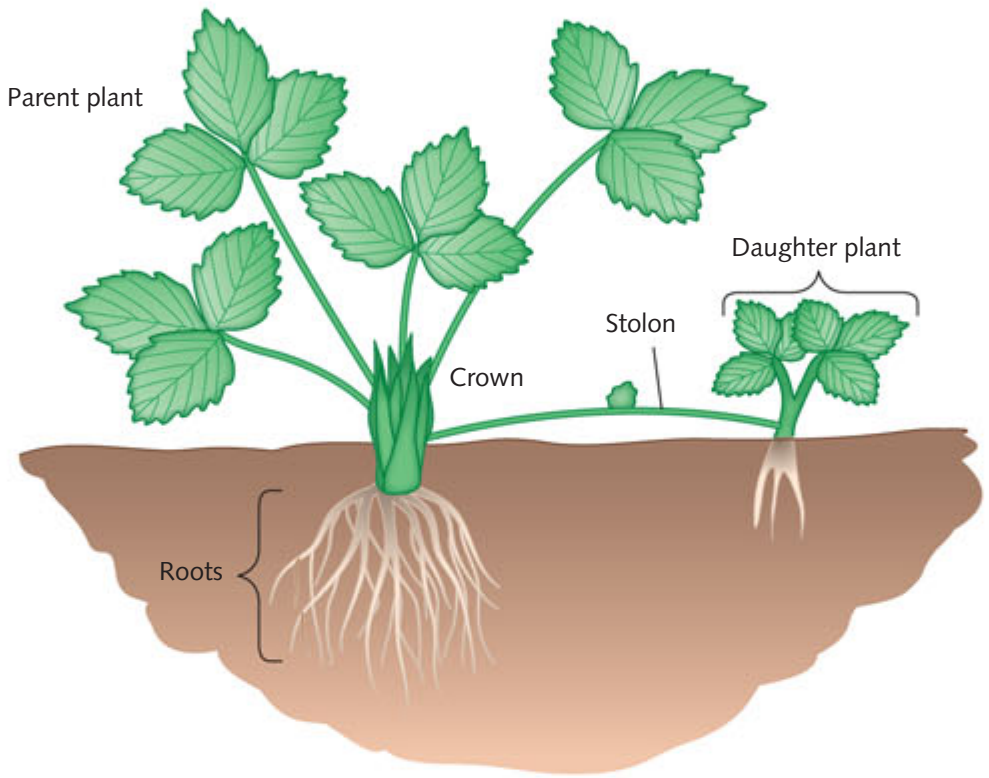


Figure 8.19 A new plant forms.

Evaluating

18 Contrast the EU and US policies on cloning of animals. Which policy appears to be scientifically sound? Provide reasons for your decision.

19 Explain why offspring produced from asexual reproduction resemble their parent, whereas offspring produced from sexual reproduction are different from their parents.

20 Using monocultures in commercial crops can be both beneficial and potentially harmful. Provide arguments for and against planting monocultures.

21 Spores have unique abilities to survive in adverse environmental conditions. Some bacteria produce spores, as do fungi, non-flowering plants and algae. Outline some of the harsh environments that each of these groups of living things might have to survive.

22 Why is sexual reproduction advantageous for survival of the species?

Creating

23 Prepare a table comparing the process of mitosis with the process of meiosis in relation to reproduction.

24 A gardener wants to grow an apricot tree in a way that ensures that his tree has all the most desirable qualities of apricot trees. Suggest the technique that the gardener would use.

9 Adaptations and diversity

By the end of this chapter you will have covered the following material.

Key knowledge

Adaptations and diversity

- the biological importance of genetic diversity within a species or population pp. 341–342
- structural, physiological and behavioural adaptations that enhance an organism's survival and enable life to exist in a wide range of environments pp. 343–355
- survival through interdependencies between species, including impact of changes in keystone species and predators and their ecological roles in structuring and maintaining the distribution, density and size of a population of an ecosystem pp. 355–368
- contribution of Aboriginal and Torres Strait Islander peoples' knowledge and perspectives in understanding adaptations of, and interdependencies between, species in Australian ecosystems pp. 369–374

Key science skills

Develop aims and questions, formulate hypotheses and make predictions

- identify independent, dependent and controlled variables in controlled experiments pp. 359–360
- formulate hypotheses to focus investigation pp. 359–360
- predict possible outcomes pp. 359–360

Plan and conduct investigations

- determine appropriate investigation methodology: case study; classification and identification; controlled experiment; correlational study; fieldwork; literature review; modelling; product, process or system development; simulation pp. 359–360
- design and conduct investigations; select and use methods appropriate to the investigation, including consideration of sampling technique and size, equipment and procedures, taking into account potential sources of error and uncertainty; determine the type and amount of qualitative and/or quantitative data to be generated or collated pp. 359–360
- work independently and collaboratively as appropriate and within identified research constraints, adapting or extending processes as required and recording such modifications pp. 348–349; 352; 355; 359–360

Comply with safety and ethical guidelines

- demonstrate safe laboratory practices when planning and conducting investigations by using risk assessments that are informed by safety data sheets (SDS), and accounting for risks pp. 346–347; 359–360

» apply relevant occupational health and safety guidelines while undertaking practical investigations pp. 346–347; 359–360

» demonstrate ethical conduct when undertaking and reporting investigations pp. 346–347; 359–360

Generate, collate and record data

» systematically generate and record primary data, and collate secondary data, appropriate to the investigation, including use of databases and reputable online data sources pp. 346–347; 348–349; 352; 355; 359–360

» record and summarise both qualitative and quantitative data, including use of a logbook as an authentication of generated or collated data pp. 346–347; 348–349; 352; 355; 359–360

» organise and present data in useful and meaningful ways, including schematic diagrams, flow charts, tables, bar charts and line graphs pp. 346–347; 348–349; 352; 355; 359–360

» plot graphs involving two variables that show linear and non-linear relationships pp. 359–360

Analyse and evaluate data and investigation methods

» identify and analyse experimental data qualitatively, handling where appropriate concepts of: accuracy, precision, repeatability, reproducibility and validity of measurements; errors (random and systematic); and certainty in data, including effects of sample size in obtaining reliable data pp. 346–347

» identify outliers, and contradictory or provisional data pp. 359–360

» repeat experiments to ensure findings are robust pp. 359–360

Construct evidence-based arguments and draw conclusions

» distinguish between opinion, anecdote and evidence, and scientific and non-scientific ideas pp. 348–349; 352; 355; 359–360

» evaluate data to determine the degree to which the evidence supports the aim of the investigation, and make recommendations, as appropriate, for modifying or extending the investigation pp. 348–349; 352; 355; 359–360

Analyse, evaluate and communicate scientific ideas

» use appropriate biological terminology, representations and conventions, including standard abbreviations, graphing conventions and units of measurement pp. 346–347; 348–349; 352; 355; 359–360

» discuss relevant biological information, ideas, concepts, theories and models and the connections between them pp. 348–349; 352; 355; 359–360

» acknowledge sources of information and assistance, and use standard scientific referencing conventions pp. 348–349; 352; 355

Online Chapter Map
Chapter 9 Map

9 Adaptations and diversity

It's good to be different! But just how good? Well, it could just save your life.

9.1 Genetic diversity

p. 341

Consider all the humans on Earth. Consider all the different alleles of genes that they have in their chromosomes. There is a huge mix of combinations. This is genetic diversity. Now think about this for all the other organisms. This is biodiversity.

9.2 Adaptations

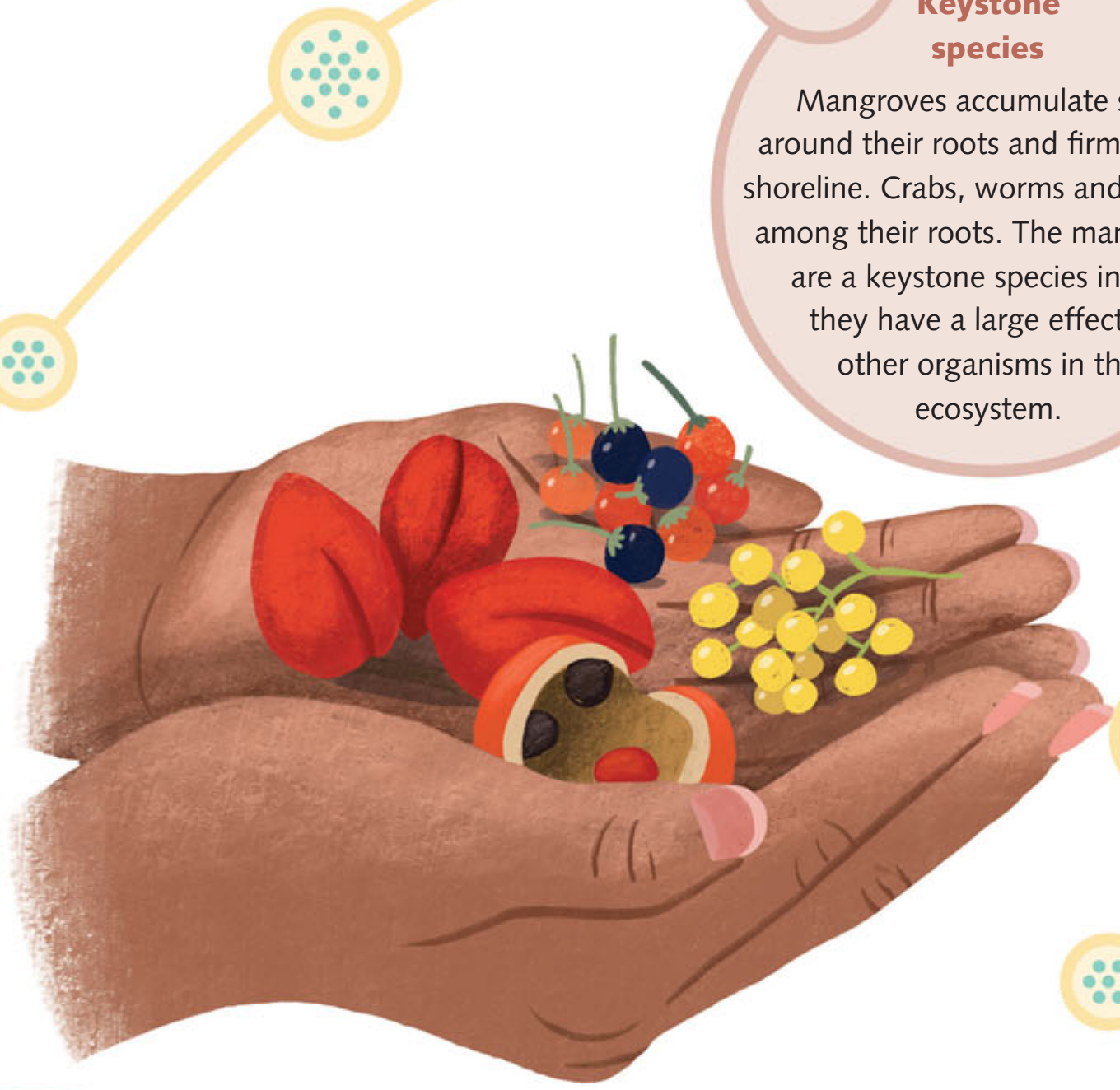
p. 343

Think about an elephant's big ears. Elephants live in hot environments, so their ears help them lose heat. This is an adaptation – an inherited characteristic that makes the elephant well suited to its environment, increasing its chances of survival and reproduction.

9.3 Survival through interdependencies between species

p. 355

When different species interact with each other while living in close physical association, this is called symbiosis. There are four different types of symbiosis, with varying relationships in each interaction.



p. 366

9.4 Keystone species

Mangroves accumulate sand around their roots and firm up the shoreline. Crabs, worms and fish live among their roots. The mangroves are a keystone species in that they have a large effect on other organisms in the ecosystem.

p. 369

9.5 Adaptations and interdependencies in Australian ecosystems

Aboriginal and Torres Strait Islander peoples have a deep understanding of the survival strategies of species that share their land. They use this knowledge to harvest food and to sustainably manage the species that they rely upon.

Genetic diversity ensures species continuation in times of environmental change, where some individuals are better suited to the changed conditions than others. Some species also work together to help each other survive. Humans too need be mindful that they work harmoniously with other species to ensure their survival.

To access resources below, visit www.nelsonnet.com.au

Online Chapter map:
- Chapter 9 map (p. 338)

Online Key Terms:
- Chapter 9 flashcards (p. 340)

Weblinks:
- CRAAP test (p. 348)
- Adaptations to the desert (p. 352)
- Biodiversity and keystone species (p. 366)

Online Worksheets:
- Adaptations to the desert (p. 352)
- Biodiversity and keystone species (p. 366)

Online Key Concepts:
- Chapter 9 summary of key concepts (p. 378)

Know your key terms

Online Key Terms
Chapter 9 Flashcards

abiotic
abundance
adaptation
amensalism
behavioural adaptation
biotic
carnivore
coexistence
commensalism
community
competition
consumer
density
distribution
ecosystem
environment
extinct
first-order consumer
food chain
food web
genetic diversity
habitat
herbivore
host
keystone species
mutualism
omnivore
parasite
parasitism
physiological adaptation
phytoplankton
population
predator
prey
producer
scavenger
structural adaptation
symbiosis
top consumer
trophic level

Remember

WB REMEMBER
PAGE 211

This chapter will build on the following concepts that you will have already met. Take the time to refresh these concepts before you start this chapter.

1 Abiotic refers to non-living factors in the environment and biotic refers to living factors.
2 An ecosystem involves the interaction of abiotic and biotic components.
3 A community is all the living species in a particular area at a particular time, whereas a population is a group of individuals of the same species in a particular area.
4 Competition and predation are two relationships between organisms living in an area.
5 Food chains show how energy is passed between the biotic part of a community and a food web is a collection of food chains.
6 An adaptation is a characteristic that gives an organism an advantage to survive and reproduce.

Madagascar is classified as one of the biological hotspots of the world. A large proportion – 75% – of the species found in Madagascar are found nowhere else in the world.

Conservation of biological hotspots is considered extremely important to the number of native species found in the area. There are 34 international hotspots recognised worldwide, each with its own unique local species. Hotspots are reservoirs of the most diverse, yet most threatened, of the many different species on Earth.

Why is **genetic diversity** important within a species such as the Coquerel's sifaka, shown in Figure 9.1? What structural, physiological and behavioural adaptations must a species have to increase its chances of survival and reproduction in a specific environment or in a wide range of environments? How do interdependencies between species and changes in their ecological roles affect the size, distribution and density of other populations in the ecosystem? This chapter will explore how these factors are important in survival of species and balance within ecosystems, including the understanding of Aboriginal and Torres Strait Islander peoples of adaptations and interdependencies of species in Australian ecosystems.

Getty

Figure 9.1 Lemurs like these Coquerel's sifakas (*Propithecus coquereli*), found only in Madagascar, show diversity in their colour patterns, size, snout length and position of their ears.

9.1 Genetic diversity

An **ecosystem** is far more than just the living organisms (**biotic** factors) and their non-living surroundings in a specific area. It involves the interdependencies between organisms that make up the populations in the community and the way they interact with each other and their physical surroundings (**abiotic** components) to maintain the community. A **population** is one group of individuals belonging to the same species living in a specific area at the same time; a **community** is the sum of the different species inhabiting a specific habitat at one time. The **habitat** is the area or **environment** where an individual or species lives within an ecosystem.

WB 9.1.1 GENETIC DIVERSITY PAGE 212

Organisms may collaborate with each other, compete for resources, be predators or preyed upon, or be in symbiotic relationships in which one or both species benefit or are harmed. They all are involved in food chains that make up the complex web of relationships in the food web of the community of the ecosystem. Within the populations of the species, there must be genetic diversity so that some members of the species will survive and reproduce if there are changes in the biotic or abiotic factors affecting the ecosystem.

Genetic diversity within a species or population

Genetic diversity is the range of genotypes of individuals in the population of a species or the entire species. Genetic diversity is essential for the survival of a population or the whole species located in different widespread areas, if it is to survive a change in the environment that affects either the biotic factors or abiotic factors in the area the species occupies. These abiotic factors may include temperature, humidity, water or soil type and availability of minerals. At least some individuals, those that have characteristics that make them better suited or better adapted to the changed conditions, will survive and reproduce. The population numbers may decrease markedly at first but, over time, they will increase again, if the genetically determined variation confers a selective advantage on those organisms. Lack of genetic variation could result in the species being lost from Earth's biodiversity. If this occurs, the species is said to be **extinct**.

WB 9.1.2 GENETIC DIVERSITY WITHIN A SPECIES OR POPULATION PAGE 213

Asexual reproduction occurs in both prokaryotic and eukaryotic organisms, both unicellular and multicellular. It involves binary fission in prokaryotic cells whereby the parent cell replicates its DNA and splits in half, producing two daughter cells each with one half of the replicated DNA. In eukaryotic cells, the process of mitosis occurs; this is an orderly division of the nuclear material resulting in the production of

CONNECT

Asexual reproduction was discussed in Chapters 2 and 8.

Figure 9.2 **The crescent nail-tail wallaby, or *Onychogalea lunata*, became extinct due to the changing environment in the early 1900s.**

genetically identical offspring, unless mutations occur during the process. If the individual organisms are adapted to an area, organisms with an identical genotype can be reproduced many times to form new individuals with the same genotype. All the individuals are equally adapted to their environment and can survive and reproduce, provided there is no limitation to resources, including space, and no disease or any other factor that alters their environment and exposes them to new selective pressures. If, however, the environmental conditions do change in an adverse way, all members of the population in the ecosystem are susceptible and may die, and the species, such as the crescent nail-tail wallaby shown in Figure 9.2, may become extinct if the change is global or widespread.

Sexual reproduction always involves two parents and the fusion of two gametes. This means there are two sets of genetic information (unless self-fertilisation occurs) providing genetic variation. Together with mutations that may occur during DNA replication, and the independent assortment, crossing over and recombination that occur during meiosis, the resultant offspring will be genetically varied. Random mutations are the only source of completely new alleles with all the other processes just shuffling the existing alleles into new combinations. Mutations result in new characteristics in organisms in a species if the mutation persists. If, now or in the future, the environment changed (for example, due to lack of food or water, introduction of a new predator or disease-causing organism, use of pesticides or other chemicals, or changes in temperature or humidity) and the mutation resulted in a phenotype that conferred an advantage on those individuals carrying it, they would have a better chance of surviving and reproducing. The frequency of individuals in the population that carry the alleles of the gene for the better-suited characteristic would increase over generations compared to other members of the same species. Any inherited feature or characteristic that increases an organism's chances of survival and reproduction in a specific environment is called an **adaptation**.

CONNECT

Sexual reproduction was discussed in Chapter 6.

KEY CONCEPTS

- An ecosystem consists of all the living organisms in a specific area that make up the populations in the community interacting with each other and their physical surroundings.
- Genetic diversity is the range of genotypes of individuals in a population of a species or the entire species.
- Genetic diversity is essential for the survival of a population of a species, or for the survival of the whole species located in different widespread areas, if there is a change in the environment (such as habitat destruction, lack of resources, introduced predator, disease).
- If a species lacks genetic diversity and is lost from Earth's biodiversity, it is said to be extinct.
- Mutation is the only way new alleles can be introduced into a species.

Concept questions 9.1

1 What is an ecosystem? What do the terms biotic and abiotic mean? Give two examples of each.
2 What is genetic diversity? Explain its biological importance.
3 If a species lacks genetic diversity, what may happen to the species if there is an environmental change?
4 What is a population?
5 How are adaptations and interdependencies different?

HOT Challenge

6 Australian megafauna are thought to have become extinct about 40 000 years ago. Humans are thought to have inhabited the tropical savannah lands in Queensland for around 60 000 years. It is thought that humans and megafauna coexisted for at least 20000 years. In 2020 evidence was discovered at a fossil site at South Walker Creek in Queensland to suggest it was a changing climate that brought on the extinction of 13 species of megafauna, not hunting by humans as was once thought. Explain this finding by considering the biodiversity and genetic diversity of the megafauna.

9.2 Adaptations

Have you ever experienced what it is like to spend winter outdoors in the freezing cold of Falls Creek, or summer in the hot, dry, desert regions of central Australia? Most of us are not very comfortable at these temperatures, yet native Australian flora and fauna live in such environments year after year. These organisms can do this because they are adapted to their natural environments.

The bilby shown in Figure 9.3 is adapted to survive in harsh desert environments. It is a nocturnal animal, only coming out at night so it is not exposed to the heat of the day. It has small eyes and hence poor vision, but it has very large ears, which serve two important functions: it has acute hearing and it can lose excess heat through its ears where the blood vessels are very close to the surface. It has small, powerful front claws so it can dig burrows and find food, and a long nose that gives it an excellent sense of smell.

Getty Images/TED MEAD

Figure 9.3 A bilby is well suited to survive in its natural environment.

An adaptation is an inherited characteristic that makes an organism better suited to its environment and increases its chances of survival and reproduction. An organism cannot intentionally change to suit its environment, nor can it produce offspring that inherit any changes acquired during its lifetime. An adaptation results from a random mutation in the genetic material of an organism that is then passed on in its gametes to its offspring. The offspring produced may have differences in features that increase their chances of survival if those features make them better suited to their environment than other members of the same species. Because the mutations arise from changes to their genetic material, the changed features can then be passed on to their offspring. Adaptations are found in all organisms. In this chapter the focus will be on adaptations found in plants and animals in specific types of environments.

Australian environments are varied and diverse, with some having harsh conditions. Some of the factors that affect survival of organisms in Australian environments are availability of water and food, types and concentrations of mineral salts, temperature, and amount of sunlight. Over thousands of years, Australian species have become adapted to survive in these diverse and often harsh conditions.

There are three main types of adaptations found in organisms.

- Structural – anatomical or physical features of an organism that help it survive in a specific environment; such as the digging claws, very large ears and long nose of the bilby. Other structural adaptations could include colour of the organism, its shape and its size.
- Physiological – functioning features of an organism that relate to how its body works to increase its chances of survival; such as the increased blood flow and blood vessel dilation in the ears and skin of the bilby in hot desert conditions. Other physiological adaptations could include changes in metabolic rate for different levels of activity and temperature regulation, production of varying concentrations of urine depending on water availability, and changes in heartbeat and breathing rate.
- Behavioural – ways in which an animal acts that may increase its chances of survival and reproduction; such as being nocturnal or active at night to avoid high daytime temperatures, digging for food, or staying in a burrow during the daytime where it is cooler and more humid, as the bilby does.

EXAM TIP
Organisms cannot adapt themselves or acquire characteristics during their lifetime that will increase their chances of survival and be inherited by their offspring. It is the species that becomes better adapted by survival and reproduction of the better suited individuals.

KEY CONCEPTS

- An adaptation is an inherited characteristic that makes an organism better suited to its environment to increase its chances of survival and reproduction.
- The three types of adaptations that are found in organisms are structural, physiological and behavioural.

Concept questions 9.2a

1 Define an adaptation.
2 For a desert dwelling frog, a jungle living parrot and a penguin living on Antarctica, list an example of each type of adaptation in each of these three organisms.
3 Outline three non-living factors in the Australian environment for which terrestrial organisms need to have adaptations if they are going to survive.
4 List the adaptations shown by the bilby.
5 How do adaptations arise in a population of organisms?

HOT Challenge

6 Australia once supported many species of megafauna (Figure 9.4).
'The fossil dig at South Walker Creek gives insights into what megafaunal life was like in the tropical Australian savanna over a period of about 20 000 years, from around 60 000 to 40 000 years ago. During this time, the northern megafauna were different to those from the south. A yet-to-be named giant kangaroo is the largest ever found. With an estimated mass of 274 kg, it beats the previous contender, the goliath short-faced kangaroo, *Procoptodon goliah*.
'The biggest of all the mammals was the three-tonne marsupial *Diprotodon*, and the deadliest was the pouched predator *Thylacoleo*. Living alongside these giants were other megafauna species that still survive today: the emu, the red kangaroo and the saltwater crocodile.'

a Why might the northern megafauna be different from the southern megafauna in the tropical Australian savanna in Queensland?
b The emu, the red kangaroo and the saltwater crocodile still survive today. Some megafauna are extinct. In terms of adaptations, why are some extinct and others not?

Figure 9.4 **The giant kangaroo of South Walker Creek may be the largest kangaroo ever found. Pictured here next to the previous titleholder, *Procoptodon goliah.* Scale bar equals 1 m.**

Structural adaptations

A **structural adaptation** relates to how an organism's chances of survival in its natural habitat are improved by how it is built anatomically. Structural adaptations are physical features on both the inside and outside of an organism. The webbed feet of a platypus enable it to swim efficiently; thin, pointed leaves on spinifex grass reduce water loss; and the caecum in a koala enables it to digest the cellulose in plant cell walls in order to absorb the maximum amount of nutrients from its food.

Structural adaptations of plants

Two factors that organisms must cope with in hot, dry desert environments are limited availability of water, and very high daytime and low night-time temperatures. Desert plants must balance water uptake, needed for photosynthesis and cell functioning, with loss of water through the stomata by transpiration, which helps the plant stay cool and pull up the continuous columns of water and dissolved mineral salts from the roots to the leaves. Plants living in areas where water is in limited supply must achieve a balance between water uptake and water loss, so they do not lose excessive water, dehydrate and die.

Xerophytes, such as some Australian plants, are plants that live where little liquid water is available. They possess structural adaptations to maximise water absorption and storage of water and minimise water loss.

One type of xerophyte is the group of plants known as succulents, such as pigface (*Carpobrotus glaucescens*) (Figure 9.5a), which have adaptations such as fleshy stems, leaves and even roots. These plant parts can swell up and retain moisture when water is available; they can then survive during dry periods by using this moisture. Australia has some succulent species, including members of the desert plant genus

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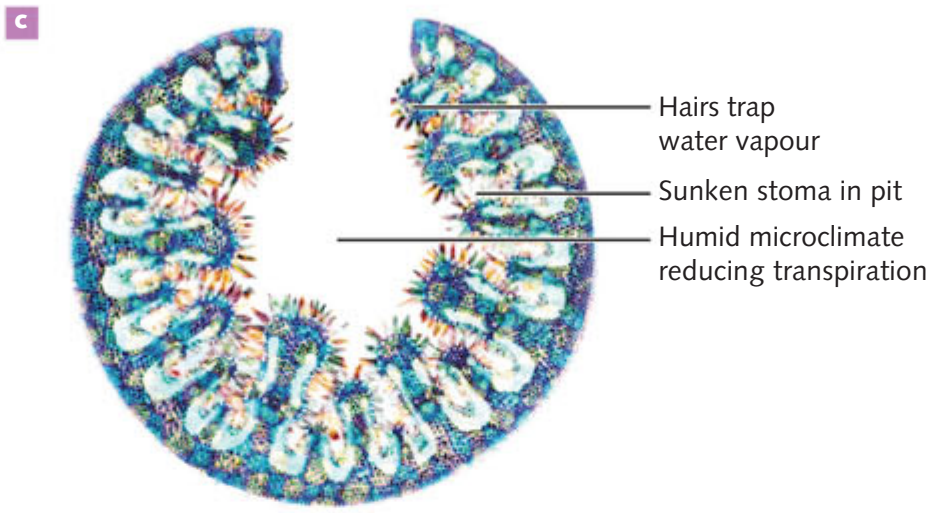

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Figure 9.5a A pigface plant has fleshy, moisture-filled stems; **b** Spinifex grass with pointed narrow leaves to reduce water loss; **c** Transverse section through a leaf of an Australian xerophyte (dune grass) showing a rolled leaf with hairs to trap water vapour, thereby increasing the humidity near the stomata; these are in pits that enable them to remain open for gas exchange while decreasing water loss

Calandrinia (parakeelya). This is an important food for Aboriginal people, who use the leaves as a green salad leaf and a source of moisture in desert environments.

Many eucalypts and banksias are native to Australia. They have coarse, leathery leaves with a thick coating of wax, or cuticle, over the leaves, to reduce water loss by evaporation and to reflect excessive sunlight because the wax has reflective properties. These features make them better adapted to hot, dry environments than plants with thinner waxy cuticles.

Leaf shape can also be important for reducing water loss. Cypress pines have tiny cylindrical leaves that have a very small surface-area-to-volume ratio. This reduces water loss through transpiration. All spinifex species have tough, pointed and narrow leaves for reducing water loss (Figure 9.5b). Porcupine grasses (*Triodia scariosa*) roll their leaves during the hottest part of the day so the stomata (leaf pores) are on the inside of the roll and not exposed to the hot, dry atmosphere. This creates a humid microclimate inside the rolled leaf that reduces transpiration (Figure 9.5c).

CONNECT

Refer to Chapters 3 and 4 for a discussion of transpiration and stomata.

Sclerophyll (hard) plant leaves have a variety of structural adaptations to reduce water loss: waxy or hairy leaf surfaces; sunken stomata; or greatly reduced leaves. Sunken stomata or stomatal pits occur in *Hakea* and in the flattened stems of she-oaks. The actual stomata are lower than the main surface of the leaf in a pit that traps moist air. Hairs in the stomatal pit also aid in trapping water vapour from transpiration, thus creating a humid microclimate. These adaptations reduce transpiration while the stomata can still remain open for carbon dioxide and oxygen gas exchange (Figure 9.6).

Epidermal hairs on the surface of leaves also trap a moist layer of air. This results in a smaller difference between the concentration gradient of water in the leaf cells and the water vapour in the

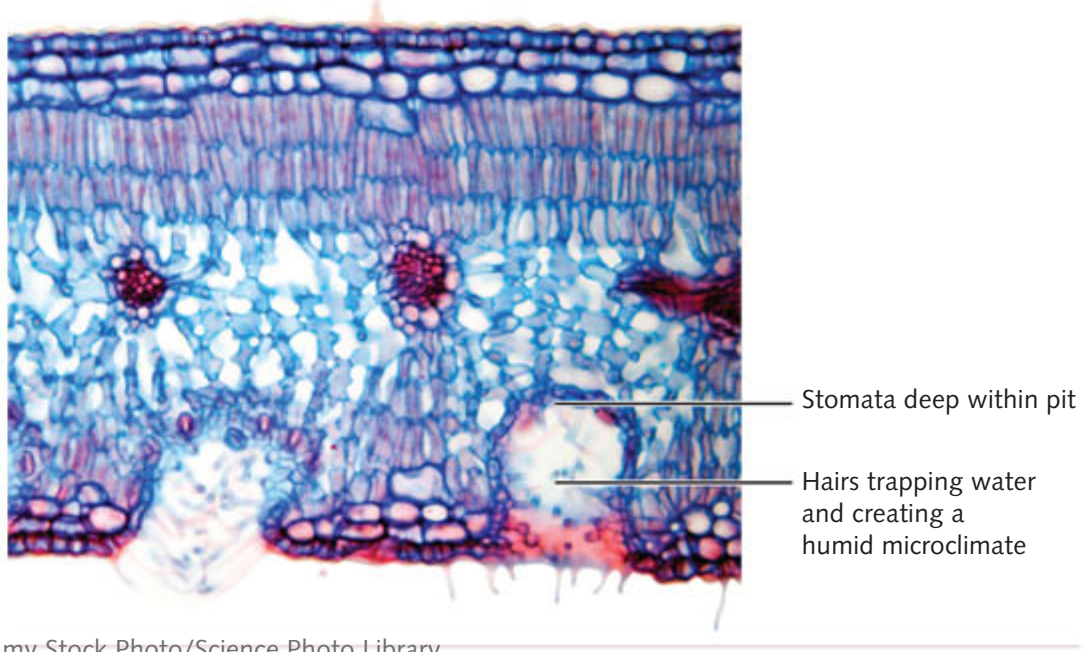

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Figure 9.6 Sunken stomata in a leaf of oleander, an exotic plant. The hairs in the stomatal pit trap water vapour from transpiration, creating a humid microclimate.

Felicity Clissold

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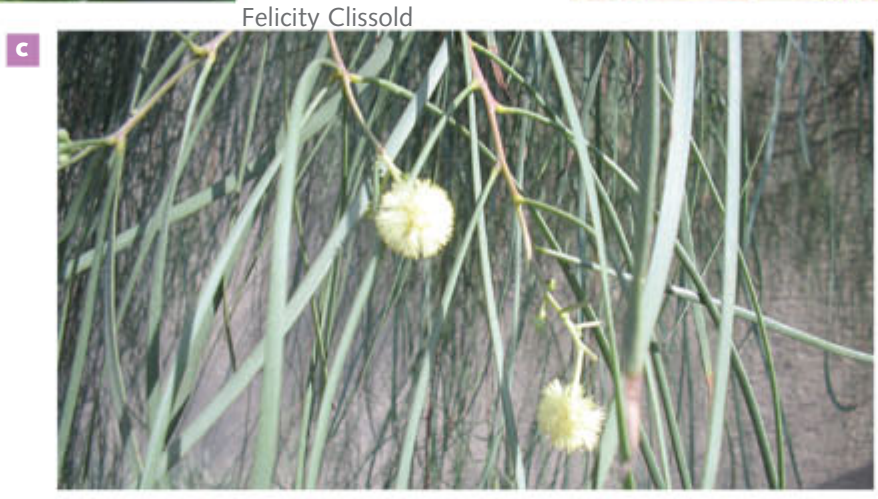

Wikimedia/Don A.W. Carlson CC

Figure 9.7a The leaves of White correa *(Correa alba)* are covered with hairs to reduce transpiration. **b** *Hakea* fruits (*Hakea drupacea*) are woody rather than fleshy to reduce water loss. **c** Leaves of shoestring wattle *(Acacia stenophylla)* hang vertically to reduce the amount of light to which they are exposed.

layer of air trapped by the hairs. This will reduce the amount of water lost from the cells. The coastal banksia (*Banksia integrifolia*) has hairs on the undersurface of leaves and leaves of *Correa alba* are hairy all over (Figure 9.7a).

Fruits are structures produced by plants to contain seeds. The fruits need to protect the seeds during their development and aid in dispersal by wind or animals that eat the fruit. Many Australian plants, such as *Hakea*, produce woody fruits rather than fleshy fruits, as an adaptation to a water-restricted climate (Figure 9.7b).

Many acacias (wattles), such as the shoestring wattle (Figure 9.7c), have vertically flattened leaflets that are oriented towards the ground, thus directing any water towards the root zone, reducing the amount of light absorbed and consequently the water loss. The deep root systems of desert plants allow access to water supplies deep underground. Some plants also possess additional shallow root systems that enable the rapid uptake of moisture when it becomes available immediately after rainfall.

INVESTIGATION 9.1

An investigation of structural adaptations in plants

Vascular plants are made up of the shoot and root systems. The shoot system is above the ground and made up of stems, leaves, fruits and flowers. The root system is below the ground and made up of a variety of different types of roots, such as fibrous roots, tap roots and adventitious roots. These structures may have modifications to suit specific sets of environmental conditions.

Aim

To observe macroscopic structural adaptations of Australian plants and to relate these to increased chances of survival of the plants in their specific environments

Materials

- Disposable gloves
- Safety glasses
- Forceps
- Stereo microscope
- Camera
- Leaf, stems, roots, fruit and/or flower samples of Australian sclerophyll plants such *Hakea*, eucalypt, wattles and spinifex; and succulents such as pigface and cactus species

What are the risks in doing this investigation?	How can you manage these risks to stay safe?
Some plants produce irritants or poisons that can affect eyes, skin and mucous membranes.	Wear disposable gloves and safety glasses, and wash your hands thoroughly after completing the investigation.
Thorns and spikes can pierce skin.	Be careful when handling plant material. Use forceps if they are available.

What other risks are associated with this investigation and how can you manage them?

Method

1. Carefully observe (see, smell, feel) each sample, looking at the stems, leaves, fruits and flowers.
2. Place each sample in turn under the stereo microscope to view structural features more closely.
3. Record any adaptations that enable the plant to conserve water (such as hairs on the underside of the leaf, woody fruits or thick, shiny wax on leaf surfaces).
4. Draw a scaled biological diagram in your logbook or take a photo. Label the specific adaptations observed.
5. Observe and note any other types of adaptations that enable the plant to survive in its natural environment.
6. Record any variations observed in plants that could not be related to their survival in their natural environment.
7. Use resources, such as the Internet or books, to find out the natural environment of each plant.

Results

Construct a table in your logbook like the one below to record the adaptations observed in each plant. Explain how each adaptation may assist in the plant's survival. Add rows as required.

Name of plant	Adaptation	Diagram or photo	Natural environment of the plant	How might this adaptation assist in the survival of the plant?

Discussion

1. List the adaptations that you identified as those that assist the plant in:
   a. conserving water
   b. reflecting light
   c. staying cool.
2. List any other types of adaptations that enable the plant to survive in its natural environment and describe how each adaptation aids survival.
3. List any adaptations observed in plants that you could not relate to their survival.
4. Outline one limitation of making inferences about structures in plants.
5. How could you ensure that your observations were reliable?

Conclusion

Write a conclusion using evidence gained during this investigation.

Structural adaptations of animals

Australian animals, like plants, need to be well adapted to their natural environment in order to survive and reproduce. Survival issues for animals include gaining enough food and water, keeping cool or warm, finding space to live, deterring predators, and avoiding bodily damage and disease.

Figure 9.8 Thorny devil (*Moloch horridus*) in its natural environment

The thorny devil (*Moloch horridus*, Figure 9.8) is a small lizard, about 20 cm long, that lives in the Western and Central Australian deserts. It feeds on a diet of black ants and termites. The body of the thorny devil is covered with large prickly spikes, making it look ferocious and hard to swallow. This helps to deter predators from eating it. Water from rain and dew is captured by a complicated set of layered scales all over the lizard's body. Each scale is attached by a hinge joint that enables the lizard to collect water and funnel it to the back of its mouth using capillary action. The thorny devil then uses its tongue to draw the water into its mouth.

On the top of the thorny devil's real head is a 'false head' made up of bony material. If the thorny devil is threatened, it will tuck its real head between its front legs, causing its body to look a lot larger. The predator may see the false head and attack this, causing no damage to the lizard's actual head. The gold and brown coloration of the thorny devil's body camouflages it against the red soil in the desert, making it difficult to be seen by predators.

The common wombat (*Vombatus ursinus*) is a nocturnal animal that lives in an extensive burrow. The burrow can be up to 11 m in depth and 30 m long. Wombats are prolific diggers, with large muscular shoulders and long claws on their front feet.

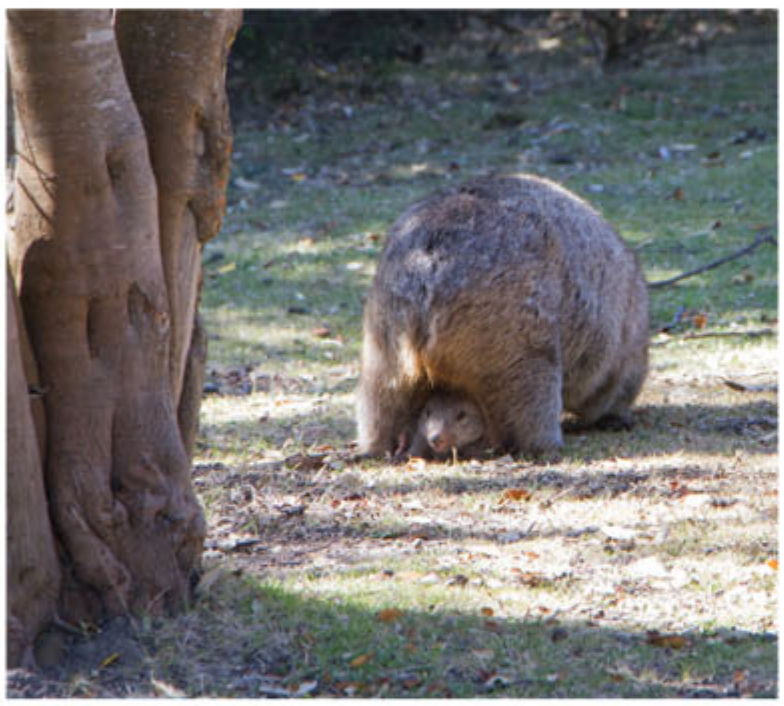

Figure 9.9 A wombat has a backward-facing pouch to protect its young while digging for food and its burrow.

Because wombats are marsupials, they give birth to an underdeveloped young (the joey), which then remains in the pouch for 5 months feeding on milk and growing rapidly. The pouch opens to the rear, not to the front (Figure 9.9). This is a structural adaptation in response to the wombat's digging habit. The pouch orientation ensures that the young, vulnerable joey will be protected from dirt, sticks and roots that would otherwise enter the pouch if it faced forwards. This adaptation assists in the survival of the species, because it ensures that the offspring are protected from harm until they can venture out on their own.

Wombats are **herbivore**, eating only plant material such as grass and leaves. The constant grinding of tough, fibrous material wears down their teeth. This could result in starvation and death if the teeth were severely ground down. Their teeth, however, are well adapted to cope with their fibrous diet. A wombat has 24 rootless teeth that grow continuously to replace those that are worn down. It has a pair of large deep-rooted incisors for snapping off grass, no canines, and a large space between its incisors and premolars. The premolars provide a large surface area for grinding plant material.

INVESTIGATION 9.2

An investigation of structural adaptations in an Australian animal

Choose one native Australian animal that has not been described above. Use secondary sources to research its natural environment, and the structural adaptations that this animal has that enable it to survive there.

Weblink
CRAAP test

Aims

1 To gather information from secondary sources
2 To analyse the information and relate adaptations to survival in a specific environment

Method

Refer to the CRAAP test of evaluating sources. (See weblink.)

1 Working in groups of three, each student selects a different Australian animal to research. Using a variety of different resources from current textbooks, websites, journals and experts, students should gather relevant information about the adaptations of their chosen animal. They may work in a Google Doc so they can share information later.

2 Use the CRAAP test to ensure the information gathered is relevant, free from bias, and current.
3 Collected information should be referenced and presented in a table, as described under the Results heading.
4 Compare the adaptations of the Australian animal researched with those of the animals researched by other group members.

Results

1 Summarise your findings in a table with specific headings that describe the environment in which the chosen animal lives, the adaptations it possesses and the way in which the adaptation increases the chances of survival of the animal.
2 Compare all animals researched by the three group members by considering:
   a the environments in which they live
   b the factors in the environment to which they are adapted
   c two structural adaptations that make them better suited to their environment.

Discussion

1 How did you ensure that the information you gathered was scientifically accurate?
2 Comment on whether you think your chosen animal is well adapted for survival in its natural environment. Justify your answer.
3 Suggest other adaptations not observed in your selected animal that could make it better adapted to survive in its natural environment. List and describe them, outlining the purpose of each.
4 Explain why making inferences about adaptations can be difficult.

Conclusion

Use the data gathered to make a general statement relating the structural adaptations of the animals studied by your group members to the survival of those animals in their specific environments.

KEY CONCEPTS

» A structural adaptation refers to the physical or anatomical features an organism possesses that increase its chances of survival and reproduction in its natural environment.

Concept questions 9.2b

1 Define structural adaptation.
2 Describe the main survival problems facing desert plants in Australia.
3 Choose one of the survival problems you listed in question 2 and state two adaptations of desert plants that assist them in overcoming that problem.
4 Outline three survival problems facing animals in Australia.
5 Choose one of the survival problems you listed in question 4 and describe two structural adaptations of animals that assist them in overcoming that problem.

HOT Challenge

6 Explain why broad-leafed tropical plants like those found in the Daintree Rainforest do not live in the Australian desert.

Physiological adaptations

The physiology of an organism refers to all the processes involved in the functioning of the organism. **Physiological adaptations** are features of an organism's functioning that increase its chances of survival and reproduction in its natural environment. They involve variations in the metabolism or activities

of the organism at a cellular, tissue, organ or system level, which give the organism increased survival advantages in a specific environment. For example, the intertidal marsh crab has gills and kidneys that function to concentrate and excrete excess salt. Flamingos can tolerate the alkaline waters of soda lakes that would kill other birds because they have resilient skin and scales on their legs that can withstand the corrosive effects. Plant cells found in the growing tips of stems are sensitive to the hormone auxin, which causes them to grow towards light for greater photosynthesis.

Physiological adaptations in plants

Various abiotic or non-living factors in the environment play an important part in determining the type of plants that can grow in an area. Many plant species have physiological adaptations in order to survive in habitats where abiotic factors play an important role in determining which plants can survive.

As well as very hot environments, Australia has some very cold environments. Plants that inhabit environments where temperatures can be extremely low, such as alpine areas, have features to reduce the risk of ice forming within and between their cells. Ice crystals pierce plasma membranes, killing the cells and ultimately the plant. Some alpine plants produce organic compounds that act as an 'anti-freeze' substance, reducing the temperature at which the cytoplasm and fluid in the vacuole freezes.

In response to lower temperatures, some trees are deciduous, losing their leaves in winter. They usually then undergo a period of dormancy which helps them to survive the lower temperatures and decreased availability of sunlight. The deciduous beech, *Nothofagus gunnii*, found in Tasmania, is one of the few native Australian deciduous trees (Figure 9.10). Its leaf fall takes place in late April and May in response to the shorter days in autumn. The decreased period of daylight leads to a waterproof layer forming at the base of each leaf. Without water entering the leaf, photosynthesis cannot occur. As the chlorophyll degrades, the pigment anthocyanin is exposed and gives the leaves their spectacular autumn coloration. Some trees are deciduous and lose their leaves due to severe water shortages, as is often seen in dry or drought-stricken areas of Australia.

Getty Images/Moment/Posnov

Figure 9.10 The deciduous beech, *Nothofagus gunnii*, showing beautiful autumn colours before leaf fall

Some plants flower in response to low temperatures, such as tulip bulbs, which must be exposed to at least 6 weeks and up to 3 months of intense cold before they will flower. This is called vernalisation and is an adaptation to living in northern hemisphere winters in central Asia, where they originated. Australian gardeners often mimic vernalisation by removing tulip bulbs from the ground in winter and storing them in a refrigerator, before replanting them in spring, to ensure that they flower.

The concentration of salt in the surrounding environment, whether in the water for aquatic plants or in the soil for terrestrial plants, can also have a high impact on determining survival in plants. Salt, even in relatively small concentrations, can have a damaging effect on cell structure and functioning, because water will pass by osmosis from a higher water concentration to a lower water concentration, causing the cytoplasm to shrink and cell functioning to be disrupted (Chapter 1, p. 38). Plants that are well adapted to saline environments are called halophytes. These plants use either salt tolerance (salt accumulation) or salt avoidance (salt exclusion) as strategies to survive in environments where they are exposed to high salt concentrations.

Salt-tolerant plants, such as sea grass and mangroves, can maintain metabolic functioning even though their cells accumulate sodium and chloride ions. They minimise salt toxicity by increasing their water content in large vacuoles. In contrast, salt-avoidant plants (salt excluders) minimise the salt concentrations of their cells through structural and physiological adaptations, such as preventing salt from entering the roots. The saltbush, *Atriplex vesicaria*, is a salt excluder. It actively transports excess sodium and chloride ions into bladder cells situated on the tips of hairs on the surface of leaves (Figure 9.11). When the bladder cell reaches maximum salt capacity, it secretes the salt into the environment, or the leaves die and drop off.

Palmer's grass, *Distichlis palmeri*, also actively secretes salts from specialised cells to avoid high salt concentration within its cells.

Succulents minimise salt toxicity or poisoning by increasing the water content in their large cell vacuoles, so that accumulation of excess salt is diluted by water drawn into the cells. Pickleweed (*Salicornia*) handles salt in two ways: some salt is filtered out at the roots by sodium–potassium pumps in the plant's plasma membranes, and excess salt is pumped by other cells to vacuoles at the tips of the plant's jointed segments.

Mangroves are extremely well adapted to changing salt concentrations, using both salt avoidance and salt tolerance strategies, because they live in water that can be up to 100 times saltier than most other plants can tolerate (Figure 9.12). The river mangrove, *Aegiceras corniculatum*, can tolerate a higher than normal solute concentration in its cells. It also actively secretes salt through glands on the leaf surface. Salt accumulates in its bark and leaves and is lost when they fall off. Up to 97% of salt is excluded from entering the roots, thereby reducing the amount of salt entering the plant's tissues.

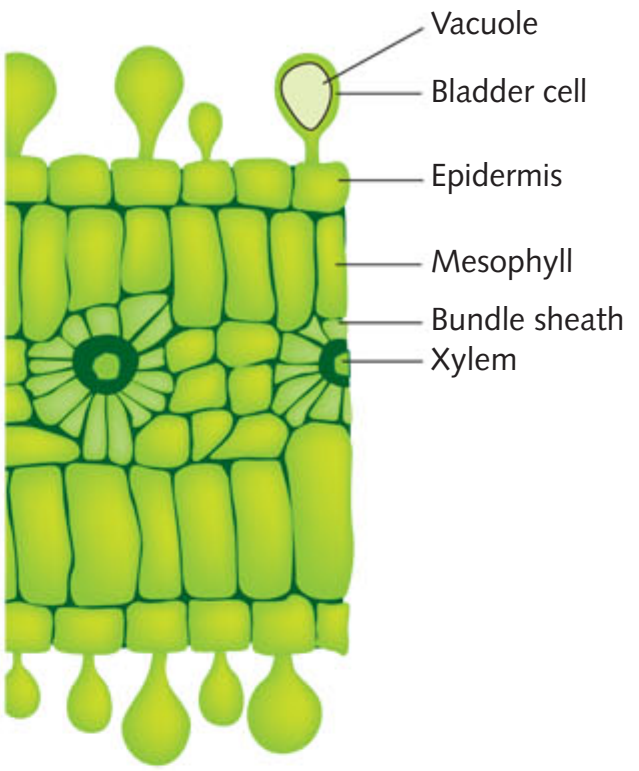

Figure 9.11 Salt-excreting bladder cells in the saltbush, *Atriplex vesicaria*

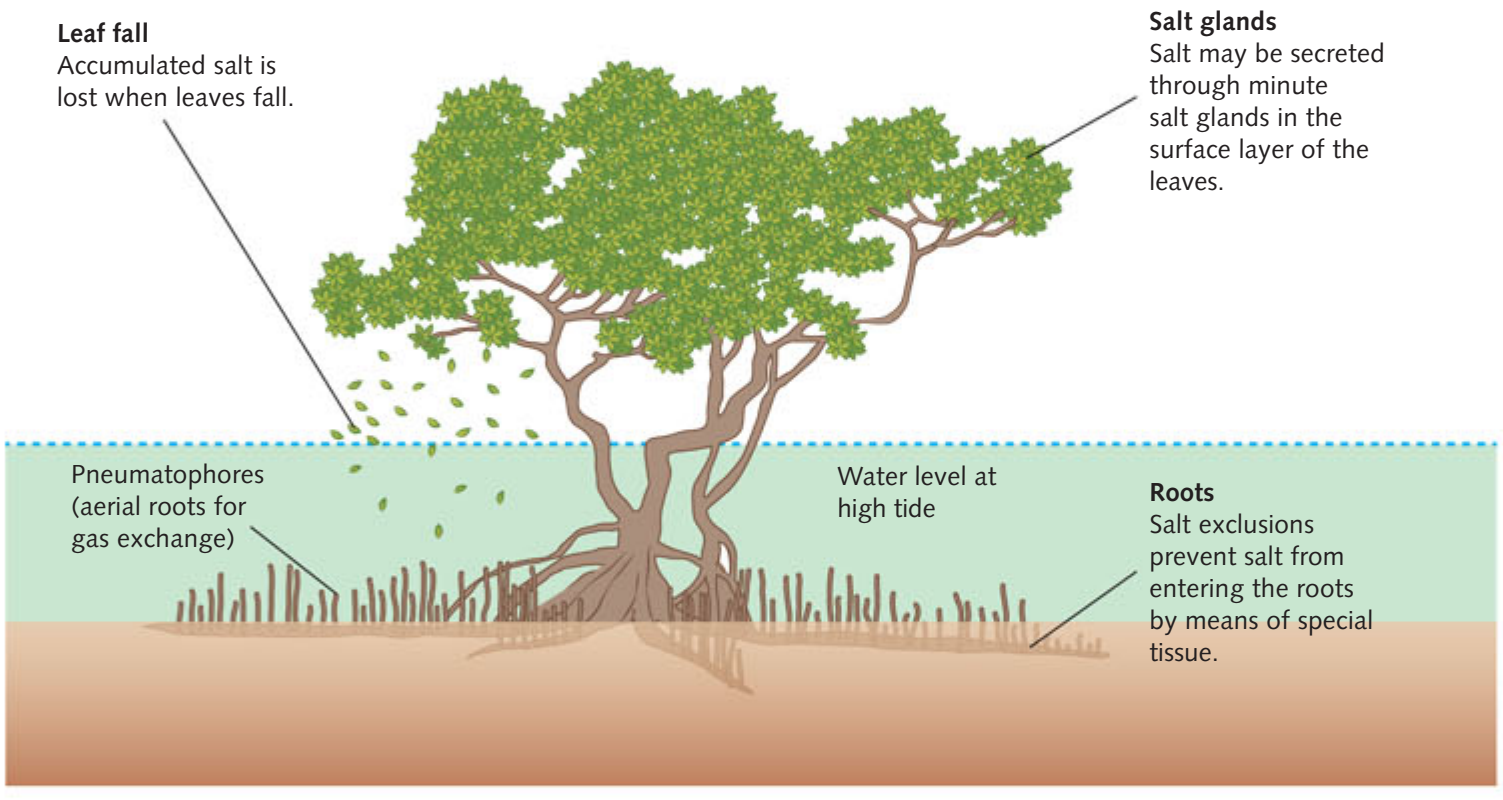

Figure 9.12 Mangroves have a variety of physiological adaptations to tolerate living in high salt environments.

Physiological adaptations in animals

Animals have a variety of physiological adaptations that enable them to survive in their natural environment. Animals can move from one region to another and so are more likely to be exposed to a larger range of environmental conditions.

WB
9.2.1 ADAPTATIONS OF ANIMALS: KING PENGUINS PAGE 215

The spinifex hopping mouse, *Notomys alexis*, and some other desert mammals, can reduce their water loss by excreting highly concentrated urine. This is due to their ability to reabsorb most of the water from their urine back into their bloodstream. They can also use the metabolic water produced as a by-product of aerobic cellular respiration (about 0.56 gram of water per gram of carbohydrate) so they have adequate water for their needs.

Freshwater fish have the opposite problem to the hopping mouse. As their body cells have a higher concentration of ions than the surrounding water, water molecules enter their tissues. To counter this, their kidneys have a high filtration rate and produce large amounts of dilute urine.

Penguins can live in very cold environments, such as the Antarctic. In common with many aquatic birds, they have a unique way of reducing heat loss called a countercurrent heat exchanger

Weblink
Adaptations to the desert

Worksheet
Adaptations to the desert

(Figure 9.13). Heat from blood travelling through the arteries to the foot is transferred to the cooler blood returning to the body in the close adjacent veins. This results in less heat being lost from the body and more being returned to maintain core temperature. The blood going to the foot is cooled in this process, reducing the gradient of temperature difference between the foot and the surroundings, so less heat is lost.

Penguins, seals, polar bears and whales convert a large proportion of their diet into a thick layer of fat (blubber) to insulate them from the cold. The layer of blubber in polar bears can be up to 12 cm thick. They are so well insulated that they cannot run for long distances or they may overheat.

Some animals survive hot or dry periods by going into a state of prolonged torpor or dormancy, thereby reducing their metabolic rate so that their body temperature is lowered. This condition, called aestivation, enables the animal to retain water, ration its fat storages and conserve energy. Land snails of the genus *Helix* will move into the shade, seal the opening to their shell with a mucus-type material and aestivate (Figure 9.14). The northern burrowing frog, *Neobatrachus aquilonius*, will aestivate by burrowing underground and sealing itself in a water-tight mucus cocoon made from an accumulation of layers of shed epidermis.

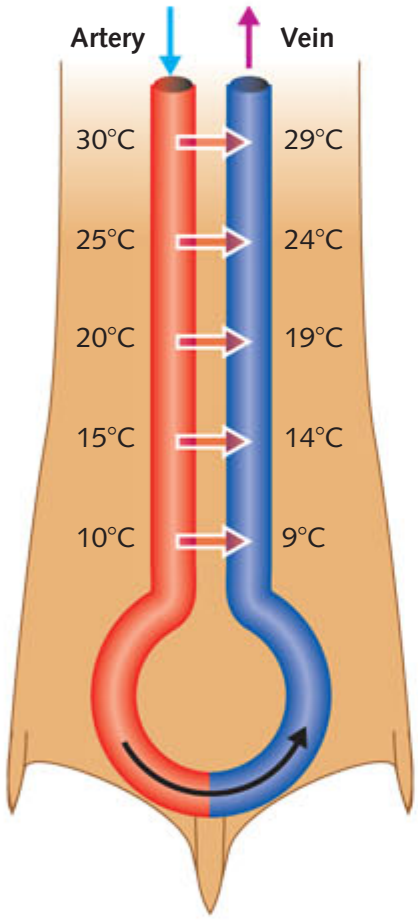

Figure 9.13 The countercurrent heat exchanger in the legs and flipper of penguins helps to reduce heat loss and retain body heat.

Alamy Stock Photo

Figure 9.14 An aestivating snail can survive hot or dry periods.

INVESTIGATION 9.3

An investigation into physiological adaptations

Working in pairs, choose one Australian plant and one Australian animal to research. One member will work on the plant and the other on the animal.

Research one physiological adaptation in the chosen plant and one physiological adaptation in the chosen animal, that assists in overcoming an environmental problem. Use resources such as journals (for example the *Australian Journal of Agricultural Research*, *Australian Geographic*, *Australian Journal of Zoology*), books and the Internet. Each person is to produce a one-page report, with photos and diagrams, that states the environmental problem overcome by the physiological adaptation and the mechanisms used to overcome this problem. All information needs to be appropriately referenced.

Peer review each other's reports, providing at least two positive comments and one area for improvement.

KEY CONCEPTS

» Physiological adaptations are features of an organism's functioning that increase its chances of survival and reproduction in its natural environment.

Concept questions 9.2c

1 Distinguish between a physiological adaptation and a structural adaptation. Use two examples of each to illustrate your answer.
2 Outline two physiological adaptations of plants that enable them to live in:
   a very cold environments
   b high salt environments.
3 Outline two physiological adaptations of animals that enable them to live in:
   a very cold environments
   b very hot environments.
4 Sea lions live on offshore islands along the southern Australian coast. They source most of their diet from the sea, including squid, sharks, lobsters and little penguins. They spend a great deal of time lying around the water's edge. They only seem to move if prey strays into their sightline. Considering the habitat of sea lions, list three physiological adaptations that you would expect sea lions to possess.
5 Sea lion males are darkish brown in colour while females are more silvery-grey on top and creamy yellow on the underbelly. Pups are chocolate brown in colour with a pale fawn crown until they moult at about two months of age. After moulting, a juvenile's coat is similar to that of an adult female. The development of hair colour by accumulation of pigment is a physiological adaptation. Account for the colours of fur in sea lions in terms of adaptation to their habitat.

HOT Challenge

6 'The formation of calluses on hands is a physiological adaptation.' Justify this statement.

Behavioural adaptations

WB 9.2.2 ADAPTATIONS OF PLANTS PAGE 217

Behavioural adaptations are actions performed by an organism in response to a stimulus that improve its chances of survival and reproduction. For example, puffer fish can pump air into their stomachs and blow up to twice their size to frighten predators. Antarctic penguins form a large huddle during winter to survive the freezing cold winds. They constantly rotate through the huddle, with those on the outside working their way to the inside so as reduce the time each is exposed to the cold.

Behavioural adaptations in plants

Plants generally do not move much. It is strange to think of plants as exhibiting behaviour, but they do by responding to stimuli in subtle ways, less obvious than in animals.

Mimosa pudica (Figure 9.15), originally from tropical America, has become a serious weed in tropical Australia. It responds to the stimulus of touch. When a leaf is touched by a predator or insect, it folds inwards, defending itself from harm.

The Venus flytrap (Figure 9.16) is a plant that is adapted to live in soil that is low in nitrogen. It can act rapidly when a small insect settles on it. A modified leaf on the plant snaps shut when the insect touches delicate sensory hairs twice in the space of a couple of seconds. The insect becomes trapped inside and the plant secretes digestive enzymes onto it for digestion, and then absorption of nutrients (mainly nitrogen from the insect proteins).

The behavioural adaptations shown by *Mimosa* and the Venus flytrap both result from rapid changes in turgor pressure. Turgor pressure usually keeps plant cell vacuoles full and pressing against the cell wall. In these two plants, however, as a result of touch, water flows quickly out of the vacuoles, resulting in a loss of turgor pressure and collapse

Alamy St

Figure 9.15 ***Mimosa pudica,*** **also known as 'touch-me-not' or 'shy plant'**

Shutterstock.com/ChameleonsEye

Figure 9.16 Venus flytrap gains required nutrients by catching and digesting insects.

of the cells. These are physiological adaptations, leading to behavioural adaptations.

Behavioural adaptations in animals

Animals display a great range of behavioural adaptations that can be shown by individuals or groups. The result of each adaptive behaviour is to increase the chances of survival of the individual or the individuals within the group.

The body temperature of ectotherms, such as lizards, tends to fluctuate over a range of temperatures because it is influenced by the surrounding air temperature. Ectotherms use external sources of heat to regulate their body temperature. They behave in such ways as to gain or lose more heat, thereby keeping their body temperature more constant.

Brown snakes are found across most of Australia, inhabiting a range of habitats from open grasslands to desert scrub, but never rainforests. They are usually diurnal, meaning they are awake during the day. The eastern brown snake, *Pseudonaja textilis*, is found in hot, dry areas along the eastern seaboard. If the surrounding temperature rises above the brown snake's tolerance level, it will seek shelter in the shade during the day and become active in the later cooler part of the day, or even at night. If the surrounding temperature drops below its optimum body temperature, the snake will bask in the sun to gain heat. In very cool weather, the snake becomes less active, slowing down its metabolism and using its fat reserves, and it may even go into a state of torpor.

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Figure 9.17 Central netted dragon

The central netted dragon, *Ctenophorus nuchalis* (Figure 9.17), is a lizard well adapted to the desert. It inhabits the plains and open scrub of Central Australia and can withstand variations in body temperature from 13°C to 44°C. In low air temperatures, the dragon will lie in the sun and alter its body position to expose more of its body surface area to the Sun's rays, thereby increasing its core body temperature. If the air temperature rises above its heat tolerance level, the lizard will retreat into the shade of rocks and vegetation or into a burrow and reduce its activity to avoid overheating. It will then emerge at night to hunt when the air is cooler.

Endotherms are animals that maintain a relatively constant body temperature by generating heat internally from cell metabolic processes. They tend to avoid the heat of the day. For example, the bilby hides in a humid burrow to stay cool and to reduce water loss by evaporation. The largest of the kangaroo species, the red kangaroo, *Macropus rufus*, rests throughout the day, usually in the shade, and then gathers in a large family group at dusk to feed. Some species of wallabies lick their wrists where the blood vessels form a dense network close to the skin surface. Even though this means loss of water, the evaporation of the saliva has a cooling effect, reducing body temperature.

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Figure 9.18 A meerkat sentry watches for danger.

Some species exhibit social behaviour aimed at increasing the survival of the group. Sugar gliders, *Petaurus breviceps*, produce a pungent aroma from scent glands located on their head, chest and near the genital opening. Members of a group are permeated by the scent of the dominant male and therefore can locate each other successfully in fading light at dusk.

Meerkats (*Suricata suricatta*) live in large social communities. They are burrowing carnivores that spend a great amount of each day with their heads in the ground searching for food. This makes them vulnerable to attack by predators, but one animal is usually posted as a sentry (Figure 9.18). When a threat is imminent, the sentry produces a series of distinctive calls as a warning for all meerkats to be alert. The rest of the colony responds by standing on their hind legs and scanning the area for predators.

INVESTIGATION 9.4

An investigation of different types of adaptations in an organism

Choose one plant or one animal to research. Use resources such as journals, books and the Internet to research the structural, physiological and behavioural adaptations in your chosen plant or animal. Present your findings as a PowerPoint presentation (or similar), showing one adaptation per slide. Include photographs and/or videos. Make sure that you cite all your sources correctly.

KEY CONCEPTS

» Behavioural adaptations refer to the ways in which organisms act in response to stimuli that improve their chances of survival.

Concept questions 9.2d

1 Define behavioural adaptation.
2 Provide an example of a behavioural adaptation in a plant. Explain how it assists in increasing the plant's chances of survival.
3 State three behaviours used by an ectothermic animal to assist in regulating its body temperature.
4 Provide three behaviours used by an endothermic animal to assist in keeping cool during the heat of the day.
5 Outline one example of social behaviour in animals that increases the chances of survival of the group.

HOT Challenge

6 Australian sea lions are excellent climbers and can often be found on cliffs a few kilometres inland.
   a What aspects of this observation demonstrate behavioural adaptation?
   b If the diet of the Australian sea lion includes fish and crustaceans and even small penguins, why might they be found on inland cliffs?

9.3 Survival through interdependencies between species

All species rely on other species in some way for survival. They may rely on them for food, shelter, water uptake, minerals, physical support or even to help them reproduce. Biological interdependencies are the interactions between different species that are essential if organisms are going to survive and reproduce and, ultimately, for the successful functioning of the ecosystem. Interdependencies may involve direct contact between different species, or species may affect each other through more indirect ways, such as sharing resources or having the same predators. All the organisms of the species have specific adaptations that have been selected for as they aid the survival and reproduction of the species and are inherited through generations.

WB 9.3.1 INTERDEPENDENCIES BETWEEN SPECIES PAGE 218

The term **symbiosis** comes from a Greek word meaning 'living together' and is used to describe a relationship in which individuals of two or more different species live together and in which at least one of the species benefits or is harmed. There are four main types of symbiosis.

» **Parasitism**: one species benefits at the expense of the other
» **Mutualism**: both species in the relationship benefit and neither is harmed
» **Commensalism**: one species benefits and the other neither benefits nor is harmed
» **Amensalism**: one species is harmed and the other neither benefits nor is harmed

Parasitism

Most species, including humans, are regularly at risk of being infected with multiple different parasites. A **parasite** is an organism (such as a bacterium, virus, fungus, worm or arthropod) that lives on or in another organism, known as the **host**. The parasite benefits by gaining food and shelter to the detriment of the host. However, the parasite does not usually kill the host until it has reproduced and been dispersed to other hosts. Parasites are very well adapted, with regards to their life cycle, structure and physiology, to find their host and survive the hazards of being dependent on them.

For example, native mistletoe is a parasitic plant that uses eucalypt trees as hosts to obtain water and nutrients (Figure 9.19a, b). The mistletoe plant is transferred from one tree to another by the mistletoe bird (Figure 9.19c), which spreads the mistletoe seeds in its faeces throughout the eucalypt ecosystem. The seeds are covered in a sticky substance that dries and sticks them to the branch, where they germinate spontaneously. The mistletoe causes reduced growth of the eucalypt host tree.

a

b

Alamy Stock Photo/BotanyFocus

c

Alamy Stock Photo/Ava

Figure 9.19a, b The mistletoe plant is spread by c mistletoe birds, which eat the berries and then defecate the sticky seeds onto branches.

Mutualism

Not all relationships cause harm to a species. In mutualism, both species benefit and neither is harmed. There are differing levels of mutualism, from a rather loose association in which the partners seem to gain little from each other to associations that are so intimate that the two partners can be regarded as a single organism. In mutualism, organisms work together and share the same ecosystem and even the same habitat, the area or environment where an individual or species lives within an ecosystem.

An example of mutualism is the relationship between the pistol shrimp and the goby fish. The 'blind' shrimp uses the goby fish to detect predators that approach its burrow and then allows the goby fish to share its burrow at night. Another example is the pygmy possum, which benefits by collecting nectar from the eucalypt blossom and acts as a pollinator to carry pollen from that eucalypt to another (Figure 9.20).

The most intimate mutualistic association is achieved when one organism lives inside the cells or tissues of another. Many coral polyps, jellyfish, clams and sea slugs have algae living in their tissues. The algae gain nitrates and phosphates for their metabolism from the waste material of their animal partner, and the animal partner, in turn, gains organic compounds from algal photosynthesis.

Alamy

Figure 9.20 This pygmy possum, while collecting nectar from eucalypt blossom, is also acting as a pollinator.

Commensalism

Commensalism is a one-sided interaction between species in which only one of the organisms benefits; the other organism does not benefit and is not harmed. For example, the remora fish gets a free ride on the back of a shark and scraps of food by attaching its suction pad to the back of the shark's head, while the shark is unaffected. Another example is the relationship between the cattle egret bird and livestock, in which the bird forages for food next to large livestock (Figure 9.21). As the livestock disturb insects in the grass, the egret feeds on them. The egret will sit on the back of the animal to have a better vantage point to spot insects.

Alamy

Figure 9.21 The commensal relationship between the cattle egret and the zebra

Amensalism

Some relationships are not beneficial to either of two species. Amensalism is a relationship that is detrimental to one species and neutral to the other. Amensalism is a type of competition because a larger or more powerful organism excludes another organism from its requirements, such as a source of shelter or food. For example, tall trees reduce the available sunshine at ground level so ground plants such as grasses do not have adequate light to grow in the shade. Another example is the bread mould *Penicillium*; it produces penicillin, which destroys many types of bacteria that grow on bread (Figure 9.22). The *Penicillium* mould does not benefit but the bacteria die.

Shutte

Figure 9.22 Example of amensalism: Penicillium mould does not benefit from killing surrounding bacteria.

KEY CONCEPTS

» Biological interdependencies are interactions between different species that are essential if organisms are to survive and reproduce and, ultimately, they are essential for the successful functioning of the ecosystem.

» Symbiotic relationships and interactions include parasitism, mutualism and commensalism, in which the organisms that benefit have inherited features that increase their chances of survival and reproduction.

Concept questions 9.3a

1 What is meant by biological interdependencies?
2 In a table of three columns:
   a name the four types of close interdependent relationships between species
   b explain each briefly
   c give an example of each.
3 The following organisms are involved in symbiotic relationships. Classify which interaction in terms of symbiotic relationships is present and the organisms involved.
   a Human gut bacteria
   b Fleas on a cat
   c Plover (bird) feeding on the meat stuck between a crocodile's teeth
4 The care of a mother bear for her cub is not considered a symbiotic relationship. Why?
5 The relationship in a lichen is a mutualistic relationship.
   a List the two organisms involved in the structure of a lichen.
   b How does each of these organisms benefit in this relationship?

HOT Challenge

6 Viruses are not living. They inject their DNA into host cells, which are taken over by the viral DNA to produce more viruses. Are viruses the ultimate parasitic symbiont? Justify your answer.

More complex interdependencies

WB 9.3.2 MORE COMPLEX INTERDEPENDENCIES: COMPETITION PAGE 220

Most species live in communities and rely on other species in some way to survive. They may rely on other species for food, for shelter, or to help them reproduce. Species are not independent; rather, they are interdependent. Different species are often part of several ecosystems because ecosystems overlap or are interconnected. Species can affect each other through various relationships involving sharing of resources (collaborators), needing the same resources and competing for them (competitors), and the flow of energy and nutrients through **food chains** in complex networks of **food webs**.

Competition

Communities consist of the complex interactions of different populations and the individuals within them. Many are in **competition** with each other because they require the same resources to fulfil their needs for survival. Competition, a struggle between organisms within and between species to gain adequate resources, is a common feature of all communities. For example, seemingly harmless sea anemones of the one species compete for the same food source (Figure 9.23). They can detect slight genetic variations in intruders of the same species. Both rivals discharge a battery of stinging cells, normally used to paralyse and catch **prey**, until one is defeated and creeps away.

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Figure 9.23 Different sea anemone species compete for food sources. The anemone on the left has discharged stinging cells to ward off the anemone on the right. This is an example of an interspecific relationship.

Predation

WB 9.3.3 MORE COMPLEX INTER-DEPENDENCIES: PREDATION PAGE 223

Within every ecosystem, there are predator–prey relationships, in which the **predator** kills another organism, the prey, and consumes part or all of it for food. Although there is usually a preferred prey species, it is unusual for a predator to depend on only one species. It is an advantage for a predator to be a member of a food web with a network of food chains so that if one prey species is in short supply, the predator can consume others. The dynamic relationship that exists between predator and prey is usually balanced, but sometimes conditions can change and upset this balance (Figure 9.24). Under favourable conditions, with increasing availability of prey, the number of predators can increase. During a period of adverse conditions, the prey population can decrease. When this occurs, there is increased competition between different species in the predator population. Predators turn to alternative prey species and the effect on the prey can be severe.

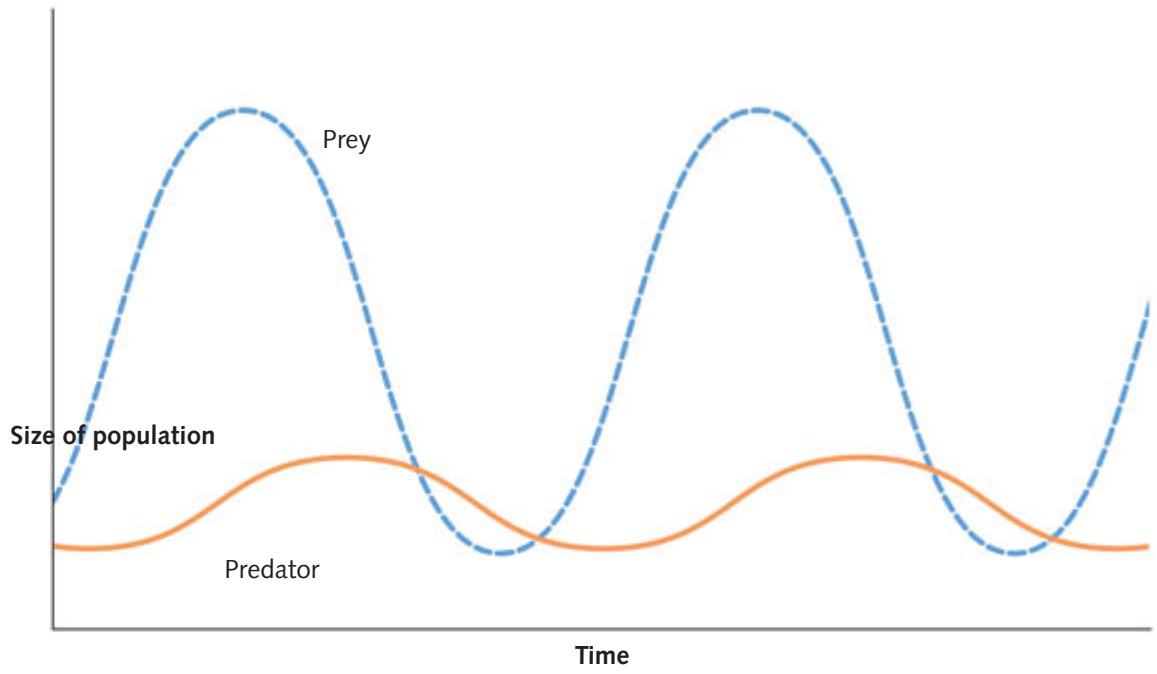


Figure 9.24 The predator–prey relationship

SOUTHERN Biological Developed by Southern Biological

INVESTIGATION 9.5

Competitive exclusion principle

Background

The competitive exclusion principle, or Gause's law, proposes that two species competing for the same limited resources cannot sustainably coexist or maintain constant population values. Intraspecific competition describes organisms within the same species competing for resources, leading the population to reach carrying capacity. Carrying capacity refers to the maximum population size a species can sustain within its environmental limitations. Interspecific competition describes competition for resources between different species of organisms. Species can be limited by both their carrying capacity (intraspecific competition) and the interspecific competition. When two species compete within the same ecological niche, the competitive exclusion principle predicts that the better-adapted species, even if only slightly better adapted, will drive the other to local extinction. In the 1930s, biologist Georgy Gause explored the idea of interspecific competition in a ground-breaking study of competition in *Paramecium*. Paramecia are aquatic single-celled ciliates that survive on a diet of bacteria, yeast, algae and other small protozoa. Based on the findings of this experiment and other research, Gause developed the competitive exclusion principle.

Aim

To test the competitive exclusion principle using two *Paramecium* species: *Paramecium caudatum* and *Paramecium aurelia*

Time requirement

45 minutes

Materials

- Pure culture of *Paramecium caudatum*
- Pure culture of *Paramecium aurelia*
- Paramecium culture medium
- 3 deep Petri dishes
- Sedgewick Rafter cell
- Graduated cylinder
- Cheesecloth or mosquito net
- Sterile plastic pipettes
- Compound microscope

What are the risks in this investigation?	How can you manage these risks to stay safe?
Paramecia are harmless to humans, but swamp or pond water may contain pathogens.	Wash hands after working with *Paramecia*.

Method

1 State your hypothesis.
2 Label three clean Petri dishes A, B and C.
3 Add 50 mL of *Paramecium* culture medium to each dish.
4 Using a graduated cylinder, transfer 20 mL of *Paramecium caudatum* into Petri dish A.
5 Transfer 10 mL of *Paramecium caudatum* and 10 mL of *Paramecium aurelia* into Petri dish B.
6 Transfer 20 mL of *Paramecium aurelia* into Petri dish C.
7 Add six grains of rice to each dish.
8 Cover each of the Petri dishes containing the *Paramecium* cultures with cheesecloth.
9 Store the Petri dishes at a consistent temperature of 24°C on a flat surface where they will not be disturbed. Keep away from direct sunlight.
10 Using a fresh sterile pipette, place 1 mL of liquid from Petri dish A into a Sedgewick Rafter cell.
11 Using a compound microscope, count the relative number of *Paramecium aurelia* and record your data in the table.
12 Repeat the counting procedure every second day for 3 weeks, recording your results each time.

Results

1 Copy Table 9.1 into your logbook and record your data in it.

Table 9.1 *Paramecium* population figures

		Day 1	Day 3	Day 5	Day 7	Day 9	Day 11	Day 13	Day 15	Day 17	Day 19	Day 21
Separate cultures (Petri dishes A and B)	*Paramecium caudatum*											
	Paramecium aurelia											
Combined cultures (Petri dish C)	*Paramecium caudatum*											
	Paramecium aurelia											

2 Plot your results as line graphs.
3 Plot the growth of each species in Petri dish C on the same axes, with time (every 2 days) on the x-axis and population size (*Paramecium*per 1 mL) on they-axis.
4 Combine your results with the rest of the class to get class results.
5 Plot the class results as a line graph.
6 Describe what has occurred in populations A, B and C. Identify whether the populations increased or decreased or remained stable.

Discussion

1 Was your hypothesis supported? Provide reasons.
2 What are the advantages and disadvantages of this counting technique?
3 What are some limitations in the experiment design? Suggest how it might be improved.
4 Compare the population sizes of each *Paramecium* species in the separated (A and B) and mixed cultures (C). What do the results reveal about how competition affects population growth?
5 Do your results support or refute the competitive exclusion principle? Provide evidence from your results.
6 Did the trends in the class results differ from your own results?

Taking it further

Exponential growth describes population growth that is unlimited. Logistic growth describes growth rates that are limited by a number of factors, including predators and food scarcity as well as competition for food and habitat. Which type of growth was exhibited in the *Paramecium* populations containing only one of the species? Determine the carrying capacity of the organism in this model environment.

Food chains

Food chains can be used to represent feeding relationships. Each link in the chain is referred to as a **trophic level**, with **producers** being the first trophic level. Each organism in the chain feeds on, and therefore obtains its energy and matter from, the preceding one. At the beginning of the food chain are the producers, which are autotrophic species that produce complex organic matter from simple inorganic molecules, predominantly using light energy from the Sun, in photosynthesis. Energy flows from the producers to the **consumers**, heterotrophs that ingest their organic matter by eating other organisms. Lower level consumers are eaten by the next level consumer in the chain, so energy and matter are transferred progressively from one trophic level to the next.

Animals that feed directly on producers are herbivores or **first-order consumers**. **Carnivores** that depend directly on herbivores are second-order consumers, and so on. The **top consumers** are not preyed upon and, like most humans, die of old age, disease or injury. Some organisms that are both herbivores and carnivores are called **omnivores**. Animals that feed on the dead remains of other animals are **scavengers**. Figure 9.25 shows how a generalised food chain and an ocean food chain can be constructed. Note that larger animals such as sharks, usually higher up in the food chain, must eat large quantities of food to meet their energy requirements, as only about 10% of the energy at each trophic level is passed on to the next level. The remaining 90% is lost to the surroundings as heat energy and chemical energy in wastes.

EXAM TIP
Producers in a food chain or web are the first trophic level, which means first-order consumers are the second trophic level, and so on.

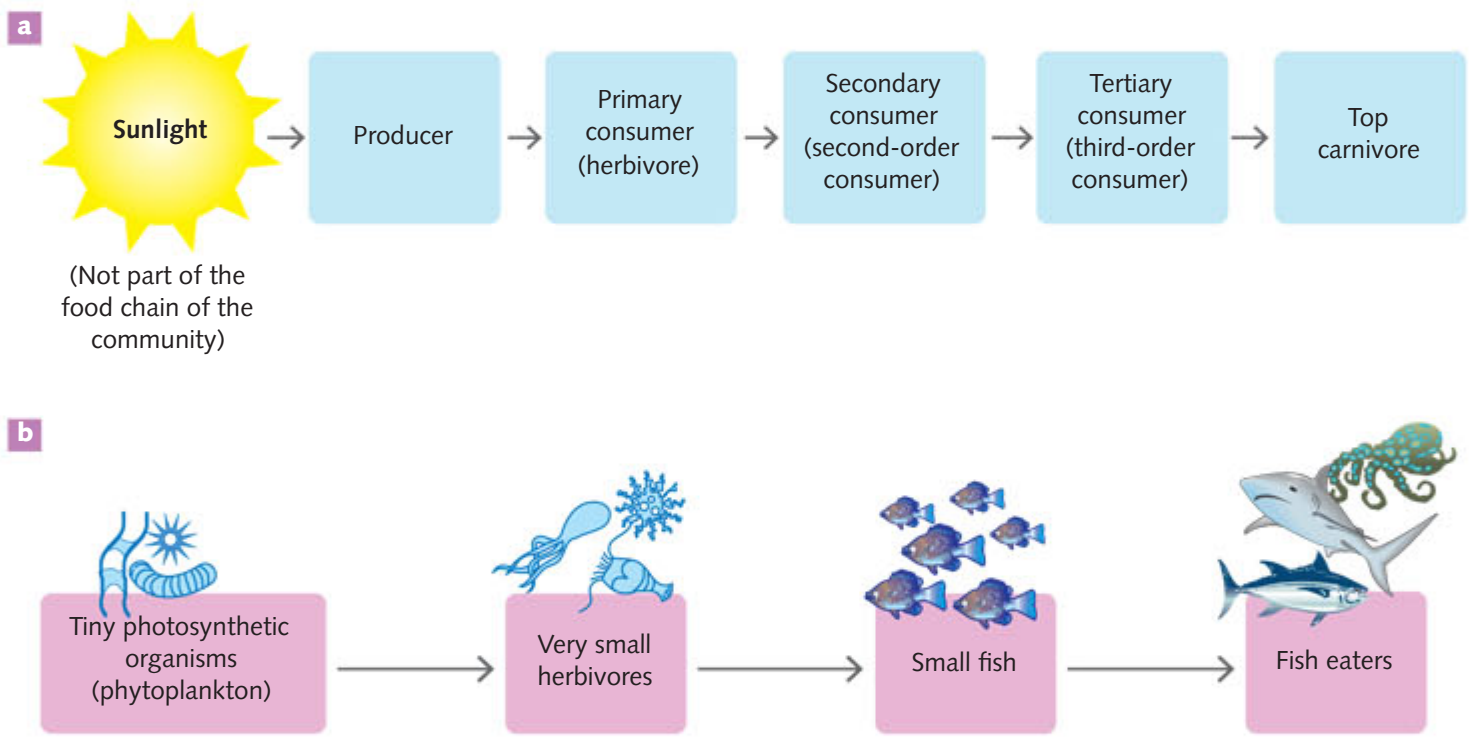
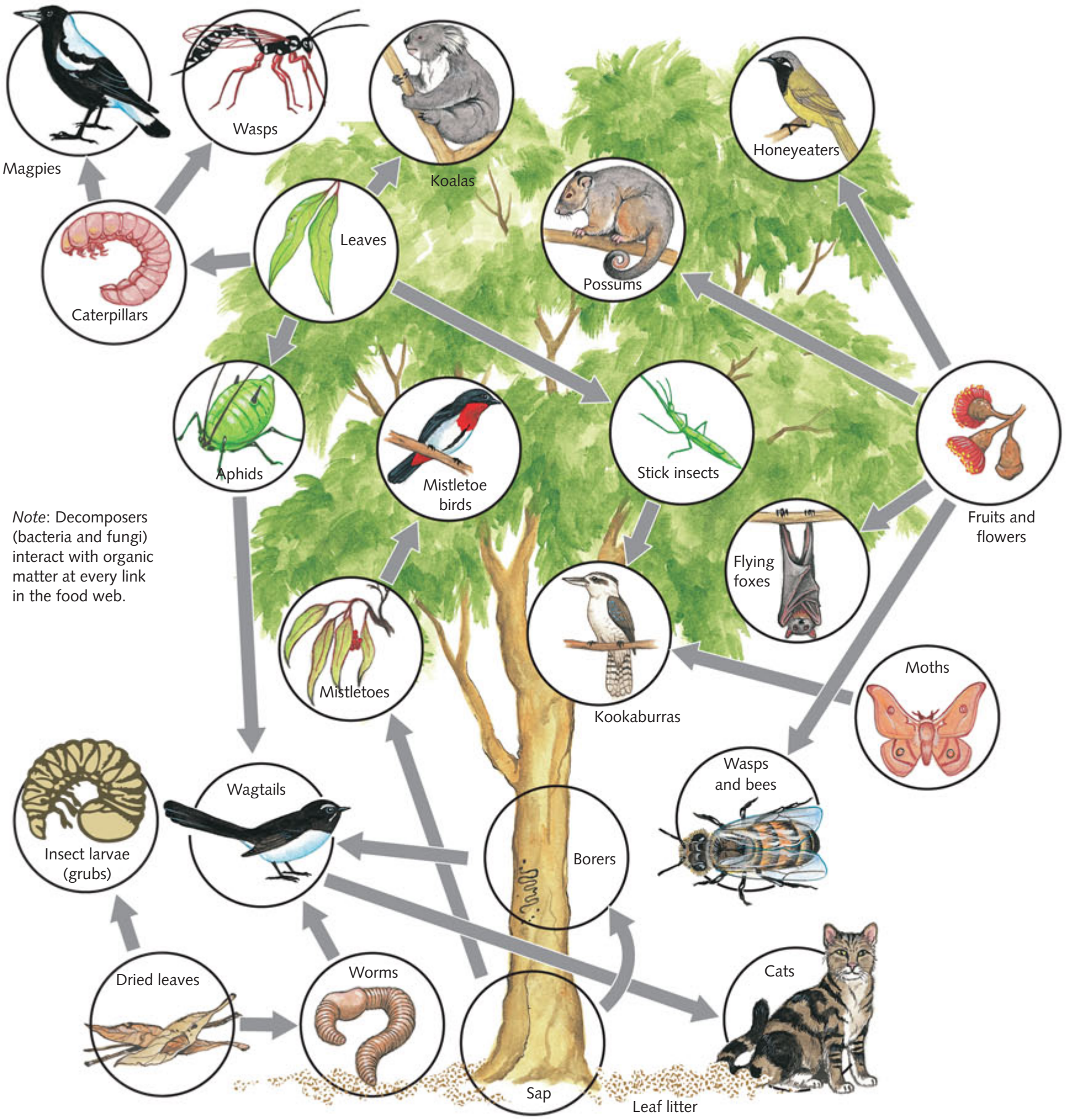


Figure 9.25a Generalised food chain; b A food chain in the ocean. The arrows represent the flow of energy.

Food webs are integrated food chains

Simple food chains are rare. Most species depend on more than one kind of organism for their food. A network of feeding relationships that shows flow of energy and matter through more complex pathways is called a food web. In other words, food webs are dynamic interactions between organisms in an ecosystem (Figure 9.26).

Members of populations of different species move in and out of different ecosystems, so an organism may be part of one food chain or web at one time but not at another time. For example, insects, birds and seeds commonly move between ecosystems wherever their needs are met. On a larger scale, migration of whole populations of animals such as albatross, mutton-birds, salmon or moths results in great changes to the pathways of energy and matter. **Phytoplankton** is a producer and a fundamental food source for marine animals. Phytoplankton can be carried great distances in ocean currents. Organisms in the next trophic level, such as whales, migrate along with this food source. These interdependencies between species show how the size, distribution and density of a population in an ecosystem can change over time.



Note: Decomposers (bacteria and fungi) interact with organic matter at every link in the food web.

Figure 9.26 A food web in a woodland ecosystem

ACTIVITY 9.1

Community interrelationships

In a small chamber of a cave in north-eastern New South Wales there is a heap of bat dung. This material (called guano) has been built up over many thousands of years by the seasonal visits of a single species of bent-winged bat (*Miniopterus schreibersii*). Each year from October to June, between 1000 and 3000 of these insectivorous bats roost in the chamber. From their roost on the roof of the chamber, the bats drop faeces and urine to form a heap on the floor. The resulting mass of guano supports a permanent natural community of organisms – a guano community.

An ecologist, John Harris, collected samples of the bat guano at regular intervals over a period of 4 years. From these samples he extracted 13 species of arthropods (insects). The major organisms in the community were the guano mite (*Uroobovella coprophila*) and the guano fly (*Cypselosoma australis*).

From December until June, Harris observed the organisms and recorded notes on their feeding habits (Table 9.2).

Aim

To explore the relationships that exist between the organisms found in the cave by organising primary data into food webs

Part A: Feeding relationships from December to June

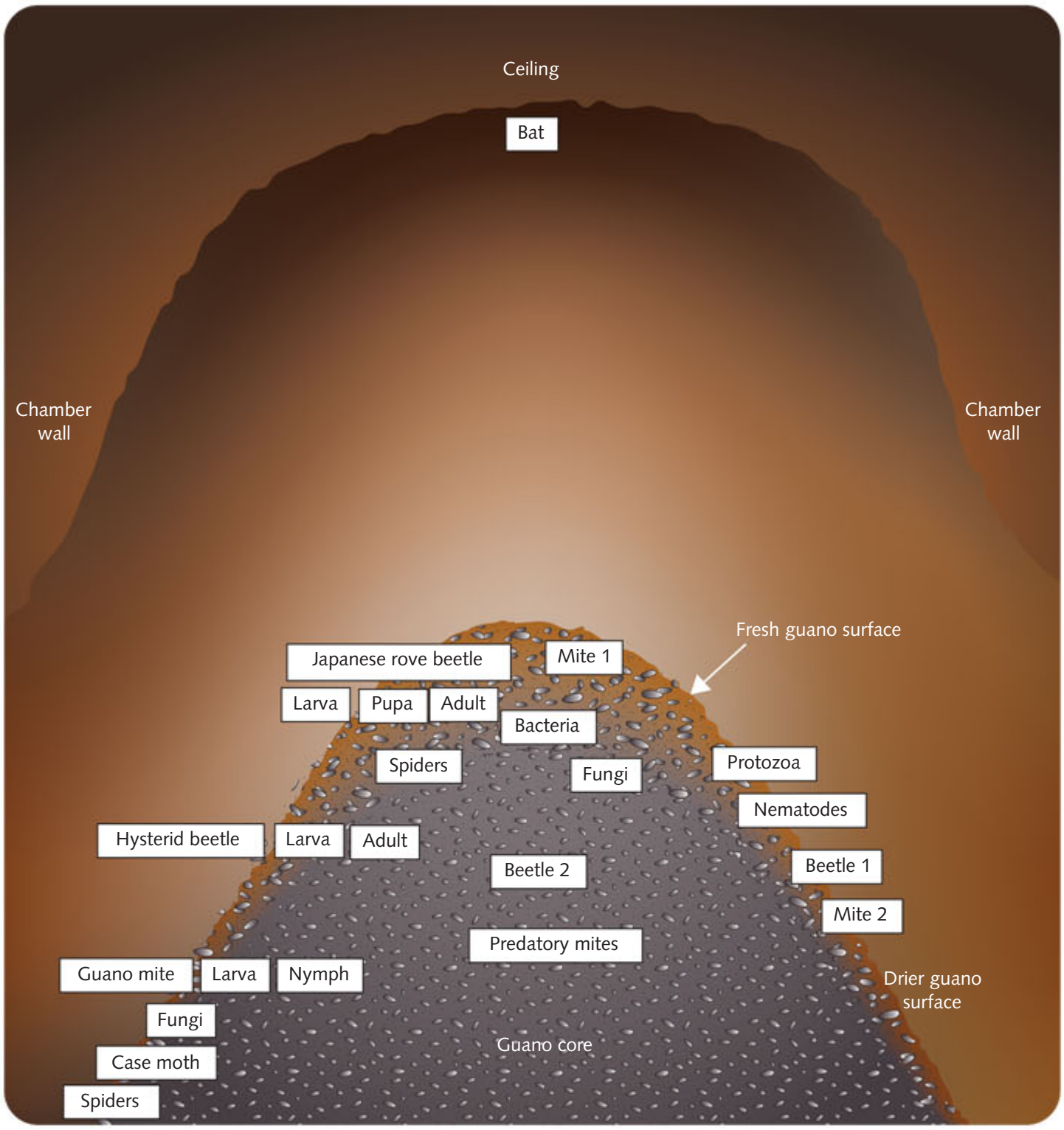
The feeding relationships found in the guano community from December to June can be represented as a food web.

What to do

Copy Figure 9.27 into your logbook and use the information in Table 9.2 to pencil in arrows to represent the food web of relationships between guano organisms. The direction of each arrow should indicate the direction in which the energy flows.

Table 9.2 Observations of cave organisms (December to June)

	Organism	Observations
1	Bent-winged bat *Miniopterus schreibersii*	In October–June roost during the day on the ceiling in the cave chamber; at night leave the cave and feed on moths in the tall open forest nearby. In December and January roost only intermittently in the chamber.
2	Fungi (filamentous forms and yeasts)	Found in and on the freshest part of the guano pile, some of which is broken down and absorbed.
3	Bacteria	Similar to fungi.
4	Protozoans, including flagellates	Feed on bacteria.
5	Nematodes	Feed on protozoa and bacteria.
6	Mite 1 (*Histiostoma* sp.)	Feed on the bacteria close to the surface of the pile.
7	Predatory mites (*Hypoaspis* sp. and *Proctolaelaps* sp.)	Feed on the larval and nymph (immature) stages of the guano mite and on the uropedid mites both close to the surface and inside the guano pile.
8	Guano mite (*Uroobovella* sp.)	Live on the surface of the pile where they feed on fungus. Mate and moult below the surface.
9	Mite 2 (Family Uropodidae)	Source of food is the same as for guano mite.
10	Guano fly (*Cypselosoma* sp.)	Feed on bacterixal colonies.
11	Case moth (*Monopis* sp.)	Larvae feed on fungi found low down on the drier parts of the pile.
12	Spiders (*Achaearanea* sp. and *Pholcus* sp.)	Feed on the guano fly adults, case moths and hysterid beetles; are found on both the heap surface and the chamber walls.
13	Hysterid beetle (*Grathoncus* sp.)	Feed on fungi.
14	Beetle 1 (*Atomeria* sp.)	Adult and larval stages feed on guano fly larva.
15	Japanese rove beetle (*Philonthus* sp.)	Adult feeds on guano fly pupa.
16	Beetle 2 (*Sarothrias* sp.)	Feed on fungi.



Adapted from Ecology, Vol 18, No 6, 1937

Figure 9.27 Relationships between guano organisms

What did you discover?

1 Does the cave community contain any producer organisms? If so, name them. If not, name the species that is the source of matter and energy on which the rest of the guano community depends.
2 Identify the original source of energy for this community. Explain your answer.
3 Name the organisms that are consumers in this community.
4 Name the consumers that bring about decomposition in the system.
5 Name the highest-order consumers.

Part B: Feeding relationships from July to September

From July to September, the bats were absent from the caves and so no fresh guano was being added to the heap. Harris made the following observations.

» Far fewer individuals of all species were present at this time.
» Bacteria and fungi were found almost exclusively in the form of resistant spores.
» Large larvae of hysterid beetles and several species of mite were found at depths of 25 cm.
» Both the nymph and adult stages of the guano mite became inactive.

» Japanese rove beetles disappeared from the heap and presumably migrated to another part of the cave.
» The number of guano flies dropped dramatically. There were very few larvae and only a few adults. The two species of spider were inactive during this period.

What to do

Construct a food web in your logbook depicting the relationships between the organisms of the guano heap during August.

What did you discover?

Describe how the changes in the cave during July to September affect the food web as you described it for the periods between December and June.

Part C: Feeding relationships from October to November

The arrival of the bats in the chamber in October and the deposition of their faeces and urine on the guano heap leads to a spectacular change in the activity of the community.

» Micro-organisms (bacterial protozoa and fungi) immediately become active, as do the nematodes soon after.
» Previously inactive mites (*Histiostoma* sp.) become active and feed as before.
» Nymphs of the guano mite grow rapidly and moult. Previously inactive adult females begin laying eggs.
» Mature larvae of the hysterid beetle pupate and the new adults emerge and make their way to the surface from 30 cm down inside the heap.
» The density of mites builds up quickly with the hatching of larvae and the emergence of adults, which begin to breed.
» The temperature of the heap rises and a few adult guano flies lay eggs in the fresh guano.
» The guano fly population takes longer to increase because of its initially low numbers. The fly larvae feed directly on the fresh guano.

What to do

Construct a food web in your logbook depicting the relationships between the organisms of the guano heap during October to November.

Discussion

1 Using the information, identify the organisms in the cave that occur in large numbers very soon after the return of the bats.
2 Compare the December to June food web with that for October to November. Identify which organisms (if any) are found in one food web and not the other. Account for this.
3 On looking at this cave community, Harris remarked: 'The bats are to the guano community what the trees are to a woodland.' Briefly explain the analogy.

'Ecosystems Underground', by J.A. Harris, Australian Natural History, Special Issue-Australian Caves, The Australian Museum, June 1975, Vol 18, No. 6, p. 220

KEY CONCEPTS

» Individuals in a species are in competition with each other and members of other species if they require the same resources to fulfil their needs for survival.
» In a predator–prey relationship, the predator kills the prey and consumes part or all of it for food.
» Feeding relationships that occur within communities in an ecosystem can be represented by food chains and food webs.
» Energy is transferred from one trophic level to the next level. Of the original input of light energy from the Sun, 90% is lost to the surroundings as heat energy and as chemical energy in wastes.

Concept questions 9.3b

1 Using examples, what is the difference between competition and predation?
2 Identify and explain the distinctive feature of a predator–prey relationship.
3 Distinguish between:
   a food chain and food web
   b herbivore and carnivore.
4 Describe the relationship between a food chain and trophic levels.
5 Match the terms on the left with the definitions on the right.

a	Producers	**i**	Herbivores, carnivores, omnivores
b	Consumers	**ii**	Break down organic remains and products
c	Decomposers	**iii**	Photosynthetic autotrophs that support the entire food web

6 About 10% of the energy available from an organism that is eaten moves up to the next trophic level. Where has the rest gone?
7 Decomposers are the great waste collection organisms, recycling, reusing, becoming energy sources for heterotrophs or producing mineral nutrients that are useful for producers.
   a List five examples of decomposer organisms.
   b State how each of your examples is involved in a food web.
   c The number of top-order consumers in a food web is very different from the number of decomposers. How is it different and why?
   d Distinguish between a decomposer and a scavenger.

HOT Challenge

8 Explain, using examples, how energy is transferred and transformed as it flows through the food chain.

Alamy Stock Photo/Tony Watson

Figure 9.28 The keystone is the stone that gives the arch its stability and strength.

9.4 Keystone species

A 'keystone' in an arch is the final stone placed at the apex (centre top) of the arch to give it strength and stability (Figure 9.28). The term **keystone species** is used in Biology to denote a species that has a disproportionately large effect on other organisms within an ecosystem and is important for maintaining balance within the ecosystem. The application of the term is debated because some scientists think it oversimplifies one type of organism's role in a complex food web. It is, however, a way of helping in understanding the importance of one species in the survival of other species in the ecosystem, including the size, distribution and density of their populations. Removal, or a decrease in numbers, of a keystone species could result in a markedly different ecosystem, or total collapse, or allow an invasive species into the area that could shift the ecosystem in a new direction.

One type of keystone species is the predators that control the population size of their prey; that is, the number of individuals of a species in a specific place at a particular time. This, in turn, affects the other consumers and producers in the food web. In Australia, scientists noticed that when tiger sharks were not near sea grass beds, the number of sea turtles increased markedly and they started to overeat the sea grass beds and destroy them. When the tiger sharks were patrolling the area of the sea grass beds, the turtles (which are one of the tiger sharks' favoured foods) moved out into a wider area. The keystone species, the tiger shark, had caused a change in the **distribution** (the pattern of where the organisms live) and **density** (number of organisms of a species per unit area) of the sea turtle population, and had helped to maintain a balance in the ecosystem by keeping the sea grass beds healthy for other lower-order consumers and producers.

In some cases, predation can affect the **coexistence** of several other species. The purple sea star, *Pisaster ochraceus*, is a natural predator of mussels in the intertidal zones of Pacific Ocean seashores (Figure 9.29). In a study of starfish in the 1960s, ecologist Robert Paine removed purple sea stars from this environment. This

WB 9.4.1 KEYSTONE SPECIES IN A MANGROVE ECOSYSTEM PAGE 225

Online Worksheet
Biodiversity and keystone species

Weblink
Biodiversity and keystone species

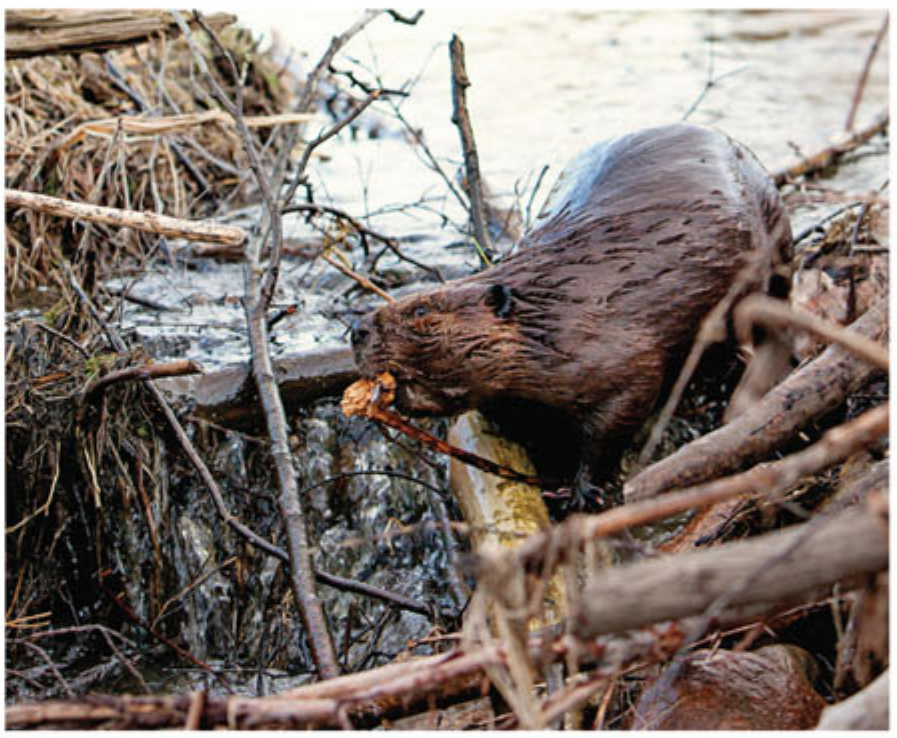
resulted in the expansion of the population of resident mussels. The mussels displaced the other organisms that attach to rocks, such as barnacles and limpets, as they spread. The number of invertebrate and algae species in the area decreased, and the size and distribution of the surviving species was changed over the 3-year period. When the sea stars were returned, the mussels were again preyed upon by the sea stars and the barnacles, limpets and other species were able to re-occupy their original space. The predator, *P. ochraceus*, allowed the coexistence of other species with the same requirements for food and space and prevented any one of the other organisms in the lower trophic levels from monopolising food resources and space. The purple sea star species is, therefore, called a keystone species.

Another type of keystone species is an 'ecosystem engineer', a species that produces or changes an environment so that existing ecosystems can flourish or new ecosystems can develop. A good example of such a keystone engineer species is the beaver (Figure 9.30). In river ecosystems in parts of the northern hemisphere, beavers take down old or dead trees to use for their dams. This allows numerous new, healthy trees to grow, providing more habitats for tree-dwelling insects, spiders, lizards and birds to live and their populations to increase in size and density. The dams created by the beavers divert water from the rivers, producing wetland ecosystems that allow populations of a variety of plants and animals to thrive.

Northern sea otters live in very cold water along the coast of the Pacific Ocean in North America. They are well adapted for the cold conditions by having a dense fur coat for insulation and a very high metabolism to generate body heat. To maintain their relatively constant high body temperature, otters must consume as much as 25% of their body weight every day (Figure 9.31). Sea otters are carnivores that feed on a variety of marine species including crabs, clams and snails, but its favoured prey is sea urchins. The sea otter is able to eat sea urchins because it can crack them open with a rock on its belly, destroying the spines embedded in the outer layer and consuming the meat inside. Other animals cannot get to the meat because of the long sharp spines of the sea urchin. The sea otter's appetite for these invertebrates exerts a strong influence on the size, density and distribution of these prey populations. Sea urchins are herbivores that feed on seaweeds such as kelp. When they are uncontrolled by predators, they become larger and more abundant. In the 1970s, Dr James Estes, when scuba diving in the Aleutian Islands, observed areas of the sea floor covered in sea urchins where no kelp remained. Dr Estes observed that in other areas where sea otters were abundant, there were fewer sea urchins and healthy kelp forests. By controlling the size and density of the sea urchin population, the sea otters had helped the kelp to grow and flourish, which in turn provided a habitat for many other invertebrates. Dr Estes described the sea otters as a keystone species because they have an extremely high impact on kelp ecosystems, disproportionate relative to their population size.

Shutter

Figure 9.29 Pisaster ochraceus, the purple sea star



Shutter

Figure 9.30 Beaver building a dam from tree branches

Alamy S

Figure 9.31 A sea otter eating a sea urchin resting on its belly

Keystone species can also be plants. Mangrove trees, already discussed for their physiological adaptations (Figure 9.12, p. 351), act as a keystone species in coastline or shallow bay ecosystems. Sand and soil accumulate around their exposed aerial root system, firming up the shoreline and reducing erosion.

Shallow water among the roots provides habitat for crabs, worms, other invertebrates and small fish, so populations of these other species increase in size and density in the mangrove ecosystem.

These examples show the importance of keystone species in maintaining the balance in ecosystems and, therefore, the need to identify and protect them in existing or developing ecosystems. Studying keystone species and the food webs in which they play an essential role can help preserve the size, density and distribution of many other species populations.

KEY CONCEPTS

- A keystone species is a species that has a disproportionately large effect on other organisms within an ecosystem and is important for maintaining balance within the ecosystem.
- The size, distribution and density of populations of other species in the ecosystem can be negatively affected if a keystone species is removed or its population decreases.

Concept questions 9.4

1 Define keystone species.
2 Explain how a decrease in numbers of a keystone species could upset the balance of an ecosystem. Give one example.
3 Chapter 8 described the impact of the crown of thorns sea star on the Great Barrier Reef. Determine whether it is a keystone species.
4 Scientists consider elephants to be a keystone species. Explain why.
5 Keystone species are often predators. Explain this statement.

HOT Challenge

6 Figure 9.32 shows a food web in an Australian rainforest.
- **a** List the producers.
- **b** Identify a food chain from this food web that has the rufous owl as the top consumer.
- **c** What does the sugar glider eat? Classify it as a carnivore, omnivore or herbivore.
- **d** What order consumer is the goanna?
- **e** Why is the dingo not connected into the food web?
- **f** Identify the keystone species.
- **g** Predict what might happen if the keystone species were removed.

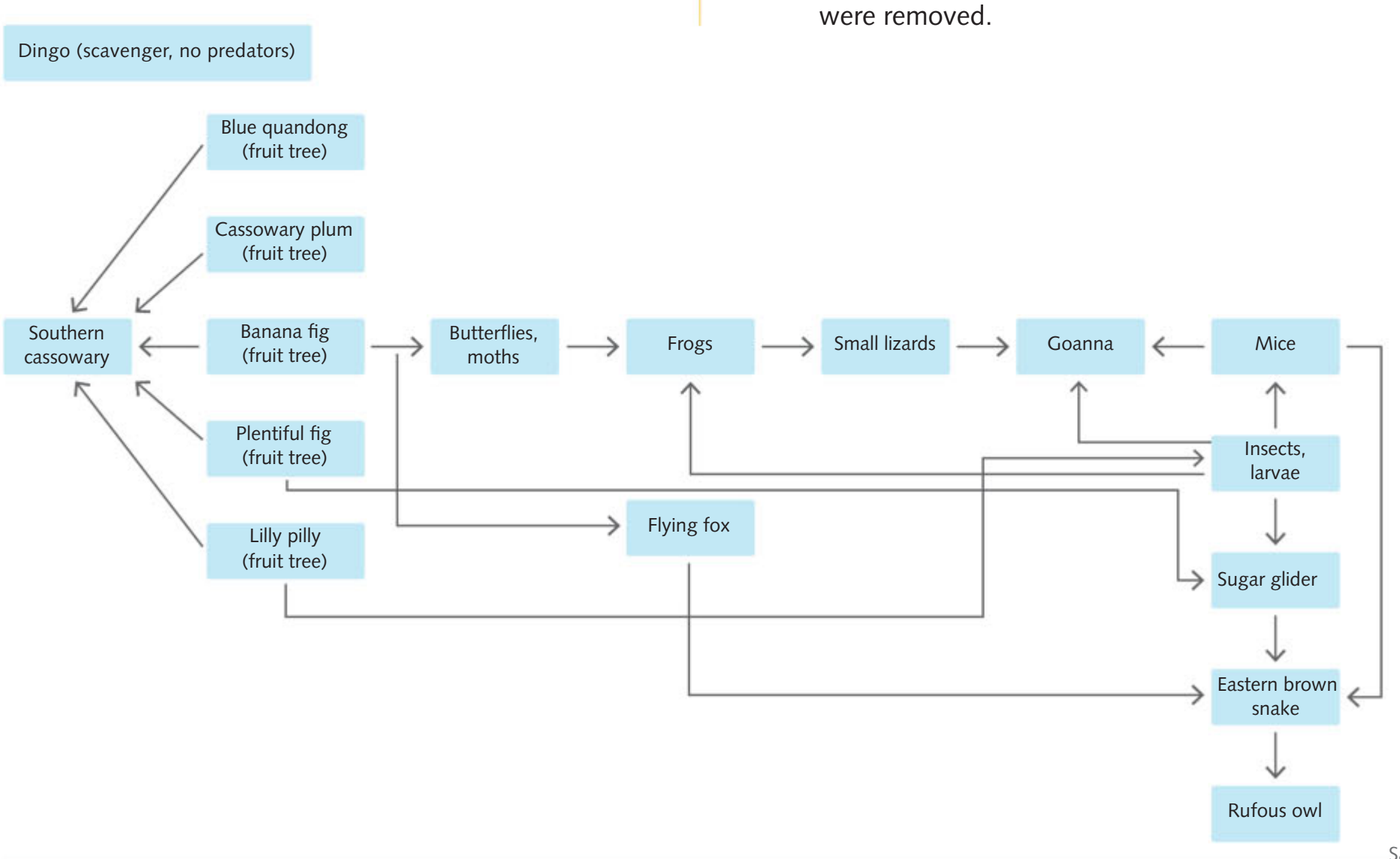


Figure 9.32 A rainforest food web

9.5 Adaptations and interdependencies in Australian ecosystems

Ecosystems do not just consist of the animals and plants that interact with the physical environment; they display complex interdependencies between members of the same species and across species. The first people of European descent to arrive in Australia in the 1780s would have had very little understanding of the animals or plants unique to Australia or of the ecosystems that existed in the wide range of environments found in Australia. Aboriginal and Torres Strait Islander peoples had arrived more than 50 000 years before. Over thousands of years, they had made observations of the organisms, their adaptations in their natural habitats, their life cycles, and changes in the size, density and distribution of the species in different seasons and environmental conditions, such as temperature, water availability and fire. Aboriginal and Torres Strait Islander peoples have a strong spiritual connection to the land. They hold strong beliefs of creation beings that following creation would return to earth as birds or other important animals. These spirit ancestors would then look after the country and the people. The First Australians cared for Country and, in return, Country and their spiritual ancestors cared for them.

Contribution of Aboriginal and Torres Strait Islander peoples' knowledge and perspectives

WB 9.5.1 ABORIGINAL PEOPLES' KNOWLEDGE AND PERSPECTIVE PAGE 227

Aboriginal and Torres Strait Islander peoples made observations of many different species that helped provide them with a deeper understanding of the survival strategies of these species. Studying their structural, physiological and behavioural adaptations provided Aboriginal and Torres Strait Islander peoples with insight into how the organisms survived and reproduced in their habitats and how this ensured survival of the species. The ecological knowledge they collected included the location of the animal habitats, the food sources of the species, seasonal patterns of movement and nesting and breeding locations.

The biocultural knowledge of Aboriginal and Torres Strait Islander peoples considers the impact of community practices on the environment to ensure that the density and distribution of populations within the ecosystems are not affected detrimentally. By recognising the specific adaptations of organisms that increase the organisms' chances of survival and reproduction, the people could then use organisms such as witchetty grubs, goannas and various plant fruits as valuable food resources; obtain additional water supplies from water-holding frogs and succulent plants; and source plant-based medicines, including tea tree and eucalyptus oils, desert mushrooms and snake vine.

Aboriginal and Torres Strait Islander peoples carried out practices such as sustainable harvesting that were beneficial for their needs but also for the conservation of species. Their cultural practices implemented sustainable management of the coastal waters of Australia for thousands of years. Aboriginal and Torres Strait Islander peoples knew when to harvest different food sources by observing the environment around them. The calendar used by Aboriginal and Torres Strait Islander peoples was not based on the counting of days and months but rather on the observable changes in the landscape that indicated a change of season and the consequent prevalence of certain resources. For example, the Wadawurrung people of south-western Victoria knew that when the stringybark, coast banksia and moonah trees come into blossom, the short-finned eels begin their migration down the rivers to the sea and the eel traps would be set. Eel traps would have a hole in the end so that small eels would not be trapped and to ensure the long-term survival of the species.

Managing dugongs

Dugongs are large marine mammals that live in shallow tropical and subtropical waters (Figure 9.33a). They have a limited lung capacity so must surface every 6–10 minutes for air, but they are structurally well adapted because their nose is at the top of their head, meaning they can have much of their body in water when they surface and so are not readily seen. Their eyes and ears are on the side of their head, so they can see and hear potential predators. They have poor eyesight; however, they are structurally and behaviorally well adapted for their lack of vision by having their upper lip covered in bristles to navigate, feel around, and find the sea grass that they eat. Female dugongs have one calf after a pregnancy of 12 months and it stays with its mother for 18 months. These unhurried animals were an easy target for coastal hunters and were killed for their oil, skin, bones and teeth. Dugongs are primary consumers and the only completely herbivorous mammal in this marine, shallow water ecosystem. As well as sea grass, dugongs may consume marine algae. Adult dugongs have few natural predators, but sharks, crocodiles and killer whales feed on juvenile dugongs. Intensive grazing of dugongs on sea grass can have effects on the organisms living in or feeding on sea grass, such as small fish and invertebrates. These interdependencies of organisms in the sea grass ecosystem were recognised by the Aboriginal and Torres Strait Islander peoples and used as an indicator of how many dugongs could be harvested and still maintain the balance in the ecosystem.

A number of species of sea turtle occur in Australia. By comparison to dugongs, sea turtles' forelimbs are long, paddlelike flippers so they are strong, faster swimmers (Figure 9.33b). Their speed is slowed by their shell, which is an adaptation for protection because it enables them to retract their head and limbs if in danger. Sea turtles are also excellent divers, spending up to 97% of their time under water. These structural and behavioral adaptations would help to reduce predation and energy use in the water. Most turtles only visit land for the females to lay their eggs, where the adaptations that make them successful in the water, such as their paddle-like flippers, make them vulnerable on land because their movement is very slow and awkward. Turtle meat and eggs provided an important source of food for coastal Aboriginal and Torres Strait Islander peoples, but they took only what they needed and were selective about the sex and maturity of the animals they took to allow the species to replenish and prevent wastage. Careful and controlled dugong and turtle harvesting was undertaken according to cultural lores and protocols and this meant informed community decisions were made regarding the numbers to be caught and taken from the sea. This essential knowledge safeguarded the species, thereby ensuring that the density and distribution of these two species were not reduced.

a

Getty Images/EyeEm/Sibylle Malinke

b

Shutterstock.com

Figure 9.33a Dugong (*Dugong dugon*) **b** Sea turtle

The Kaurareg people of the lower Western Islands of the Torres Strait developed a collaborative approach with the Traditional Owners of the surrounding islands for sustainable harvesting of turtles and dugongs. This ensured conservation of the species and safeguarded the continuation of important cultural practices associated with these organisms. Only a certain quota of dugongs and turtles could be harvested to maintain population numbers. People of some of the Western Torres Strait Islands kept the skull bones of dugongs and turtles to monitor the number of animals being harvested in a season. Small dugongs, mother and calf, and pregnant dugongs, were not permitted to be hunted. Experienced Aboriginal and Torres Strait Islander people had the skill to determine how many times a dugong had bred by the length and size of the female's teats. The practice of harvesting turtle eggs was also limited to a specific quota and required ecological knowledge to identify the beaches where turtles return to lay eggs and the time within the season that the eggs could be harvested. Such long-term ecological knowledge of their adaptations and habitats ensured sustainable population numbers of dugongs and turtles for thousands of years.

Recent studies on dugong and turtle populations have confirmed that traditional hunting rights of Aboriginal and Torres Strait Islander peoples are not responsible for the decline in the density and distribution of these species; rather they are being impacted by modern issues, such as climate change affecting native habitats, marine debris including floating misplaced fishing nets, water pollution, commercial fishing, feral animals that destroy turtle nests, and by boat strikes. These contemporary issues are more predominant in areas of higher human presence and activity, such as the Great Barrier Reef region of northern Queensland, where dugongs face many threats, such as shark nets and tourist boats, that are causing a decline in their populations.

Value of billabongs

Billabong is a word from the language of the Wiradjuri people in south western New South Wales used to describe a pool of water left behind when a river alters its course or after floodwaters recede. Billabongs are not only a valuable source of freshwater, but also provide a habitat for many freshwater species. The life cycles of the plants and animals of the billabong ecosystem are intrinsically connected with seasonal changes.

Shutte

Figure 9.34 A billabong covered in water lilies, an important food source for Aboriginal and Torres Strait Islander people

The Ngan'gi peoples in the Daly River region of the Northern Territory have continued to manage the billabongs in their country sustainably. At the end of the wet season, when the billabong levels recede, the Ngan'gi people can collect water lilies and red lotus lilies (Figure 9.34). Lilies are an important resource because the plant can be eaten through all stages of its life cycle and each stage has specific adaptations: tubers are an expansion of the root that functions to store carbohydrates and, when roasted, are a valuable food source; seeds, for dispersal of the species, can be eaten or ground to make bread; buds and stalks can be eaten; and flowers provide nectar. The seeds of the lilies are well adapted to the billabong habitat because they absorb water and sink to the bottom. They then germinate in the mud, the stem sprouts and rises to the surface, and the characteristic leaves grow broad and flat for maximum photosynthesis. All these adaptations were valuable in resourcing lilies as an important food source.

Spores of nardoo, an aquatic fern that grows in freshwater environments such as billabongs, provides a nutritious and important food source for many Aboriginal groups. The unique life cycle of nardoo allows the spores to remain viable in environments of low water availability or in times of drought, when the billabong waters dry up. The spores can remain dormant in these conditions until rainfall or floods triggers germination. The Yandruwandha peoples of the Lakes area in South Australia used their knowledge of the adaptations and life cycle of nardoo to cultivate and harvest large quantities when the spores were available, ensuring a plentiful supply for making bread.

The water-holding frog (Figure 9.35a) inhabits billabongs, swamps and claypans and is very well adapted for dry periods. As surface water disappears, the frog burrows into a waterproof cocoon-like chamber, lined with shed skin. Water is stored in its bladder and in pockets under the skin and can be up to 60% of its weight. The frog can reduce its metabolic rate and stay in this chamber for several years. After rain or floods, the water-holding frog emerges from underground to continue its life cycle, laying eggs in still pools of water. The fertilised eggs hatch into tadpoles that develop into frogs. The hot desert habitat of water-holding frogs and limited water availability triggers a more rapid change from tadpole to frog than in many other frog species, with the development occurring in approximately 14 days before the water dries up. This is another adaptation of benefit to the frog as it results in more of the species. Aboriginal people take advantage of the water-storing adaptation when they use the frogs as a source of water when conditions are extremely dry. These adaptations have helped Aboriginal people to obtain a source of water in extremely dry areas because they can recognise markings from the frog on the soil or by tapping the surface, and then gently squeeze the frog to release its stored water.

Figure 9.35a Water-holding frog (*Ranoidea platycephala*) **b** Australian pelican (*Pelecanus conspicillatus*)

The Australian pelican (Figure 9.35b) is a water bird found in many parts of Australia. Breeding of the species is dependent on water availability and rainfall. The female pelican uses the billabong habitat to build a nest on the ground close to the water's edge. After hatching, the chicks remain in the nest for about 2 months and then form a pod with up to 100 other newly hatched chicks. They remain with this group until they can fly, at about 3 months. This interdependency between individuals of the same species increases their chances of survival. The Australian pelicans are carnivores that feed on crustaceans, fish, turtles and other water birds. The interdependency and balance in the billabong ecosystem was used as an indicator to the local Aboriginal people. Pelicans were traditionally an important food resource in many parts of Australia, so knowledge and understanding of the pelicans' adaptations, needs and life cycle were important to the careful management of billabong ecosytems and sustainable harvesting of pelicans and other billabong species for food.

Many Aboriginal nations lived along the Murray River, stretching from Mt Kosciuszko where it starts, through the saltbush and mallee plains of New South Wales and Victoria, till it reaches Lake Alexandrina in South Australia. For example, people of the Yorta Yorta Nation lived in the Echuca region, and many others lived on the banks and flood plains of this vast river system. Much of their food, including fish, crayfish and yabbies, was caught in nets and dams. They also hunted with spears and trapped birds, such as ducks, pelicans and black swans in nets strung across the waterways. They sometimes made rods to snare waterbirds. Using branches of reeds on their heads, the men would swim under the water and snare the waterbirds around the neck.

Over thousands of years, Aboriginal and Torres Strait Islander peoples' knowledge of their environment and comprehensive understanding of the adaptations and interdependencies of the organisms in the various ecosystems helped them to maintain the density and distribution of populations, despite harvesting them for food. Their cultural practices and their spiritual connection to the land allowed them to implement sustainable management of many species in Australian ecosystems.

KEY CONCEPTS

- Aboriginal and Torres Strait Islander peoples came to Australia 40 000–50 000 years ago and gained a good understanding of the adaptations and interdependencies of species in Australian ecosystems.
- Their knowledge and understanding allowed them to recognise species with adaptations that were beneficial to their needs for food, water and other resources.
- Careful and controlled harvesting of species was undertaken according to cultural laws and protocols and this meant informed community decisions were made regarding the numbers of a species that could be used for food. This essential knowledge safeguarded the species, thereby ensuring that their density and distribution were maintained.

Concept questions 9.5

1 Why was it useful for Aboriginal and Torres Strait Islander peoples to make detailed observations of living things in the Australian landscape over many thousands of years?

2 Seasonal calendars were passed down by oral tradition and used by traditional Aboriginal and Torres Strait Islander owners to predict what was happening in the areas where they lived. More and more of this knowledge is being translated into written and pictorial form and becoming part of vital records for future use. The seasonal calendar depicted in Figure 9.36 is one from the Bodkin/Andrews clan of the D'harawal People, the traditional owners around Sydney.

a How did the D'harawal People recognise the changing of seasons?

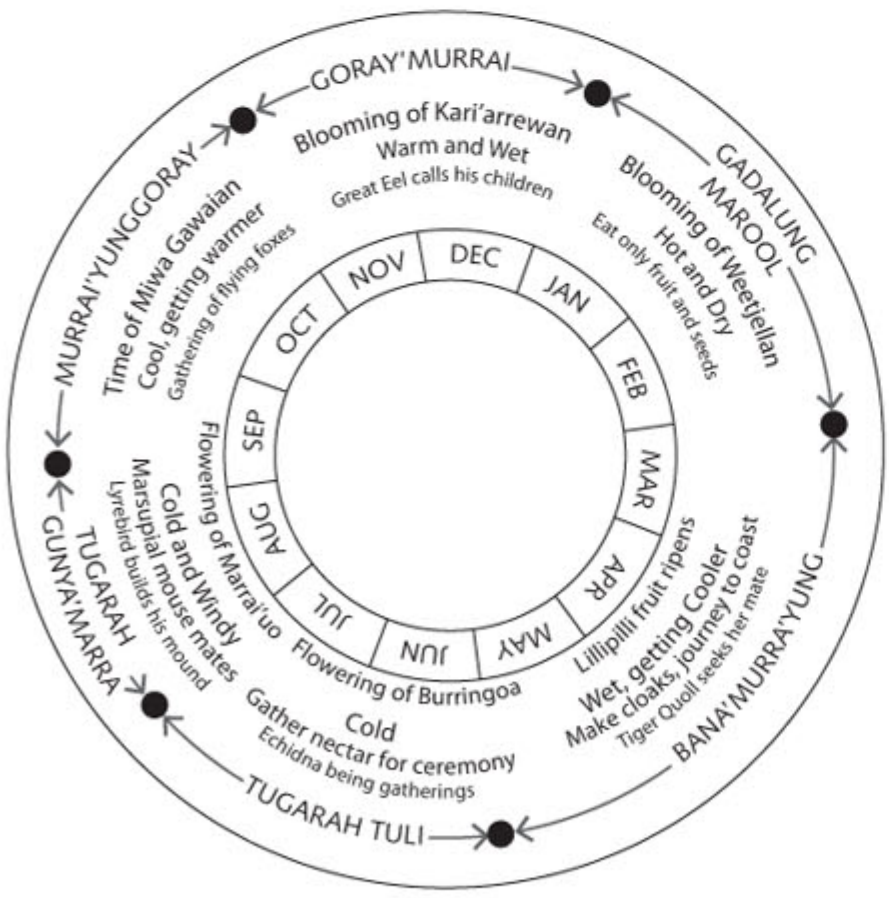


Figure 9.36 Seasonal calender of the Bodkin/Andrews clan of the D'harawal People, the traditional owners around Sydney

Weather cycles around Sydney, from the Bodkin/Andrews clan of the D'harawal People

b What evidence is there in the calendar that the D'harawal People had a deep understanding of the survival strategies of the plant and animal species living in the area?

c Aboriginal and Torres Strait Islander peoples have lived on the Australian continent and islands for more than 50 000 years. What does this suggest about their ability to live in harmony with nature?

3 Eel fishing at Lake Condah in western Victoria is a farming practice that, based on radiocarbon dating, goes back at least 6600 years.

a How was this farming practice an interdependent relationship between eels and the local people until at least 200 years ago?

b What type of interdependent relationship existed between the local people and the eels? Explain your answer.

HOT Challenge

4 The terms 'traditional owner' and 'custodians' have a distinct meaning in Aboriginal and Torres Strait Islander Dreaming concerning the interdependent relationships to the Land. Read the following.

As part of the complex cultural and spiritual systems underpinning Aboriginal society, there are Aboriginal custodians for particular culturally important plant species. There is no consistent English translation of Aboriginal roles and responsibilities in relation to land and its resources. However, terms such as 'traditional owners', 'custodians' or 'native title holders' have been used in different cultural and/or legal contexts such as the Aboriginal Land Rights (Northern Territory) Act 1976 and the Native Title Act 1993 (Cth).

It is important to understand the complexity of custodial ownership, rights and responsibilities for species/plants. There are multiple groups who have rights defined

by multiple processes – custodians of plant Dreamings that are specific to a particular country, and custodians of the land on which the plant grows. For example, Akatyerr [bush tomato] is extensively distributed over a distance of approximately 2,500 km from the western Great Sandy Desert to the Simpson Desert; consequently, hundreds of people are potentially affiliated with it. This complexity needs to be understood by external agents or parties who seek to negotiate with collective Aboriginal entities. It is a legal responsibility of Land Councils to identify traditional owners and consult with them about proposals related to the use of land trust areas and their resources.

Credit: Douglas, J and Walsh, F. (2011) *Aboriginal People, Bush Foods Knowledge and Products from Central Australia: Ethical guidelines for commercial bush food research, industry and enterprises*. Merne Altyerre-ipenhe (Food from the Creation time) Reference Group , Report 71.

There is huge world-wide interest in indigenous cultures and their knowledge of native plant species as potential sources for pharmacological drugs to cure illness.
What types of considerations need to be given to the relationships of the Aboriginal and Torres Strait Islander peoples in Australia based on the information above?

BRANCHING OUT

Eradicating invasive species from Macquarie Island

Macquarie Island is a World Heritage listed nature reserve. It is the only piece of land located between Australia and Antarctica, making it an important refuge and breeding ground for many seal and bird species. In 1810, sealers arrived on the island and, in 10 years, fur seals were almost hunted to extinction. From 1870 until 1919, elephant seals and king penguins were harvested for their oil. This harvesting of native animals was not the only terrible legacy left by humans; they also introduced wekas (also known as the Maori hen or woodhen), cats, rabbits, rats, mice and invasive plants.

Millions of seabirds from 23 different species breed on Macquarie Island. Thirteen species are listed as threatened, including species of albatross and giant petrel. These birds breed on land in tussock vegetation or in burrows, exposing them to threats from invasive species through predation and loss of nesting habitat (Figure 9.37). The change in biodiversity on Macquarie Island since humans first arrived has been substantial.

Figure 9.37a Grazing by rabbits b causes loss of breeding habitat for nesting seabirds.

To monitor the biodiversity of island ecosystems, scientists survey the **abundance** and distribution of species. Data relating to abiotic factors such as weather patterns and air, soil and water quality are often collected at the same time. This

provides a record of what species are living in particular locations at a given time and the conditions they are living in. The survey data can be compared to archived material to monitor changes in populations over time and to study how these changes correlate with other factors in the ecosystem. Models can be constructed to predict why species numbers have changed or to determine how species might be impacted in the future. These models are valuable in environmental impact studies.

Eradication of invasive species is a key approach in island restoration and recovery of native species. Impact studies are used to inform decisions on island eradications. An impact study found that cats were having a negative effect on seabird populations through predation of adults, chicks and eggs. A decision was made to eradicate cats. After 15 years of trapping, success was achieved in 2000.

However, eradication of a single species when multiple pest species are present can have unpredicted detrimental effects if other invasive species are also on the island. An explosion in rabbit populations that occurred from 2000 to 2006 was correlated with the eradication of cats, but it was not directly caused by the eradication.

In 2006, the Federal minister of environment approved an eradication plan for removal of all rabbits, rats and mice from the island, at a cost of $25 million. In 2011, helicopters dropped poison baits across the island and dogs were then used to locate and kill any remaining rabbits (Figure 9.38). Following 2 years of monitoring without seeing evidence of the target species, the project was declared a success in 2014.

a

Tasmania Parks and Wildlife Service

b

AAP Image/P

Figure 9.38a Aerial baiting and **b** use of dogs to locate surviving rabbits led to the success of the rabbit eradication program on Macquarie Island.

Questions

1 In 1891 the Macquarie Island parakeet became extinct. This parakeet nested under tussocks of vegetation on the treeless island. On reading a variety of accounts describing abundance of introduced and native fauna on the island from 1810 to 1920, naturalists constructed a model to compare the relative abundance of introduced species against the parakeet (Figure 9.39).

a Use Figure 9.39 to predict why the Macquarie Island parakeet became extinct.

b This model has limitations. While it provides possible correlations between species, does it provide enough information to prove the cause of parakeets becoming extinct? What further information might be required?

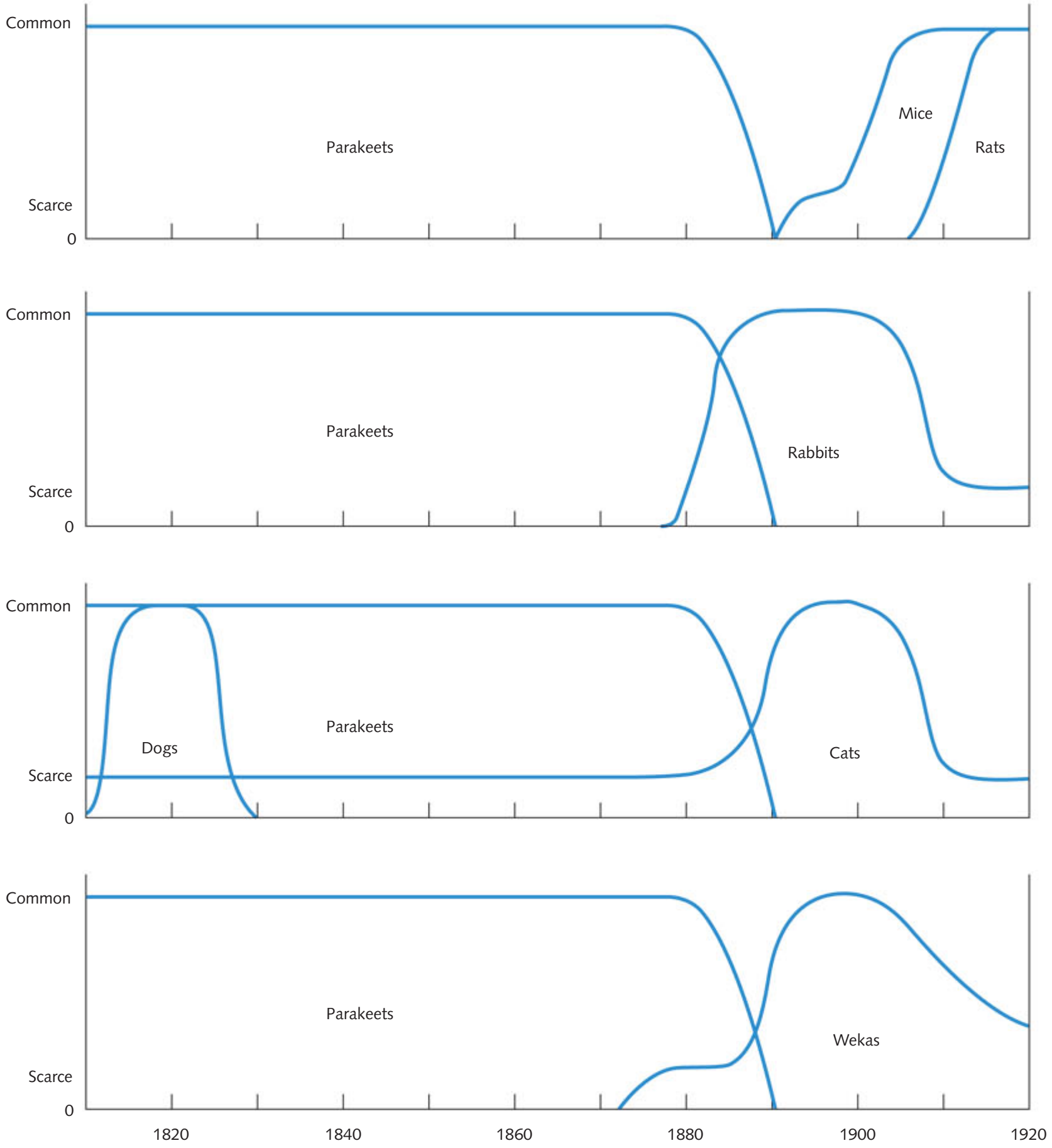


Figure 9.39 **A diagram constructed using early accounts of fauna on Macquarie Island to indicate relative abundance of parakeets and introduced species from 1810 to 1920. Not to scale.**

2 Rabbits negatively impact vegetation and cause land erosion through grazing and the construction of warrens.

a Use Figure 9.40 to describe trends in the rabbit population on Macquarie Island from 1974 to 2012. What factors correlate with a population increase? What factors correlate with a population decrease?

b Both native and invasive species of flora are found on Macquarie Island. Describe possible effects that the removal of rabbits might have on the island's flora and fauna.

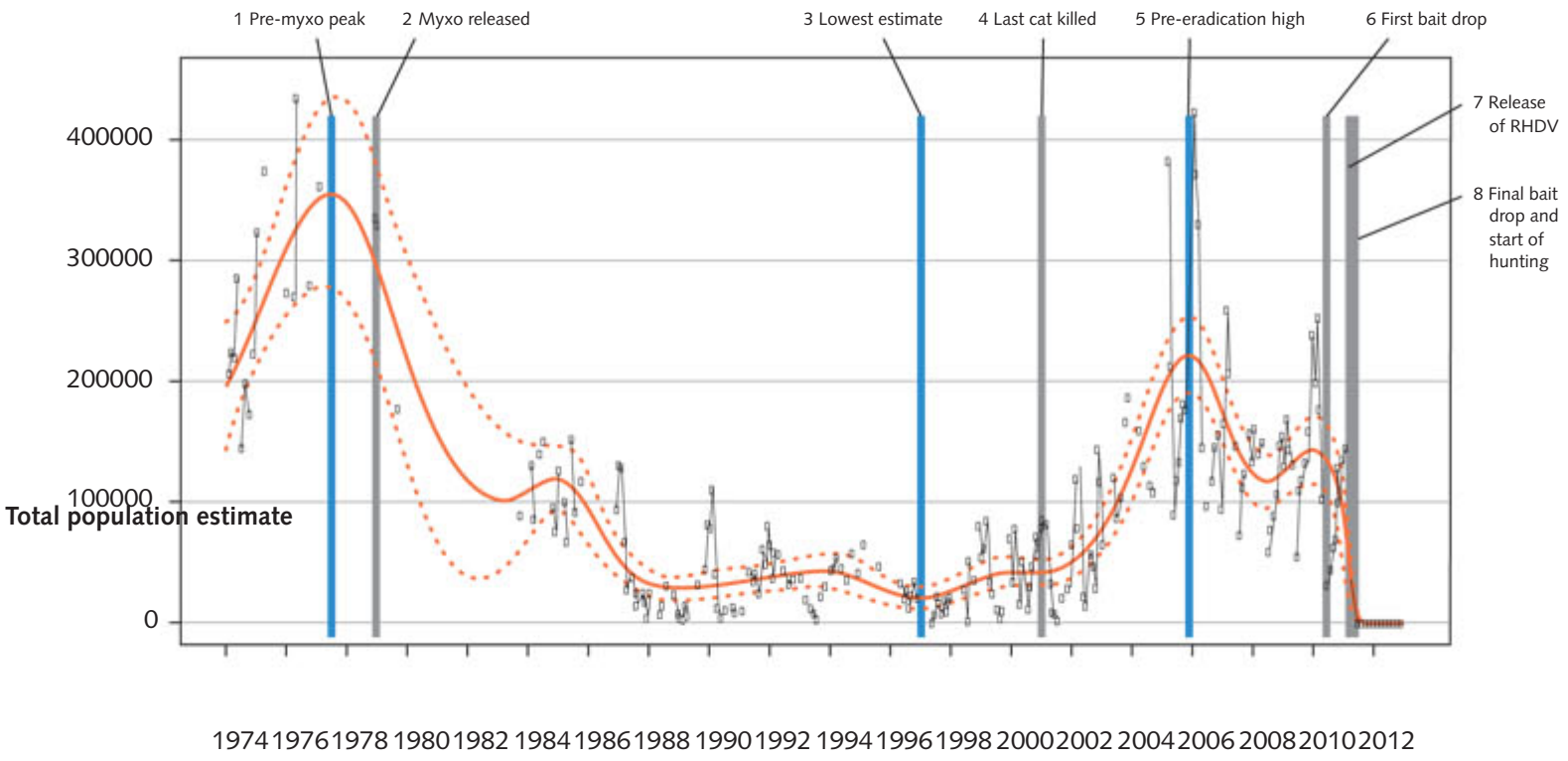


Figure 9.40 Long-term rabbit population trends on Macquarie Island from 1974 to 2012. Rabbit population trends are shown by the solid orange line. Large fluctuations in the population levels of rabbits over the past 40 years are linked to the history of feral animal management interventions such as introducing the myxoma virus (myxo) and calicivirus (RHDV) and using poison baits and dogs trained to hunt rabbits.

Online Key Concepts
Chapter 9: Summary of key concepts

9 Summary of key concepts

9.1 Genetic diversity

KEY CONCEPTS

p. 341

- An ecosystem consists of all the living organisms in a specific area that make up the populations in the community interacting with each other and their physical surroundings.
- Genetic diversity is the range of genotypes of individuals in a population of a species or the entire species.
- Genetic diversity is essential for the survival of a population of a species, or for the survival of the whole species located in different widespread areas, if there is a change in the environment (such as habitat destruction, lack of resources, introduced predator, disease).
- If a species lacks genetic diversity and is lost from Earth's biodiversity, it is said to be extinct.
- Mutation is the only way new alleles can be introduced into a species.

Getty Images/Kathleen Rock

Figure 9.1 Lemurs like these Coquerel's sifakas (*Propithecus coquereli*), found only in Madagascar, show diversity in their colour patterns, size, snout length and position of their ears.

9.2 Adaptations

KEY CONCEPTS

p. 343

- An adaptation is an inherited characteristic that makes an organism better suited to its environment to increase its chances of survival and reproduction.
- The three types of adaptations that are found in organisms are structural, physiological and behavioural.
- A structural adaptation refers to the physical or anatomical features an organism possesses that increase its chances of survival and reproduction in its natural environment.
- Physiological adaptations are features of an organism's functioning that increase its chances of survival and reproduction in its natural environment.
- Behavioural adaptations refer to the ways in which organisms act in response to stimuli that improve their chances of survival.

Shutterstock.com/EcoP

Figure 9.18 A meerkat sentry watches for danger.

9.3 Survival through interdependencies between species

KEY CONCEPTS

p. 355

- Biological interdependencies are interactions between different species that are essential if organisms are to survive and reproduce and, ultimately, they are essential for the successful functioning of the ecosystem.
- Symbiotic relationships and interactions include parasitism, mutualism and commensalism, in which the organisms that benefit have inherited features that increase their chances of survival and reproduction.
- Individuals in a species are in competition with each other and members of other species if they require the same resources to fulfil their needs for survival.
- In a predator–prey relationship, the predator kills the prey and consumes part or all of it for food.
- Feeding relationships that occur within communities in an ecosystem can be represented by food chains and food webs.
- Energy is transferred from one trophic level to the next level. Of the original input of light energy from the Sun, 90% is lost to the surroundings as heat energy and as chemical energy in wastes.

Alamy Stock Phot

Figure 9.20 This pygmy possum, while collecting nectar from eucalypt blossom, is also acting as a pollinator.

9.4 Keystone species

KEY CONCEPTS

p. 366

- A keystone species is a species that has a disproportionately large effect on other organisms within an ecosystem and is important for maintaining balance within the ecosystem.
- The size, distribution and density of populations of other species in the ecosystem can be negatively affected if a keystone species is removed or its population decreases.

Shutterstock.com/Aimee Grenier

Figure 9.30 Beaver building a dam from tree branches

9.5 Adaptations and interdependencies in Australian ecosystems

KEY CONCEPTS

p. 369

- Aboriginal and Torres Strait Islander peoples came to Australian 40 000–50 000 years ago and gained a good understanding of the adaptations and interdependencies of a species in Australian ecosystems.
- Their knowledge and understanding allowed them to recognise species with adaptations that were beneficial to their needs for food, water and other resources.
- Careful and controlled harvesting of species was undertaken according to cultural laws and protocols and this meant informed community decisions were made regarding the numbers of a species that could be used for food. This essential knowledge safeguarded the species, thereby ensuring that their density and distribution were maintained.

Shutterstock.com/Janelle Lugge

Figure 9.34 A billabong covered in water lilies, an important food source for Aboriginal and Torres Strait Islander people

WB
9.6.1 KEY TERMS PAGE 229

9 Chapter glossary

abiotic relating to the non-living components of an ecosystem

abundance the number of individuals of a species in a population

adaptation an inherited characteristic that makes an organism better suited to its environment and increases its chances of survival and reproduction

amensalism a symbiotic relationship whereby one species is inhibited or destroyed, while the other remains unaffected

behavioural adaptation an inherited way in which an organism acts that increases its chances of survival and reproduction

biotic relating to the living components of an ecosystem

carnivore an organism that feeds on other animals

coexistence different species living together

commensalism a symbiotic relationship whereby one species benefits and the other is unaffected

community the sum of the different species inhabiting a particular habitat at one time

competition the struggle between members of a species or between two or more species for resources to fulfil their needs for survival

consumer any organism that cannot manufacture its own food and depends on others for food

density the number of organisms of a species per unit area

distribution the pattern of where the organisms of a species live

ecosystem a self-sustaining unit consisting of the interactions between the community and the environment

environment abiotic and biotic factors of an area

extinct the status of a species when there are no living members

first-order consumer a consumer that feeds directly on producers; also known as a herbivore

food chain a sequence of trophic levels in which an organism is consumed by an organism in a higher trophic level, creating a chain in which energy and matter are passed to progressively higher levels

food web a network of feeding relationships that shows flow of energy and matter through complex pathways

genetic diversity the range of genotypes of individuals in the population of a species or the entire species

habitat an area or environment in which an individual or species lives within an ecosystem

herbivore a first-order consumer that feeds on plants

host an organism that another organism lives on or in

keystone species a species that has a disproportionately large effect on other organisms within an ecosystem and is important for maintaining balance within the ecosystem

mutualism a symbiotic relationship whereby each species in the relationship benefits from the other

omnivore an organism that feeds on a range of foods, including plant and animal matter

parasite an organism, such as a bacterium, virus, fungus, worm or arthropod, that lives on or in another host organism

parasitism a symbiotic relationship in which one species benefits to the detriment of the other

physiological adaptation an inherited characteristic in the functioning of an organism that increases its chances of survival and reproduction

phytoplankton the collective term for the tiny photosynthetic organisms present in bodies of water

population a group of individuals belonging to the same species living in a particular area at the same time

predator an organism that hunts another organism for its food

prey an organism that is hunted by another organism for food

producer autotrophic species that produce complex organic matter from simple inorganic molecules, predominantly using light energy from the Sun, in photosynthesis or chemical energy in chemosynthesis

scavenger a consumer that feeds on dead and decaying flesh or remains

structural adaptation an inherited feature of an organism's anatomy that increases its chances of survival and reproduction

symbiosis the relationship between individuals of two or more species that interact together whereby at least one organism benefits from or is harmed by the relationship

top consumer the last link in a food chain

trophic level a feeding level in the food chain of an ecosystem

WB
9.6.2
PRACTICE TEST
QUESTIONS
PAGE 230

9 Chapter review

Remembering

1 Distinguish between structural, physiological and behavioural adaptations.

2 Distinguish between an ectotherm and an endotherm.

3 Describe how sexual reproduction contributes to diversity in a species.

4 Distinguish between the following terms.

a Biotic and abiotic

b Population and community

c Diversity and biodiversity

Understanding

5 State each of the links in a general food chain and describe how they relate to one another.

6 Is it possible for a carnivore to occupy more than one trophic level in a food web? Give an example to support your answer.

7 Why does a herbivore depend on producers for its energy requirements?

Applying

8 Copy and complete the table below, which summarises the relationships and interactions between living species.

Relationship or interaction	Description	Example
	Different species living together and sharing the same resources	
Commensalism		
	Rivalry between species for particular resources	
Mutualism		
	Transfers pollen between flowers	
	An animal that kills for food	
Keystone species		

9 The Yellowstone cutthroat trout is a keystone species in Yellowstone National Park, in Wyoming in the United States. Apply your understanding of a keystone species to explain Figure 9.41 and why it is essential to conserve population numbers of the Yellowstone cutthroat trout.

Figure 9.41 Yellowstone cutthroat trout is a keystone species.

10 State two behavioural adaptations shown by the thorny devil that assist it in surviving in its natural environment.

11 A plant with broad, thin, shiny leaves is growing in a desert. List the survival threats that this plant would face in this environment.

Analysing

12 Explain why it is difficult to explain a physiological adaptation without talking about related structural adaptations as well. Provide an example.

13 Refer to Figure 9.26 (p. 362), which shows a food web within a woodland ecosystem.

a Draw two food chains that are within this food web. Use arrows to show the flow of energy.

b Identify an organism that is a second-order consumer in one chain but a third-order consumer in another. The chains do not have to be those of your answer to part a.

14 The Galapagos Rift, which receives no light, is a deep-sea boundary between oceanic plates. Sulfate in the sea water is converted into hydrogen sulfide at high temperatures. Chemosynthetic bacteria obtain energy from the hydrogen sulfide; they use this energy to convert carbon dioxide dissolved in the water into organic molecules. In the same area, clams that feed on the chemosynthetic bacteria are an energy source for crabs and octopus. Chemoheterotrophic bacteria return resources to the community.

Choose which one of the combinations in the following table correctly identifies the producer, the first-order consumer, the second-order consumer and the decomposer for the community described above.

	Producer	First-order consumer	Second-order consumer	Decomposer
A	Photosynthetic bacteria	Clams	Octopus	Chemosynthetic bacteria
B	Chemosynthetic bacteria	Clams	Crabs	Chemoheterotrophic bacteria
C	Photosynthetic bacteria	Octopus	Crabs	Chemosynthetic bacteria
D	Chemosynthetic bacteria	Crabs	Octopus	Chemoheterotrophic bacteria

15 a Draw a graph to show what would happen to a population of rabbits if there were no predators in the areas where the rabbits lived.

b Introduce a predator such as a fox into your population and show on your graph what may be expected to happen to the rabbit population.

16 Use an example to show how Aboriginal and Torres Strait Islander peoples understood and used the adaptations of particular species for their own benefit.

17 Two populations of different species within an area are measured at 3-year intervals. Over that time, the numbers of the two species vary as shown in the following table.

Time	Number of species 1	Number of species 2
Year 0	25	85
Year 3	50	50
Year 6	30	75
Year 9	60	70

a Graph the results on one set of axes.

b Describe the trend you see with the two species.

c One species preys on the other. Explain which species you think is the predator and why.

18 The black rhinoceros often has birds on its back that remove ticks from its skin. What type of relationship is this?

Evaluating

19 Many ecologists believe that keystone species should be central to the efforts to amplify biodiversity. However, others are of the opinion that the definition of a keystone species is not yet refined enough to form the basis of conservation efforts. They speculate that this process could be detrimental to species that are not considered key to biodiversity and yet are indicators of habitat health. What is your opinion on this issue? Provide justification for your stance.

20 Consider the grasshopper shown in Figure 9.42. Grasshoppers are widespread, thriving in hot and dry grasslands. Their main diet is plant shoots and leaves. List five structural adaptations that you can see on this grasshopper that would make it well adapted to living in such an environment.

Alamy Stock Photo/Nature Picture Library

Figure 9.42 A Leopard grasshopper

21 Justify this statement: 'The world is a more diverse place because of the relationships found within ecosystems.'

22 'Ecosystem models are useful representations of elements within the ecosystem, the relationship between the elements and the relationship with surrounding ecosystems.' Identify the elements, the types of relationships between species and the types of relationships with the environment using the food web in Figure 9.26 (p. 362).

Creating

23 Create a table to clearly show how different organisms are affected by the four symbiotic relationships.

24 African *Senegalia* species are often plagued by beetle grubs that destroy their seeds and prevent them from germinating. This could have dire consequences for the trees, if not for elephants. Elephants feast on *Senegalia* fruits, which they do not chew very much and so consequently a great deal of fibrous matter, including whole beetle-free *Senegalia* seeds, end up in their dung. On average, 90% of *Senegalia* seeds deposited in elephant dung will germinate. Construct a diagram to show the relationships that exist between the *Senegalia* trees, beetles and elephants.

25 Aboriginal and Torres Strait Islander peoples lived in harmony with, and cared for, their land and sea creatures. Use examples to discuss this statement.

Unit 2 Area of Study 2 review

Multiple choice

Question 1 Sexual reproduction takes place in flowering plants when:

A a plant grows from a cutting.
B a plant sprouts from the roots.
C pollination occurs.
D pollen fertilises an ovule.

Question 2 ©VCAA 2006 E2 Sec. A Q5 ADAPTED HARD

In bees a drone (male) can develop from an unfertilised egg. This means that:

A the drone will have the same number of chromosomes as a female bee.
B the egg will be haploid.
C the drone will be diploid.
D the drones will be genetically identical.

Question 3 The most common banana found in supermarkets is the Cavendish banana. It is sterile and relies on vegetative propagation. One disadvantage of growing this type of banana crop is:

A the bananas have a uniform quality fruit.
B the bananas can be grown by cuttings.
C the bananas are vulnerable to disease outbreaks.
D bananas do not have seeds.

Question 4 Many of the molluscs that inhabit the intertidal regions of Victoria's rocky shore have adaptations that enable them to survive wave action and drying out between tides. Which of the following adaptations would be classified as behavioural?

A Clumping together and sheltering in alga masses
B An operculum that can trap water in the shell
C Hard external coverings
D Production of a cementing compound to hold shells to the rock surface

Question 5 Which of the following is a physiological adaptation found in a mammal for the purpose of maintaining its body temperature?

A Sheltering in the shade
B Body covering of dense hair
C Licking its skin
D Vasodilation

Question 6 Phytoplankton is eaten by krill, krill is eaten by humpback whales and penguins, penguins are eaten by killer whales.

If a food web was drawn of this relationship, krill would be:

A a first-order producer.
B a first-order consumer.
C a carnivore.
D a second-order consumer.

Question 7 Sea stars, mussels, limpets and barnacles, along with several species of algae, all live on a rock platform. Sea stars feed on mussels. Barnacles and mussels are filter feeders. Limpets graze on algae.

The following is true of this ecosystem.

A Mussels and limpets are competing for food.
B Limpets and barnacles are competing for food.
C Sea stars and limpets are competing for space.
D Mussels and barnacles are competing for space.

Question 8 CAM plants make up 10% of plants. They are adapted to an arid environment. The main feature of CAM plants is the reversal of the timing of opening and closing of the stomata.

Which of the following statements about CAM plants is correct?

A Plants photosynthesise at night.
B Water is taken in through the stomata at night.
C Carbon dioxide is taken in by the plant at night.
D Oxygen is released by the plant at night.

Question 9 Deciduous plants are found in regions of low temperatures and drought. Leaves are dropped because:

A there is no plant growth possible due to the environmental conditions.
B there is not enough sunlight for photosynthesis.
C there is not enough carbon dioxide for photosynthesis.
D there are no insects available for pollination.

Question 10 Halophytes are a group of plants that are considered to be salt tolerant. An example of a structural adaptation in response to the salty environment is:

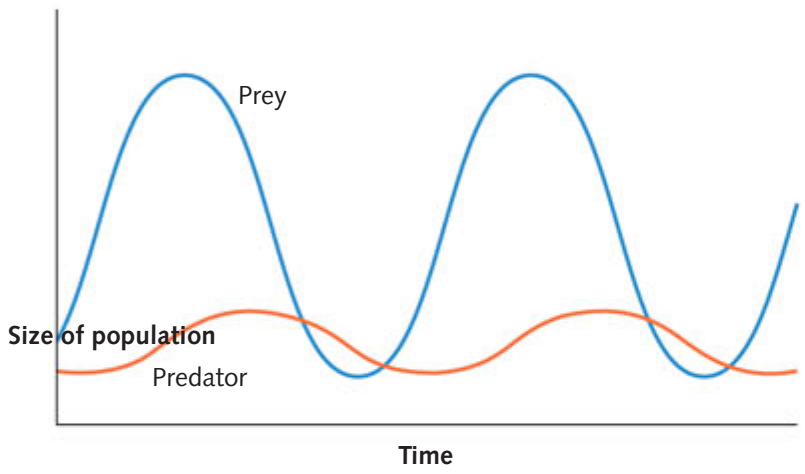
A salt crystals forming in the air spaces around cells.
B buttress roots in mangroves.
C salt accumulation in leaves.
D salt exclusion tissue in roots.

Question 11 A koala is able to survive on a relatively nutrient-poor diet of eucalyptus leaves. Koalas can sleep up to 22 hours a day. The male koala has scent glands on his chest. The koala has strong arms and legs and long claws. It has a large caecum that houses bacteria that provide the enzymes to digest eucalypt leaves.

Which one of the following is a structural adaptation that allows the koala to survive on a diet of eucalyptus leaves?

A Long claws
B Sleeping 22 hours a day
C Large caecum
D Scent glands

Question 12 The graph below shows the numbers of predator and prey species over time. From the graph it can be concluded that:



A the prey species reproduces asexually.
B an increase in predator numbers causes prey numbers to increase.
C predator numbers grow at a faster rate than prey.
D as the number of prey species decreases, the competition between predators will increase.

Question 13 Cool burns were a fire practice regularly carried out by Aboriginal people on the volcanic plains of Western Victoria. The main purpose of the cool burns was to:

A kill kangaroos.
B remove large trees from the grasslands.
C encourage regrowth of food plants.
D kill insects.

Question 14 The Tasmanian devil was once common on the Australian mainland. Now it only survives in Tasmania. The Tasmanian devil population shows very little genetic diversity. Tasmanian devil numbers are in decline due to the spread of devil facial tumour disease (DFTD), being killed by humans that think of them as a pest, and being hit by vehicles.

Which factor is likely to have contributed to the large impact of DFTD on Tasmanian devil numbers?

A Lack of genetic diversity in Tasmanian devils
B Lack of a vaccine
C Disease is spread by a scratch or cut
D Habitat destruction

Question 15 Gilbert's potoroo is a critically endangered marsupial that is endemic to the region around Albany in Western Australia. Its diet consists of 40 different species of fungi. The potoroo disperses the spores of the fungi in its faeces. The potoroo is best described as:

A a predator.
B a parasite.
C a herbivore.
D a keystone species.

Question 16 A plant living in arid conditions needs to minimise water loss in order to maintain photosynthesis. Which one of the following is a physiological adaptation that plants have to reduce the amount of water that they lose?

A Thick, hard cuticle
B Epidermal hairs
C Vertical leaf orientation
D Storing carbon dioxide as malic acid

Short answer

Question 1 ©VCAA 2002 E2 Sec. B Q6 ADAPTED

a Copy and complete the table to explain how the following characteristics of asexual reproduction can be considered both an advantage and disadvantage to the organism. (4 marks)

Characteristic	Advantage	Disadvantage
Lack of genetic diversity		
Large number of offspring produced		

b Genetic diversity is thought to give a species a greater chance of survival. Explain why greater genetic diversity gives a species a greater chance of survival. (1 mark)

Question 2 ©VCAA 2006 E2 Sec. B Q5 ADAPTED

Snuppy, the first cloned dog, was born in South Korea in 2005. The nucleus of Dog A's egg cell was removed. A somatic cell from the donor male dog (Dog B) was fused with the enucleated egg cell. The egg cell with the transplanted nucleus was transferred into Dog C. Snuppy was delivered by caesarean section from Dog C.

a Why was the nucleus removed from the egg cell of dog A? (1 mark)
b What is a somatic cell? Why is this cell fused with the enucleated egg cell? (2 marks)
c Is Snuppy a male or female? Explain. (2 marks)

Investigating a bioethical issue

10

By the end of this chapter you will have covered the following material.

Key knowledge

Scientific evidence

- the distinction between primary and secondary data pp. 396–397
- the nature of evidence and information: distinction between opinion, anecdote and evidence, and scientific and non-scientific ideas pp. 397–398
- the quality of evidence, including validity and authority of data and sources of possible errors or bias p. 399
- methods of organising, analysing and evaluating secondary data pp. 394–395
- the use of a logbook to authenticate collated secondary data p. 393

Scientific communication

- biological concepts specific to the investigation: definitions of key terms; use of appropriate biological terminology, conventions and representations p. 408
- characteristics of effective science communication: accuracy of biological information; clarity of explanation of biological concepts, ideas and models; contextual clarity with reference to importance and implications of findings; conciseness and coherence; and appropriateness for purpose and audience pp. 408–410
- the use of data representations, models and theories in organising and explaining observed phenomena and biological concepts, and their limitations pp. 399; 410–412
- the influence of social, economic, legal and political factors relevant to the selected research question pp. 401–403
- conventions for referencing and acknowledging sources of information pp. 394; 410

Analysis and evaluation of bioethical issues

- ways of identifying bioethical issues pp. 391–394
- characteristics of effective analysis of bioethical issues pp. 403–404
- approaches to bioethics and ethical concepts as they apply to the bioethical issue being investigated pp. 404–407

Online Chapter map
Chapter 10 map

10 Investigating a bioethical issue

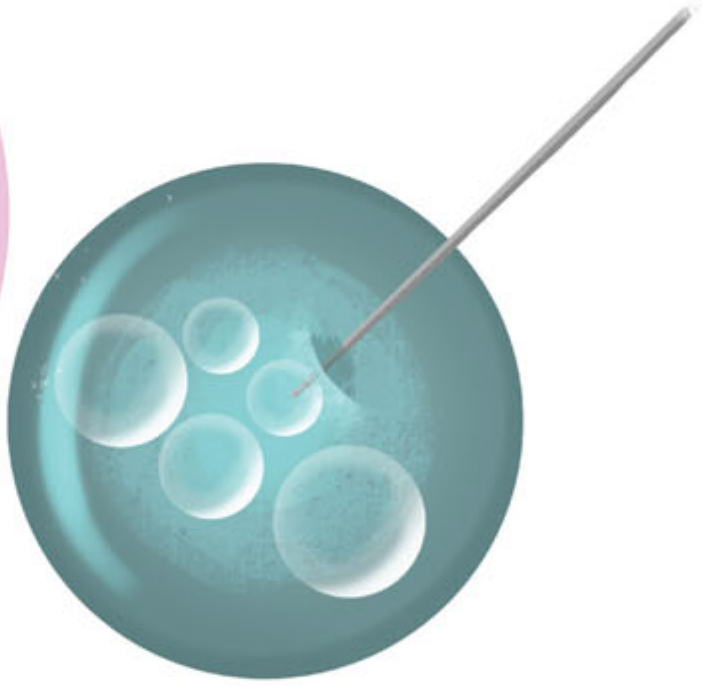
We all have opinions about what we consider to be right and wrong. Sometimes we do not agree with other peoples' opinions on the same topic. Where do you stand, for example, on the issues of assisted dying, genetic engineering of animals, animals in research and stem cells for therapeutic remedies? This chapter will provide you with a framework that you can use to consider bioethical issues and assist you with your Unit 2 Outcome 3 assessment.

10.1 Beginning an investigation p. 391

When considering a bioethical issue you will quickly find that everyone stakes a claim depending on their personal point of view. You need to investigate these claims and assess the evidence that supports each. Is this evidence legitimate scientific evidence supported by research, or opinion or anecdote?

10.2 Evaluating evidence p. 395

Investigating a bioethical issue starts with good research skills. Organise your investigation around a problem statement about the conflict that needs to be addressed. Keep a logbook and record your sources, the information you retrieve from them and your evaluation of their reliability.



10.4 Preparing a report p. 408

The communication method that you choose to convey your message needs to be suitable for your intended audience. Use your communication to show how you arrived at your informed decision about your chosen bioethical issue, while still adhering to all the requirements of good science communication.

10.3 Evaluating a bioethical issue p. 400

The bioethical issue will have legal, political and economic implications. When assessing the issue, apply bioethical principles such as respecting those who are affected, maximising the benefits and minimising the harms, and equitably sharing the costs and benefits.

As you can see, studying Biology is more than studying the science. Other issues such as safety, ethics and bioethics all have to be considered, analysed, evaluated and acted upon.

To access resources below, visit www.nelsonnet.com.au

Online map:
- Chapter 10 Chapter map (p. 388)

Online Key Terms:
- Chapter 10 flashcards (p. 390)

Weblinks:
- The future of vaccination (p. 391)
- What are stem cells? (p. 391)
- What is stem cell tourism? (p. 391)
- The hopes and risks for gene therapy. (p. 391)
- Genetically modified foods (p. 401)
- HeLa cells. (p. 403)

Online Worksheets:
- What are stem cells? (p. 391)
- HeLa cells. (p. 403)

Online Key Concepts:
- Chapter 10 summary of key concepts (p. 416)

Know your key terms

Online Key Terms
Chapter 10 flashcards

anecdote
authority
bioethical issue
biopiracy
bioprospecting
consequences-based approach
contextual clarity
dogma
duty-based approach
individual rights
intellectual property
in-text citation
opinion
paraphrasing
patent
peer reviewed
plagiarism
problem statement
public opinion
quoting
reference list
scientific evidence
secondary data
stakeholder
summarising
virtues-based approach
weak evidence

Remember

This chapter will build on the following concepts that you will have already met. Take the time to refresh these concepts before you start this chapter.

WB
REMEMBER
PAGE 232

1 A controlled experiment is when an independent variable is manipulated and the dependent variable is measured. All extraneous variables are controlled.
2 In a controlled experiment, the control is a set-up that does not contain the independent variable.
3 Correlation is a statistical measure of the relationship between two variables.
4 Valid results are affected by only a single independent variable.
5 Results are repeatable if the investigation can be conducted again by the same investigator under the same conditions to generate similar results, whereas results are reproducible when similar measurements are made by a different investigator.

Throughout history, innovations in biological research have met with popular anxiety whenever it was proposed to translate them into practical applications. This underscores the perception from both scientists and the public that such innovations carry potential risks of harm, as well as potential benefits.

The background against which people consider risks and benefits may be informed by scientific, legal, religious, social or moral viewpoints, among other influences. Consequently, there are often conflicts between positions taken by different individuals or sectors of the community. Scientific and public perceptions sometimes do not align. For example, scientific reassurances about the health benefits and the relatively low risks associated with vaccinations are rejected by some segments of the public (Figure 10.1). On the other hand, scientific warnings about the risks of some unproven stem cell therapies are rejected by affected individuals who believe the therapies at least offer them hope (Figure 10.2).

Weblink
The future of vaccination.

AAP Image/BIANCA DE MARCHI

Figure 10.1 Anti-vaccination activists protesting against mandatory vaccinations

Shutterstock/alexkich

Figure 10.2 Despite the warnings of scientists, people with chronic disorders are sometimes willing to try unproven therapies.

Navigating to a decision about the applications of biological innovation requires critical thinking supported by effective communication. It is necessary to critically evaluate the science and the scientific credibility of the claims being made. This includes assessing what evidence may be lacking. It is also necessary to consider the ethical implications of applying the technology. That requires identifying our moral position and recognising alternative positions to evaluate the consequences of exercising our moral judgement. Putting the scientific and ethical aspects together, conclusions are drawn about how severe the risks are, how they compare with the benefits, who potentially stands to benefit, who potentially stands to suffer, and what the likely consequences are of taking a particular course of action.

10.1 Beginning an investigation

There are two aspects to a **bioethical issue** or an ethical issue that involves biology. The first is the biological technology, intervention, or process that is the context for the issue. The second is the ethical concerns that lie at the heart of the issue. The issue directly affects certain people or other living organisms (the **stakeholders**), but often carries implications for the whole of society. The nature of the ethical issue is that it involves a conflict between the interests of different stakeholders.

Investigating the issue requires evaluating the claims of impact and the motivations of competing stakeholders. It requires clearly defining what the investigation will focus on, gathering the information that is required, evaluating the scientific evidence backing the claims, evaluating the legal and economic context relevant to the issue, and evaluating the ethical concerns and responsibilities of the stakeholders.

Weblinks
What are stem cells?
What is stem cell tourism?
The hopes and risks for gene therapy.

Online Worksheet
What are stem cells?

The steps to take toward investigating a bioethical issue will be outlined. This guide will help you to identify, research, evaluate and report your investigation.

Identifying a bioethical issue

Bioethical issues carry implications for all parts of society. The biological issue that raises bioethical concerns can be technological or an intervention based on a change in practice. The issue could be research-based, medical, social, economic or environmental. Discussions about bioethical issues are therefore widespread in science, industry, politics, media and the general public. Bioethical issues may arise as biological technology evolves, as new strategies for managing biological resources emerge or as public attitudes towards a biological intervention change (Figure 10.3).

Getty Images Plus/E+/Reptile8488

Figure 10.3 Bioethical issues arise as a consequence of progress in biological technology and social attitudes.

Some major bioethical issues currently debated by science and society include the following.

- Who owns human biological samples? What rules should guide the use of human biological material for research and laboratory diagnosis?
- How do we monitor therapies being offered and the associated risk to patients?
- What does it mean to be human and when does human life begin?
- The clinical use of stem cells – how can we best monitor the validity of therapies being offered and assess the risks?
- Should we invest in anti-ageing research and assisted reproduction? How can we sustain a growing and ageing population?
- The use of animal models in research and industry – what kinds of experiments, what animals, and what considerations are there for the welfare of these animals?
- Genetic engineering – for what organisms (including humans) should this be used, and under what circumstances? What are the benefits and the risks?
- Who owns the results of scientific research? What regulations should we have for patents on biological materials?
- What value should we place on biodiversity and how do we measure it? Are some species more important than others? How should decisions be made about conservation, and who should make them?

WB
10.1.1 IDENTIFYING A BIOETHICAL ISSUE PAGE 233

Problem statement

Once you have identified the issue you are investigating, you will benefit by organising your research in a systematic way. It is helpful to frame your investigation around what you need to find out. One way of doing this is to write a **problem statement** that outlines what your investigation will address.

The problem statement is ideally a paragraph of a few sentences that outlines the conflict or dilemma that needs to be resolved. The problem statement helps you to stay focused and avoid becoming overwhelmed by the volume of material you could potentially review. It is intended to give you a clear understanding of the motive for your investigation and to clarify the kind of information you need.

When crafting the problem statement, it is helpful to take account of the five Ws: what, who, when, where and why.

- What – what is the issue, what are the impacts of the issue, what would happen if the issue is resolved or left unattended?
- Who is affected – is it a species under threat, cloned organisms, patients for a proposed medical intervention, subjects of a genetic test, certain sectors of the community who may be either advantaged or disadvantaged by the introduction of a new technology, a particular cultural group, or the broader public?
- When – how long has the issue persisted, is it a future problem, and what is the timeframe for resolving it?
- Where is the issue a problem – is it unique to a country, a region or an ecosystem, or is it more widespread?
- Why is it necessary to address the issue – what significance does the issue have? How does it impact on stakeholders, such as consumers, businesses, farmers, patients, medical practitioners, wildlife, livestock, governments and the public?

Record your initial thoughts and feelings, and make a list of questions that need further investigation. What do you need to know more about? What evidence do you need to collect? That framework will guide you to source and gather secondary data relevant to the issue and to evaluate its quality.

Maintaining a logbook

Use your logbook to collect and record information from your sources and to document your own thoughts and ideas as you process the information. The logbook can be a digital or paper-based record. There is no fixed format for a logbook but each entry ideally includes the following details:

- The date of the record
- Reference details of your sources (Refer to Referencing and acknowledging sources on page 394.)
- Your evaluation of the quality of each source (Refer to CRAAP test, Table 10.2, p. 396.)
- A description or summary of the information in the source. This can include copies of pertinent tables, graphs, web links or quotes from the source. What are the main conclusions from the data? Include any terms that are new to you and their definitions.
- Your evaluation of the data in the source. Describe what methods were used to collect the data. Assess what measures were used to validate the data and minimise the effects of error and bias.
- Your reflections, conclusions, ideas, or questions that were raised by digesting and evaluating the information. Some of these may contribute to addressing your problem statement; others may be springboards to fact checking or further inquiry. For example, what data do you still need to address aspects of your problem statement?

As you add to your logbook, you may discover that your beliefs, assumptions and understandings about a biological issue change over time. By keeping a record of your investigation, you will be able to return to specific entries and pinpoint key sources of information or data that influenced your thinking.

Background research

Investigators complete background research from a wide variety of secondary sources to help them establish facts on an issue. These include books, magazines, television programs, websites, government reports, reports by scientific agencies (for example, from CSIRO) and academies (for example, the Australian Academy of Science), company or trade reports, and **peer reviewed** scientific articles.

Scientific articles in established scientific journals may be retrieved through searchable databases like JSTOR, EBSCO or PubMed if your library has access to them. These are used in the same way as a Google search. When you enter key words in a search page, the database retrieves entries of scientific articles that contain those words.

Record details about each source as you conduct your research. There are different methods you can follow to do this. The American Psychological Association (APA) citation method has been adopted for referencing in many scientific disciplines. Table 10.1 provides a guide to referencing information using this method.

WB 10.1.2 REFERENCING AND ACKNOWLEDGING SOURCES PAGE 235

Referencing and acknowledging sources

As you progress in your research, use your logbook to build a **reference list** by arranging your sources in alphabetical order based on the surname of the leading author/producer. For more detailed information on referencing, you can consult library websites and librarians.

Table 10.1 How to reference information using the APA citation method

Source of information	Citation method	Example
Books	Author names or name of organisation if authors not supplied. (Year of publication). *Title of book*. Location. Publisher. (Include URL and date of access if electronically accessed.)	Suzuki, D. and Knudtson, P. (1988) *Genethics: the ethics of engineering life.* Toronto, Canada: Stoddart Publishing Co Ltd.
Journal, magazine and newspaper articles	Author names. (Year). Article title. *Journal title*, volume number (issue number), page numbers. (Include URL and date of access if electronically accessed.)	Hankey, G.J. (2017) Stroke. *Lancet* 389 (19 969): 641–654.
Websites	Author names or name of organisation (if provided). (Year published). Title of work. Date you retrieved the information, website URL.	Faa, M. (2019) Dengue fever virtually eradicated from Far North Queensland, scientists say. Retrieved 2020 May 17 from http://www.abc.net.au/news/2019-09-27 /11555792
Personal correspondence or interviews	Interviews should be cited in the text as 'personal communication' (including month, day, year) and not included in the reference list. Names, initials (of interviewee). (Date).	Prof. M. Munsie (personal communication, 30 April 2020)
Television	Names, initials (of executive producer). (Date). Episode or story title. *Title* (of television program). Country or city of production: production studio or network.	Taylor, A. (producer and presenter) (2016) Live long, die young [Television series episode] in *Catalyst*. Sydney, Australia: ABC iview.
Film	Names (of producer), and names (of director). (Year). *Title of film*. Country of origin: studio name.	DeVito, D., Shamberg, M., Sher, S. and Lyon, G. (producers), Niccol, A. (director and writer) (1997) *Gattaca*. USA: Jersey Films.

Recording ideas as you progress

Your report will present important ideas as well as data. You can do this by summarising, paraphrasing and quoting. In **summarising**, you put the main ideas into your own words to capture a broad overview. In **paraphrasing**, you re-write a particular passage in your own words and retain the original meaning, ensuring you maintain relationships between main ideas and supporting points. When **quoting**, you match the source word for word, enclosing the text in quotation marks. When recording quotes, note the page number it appears in the source.

Keep a glossary of biological terminology in your logbook as your investigation progresses.

KEY CONCEPTS

- Bioethical issues are ethical issues concerned with implementing a biological technology, intervention or process.
- Investigating a bioethical issue requires identifying the issue and the conflict; analysing the evidence in support of claims; analysing the legal and economic context for the issue; and evaluating the ethical concerns and responsibilities of the stakeholders.
- A problem statement helps to organise secondary data.
- Maintaining a logbook and using APA referencing helps to record the details and your evaluation of secondary data.

Concept questions 10.1

1 Give two examples of a bioethical issue.
2 Describe the features of a problem statement.
3 Why is it preferable to record all your research in a logbook?
4 Distinguish between summarising, paraphrasing and quoting.
5 Define a reference list.

HOT Challenge

6 What is plagiarism, and how do you avoid plagiarising someone else's thoughts in print?

10.2 Evaluating evidence

When evaluating claims about the effects of a biological issue, we may be overwhelmed with claims from a variety of sources, including scientists, interest or lobby groups, government bodies, media commentators, the public, social media and affected individuals. Ultimately, the substance of the claims lies with the characteristics of the evidence that supports them. When assessing scientific claims, it is crucial to understand the source and the legitimacy of the evidence that supports the claim (Figure 10.4). We begin by analysing the source of the claim.

Evaluating secondary sources

When you begin to assemble data for your investigation, it is worthwhile evaluating the quality of the sources of the information to determine their dependability. What is the claim, who is making it, and what is motivating them to make it? A useful framework for assessing these concerns is the Harvard University's CRAAP test (Table 10.2, p. 396).

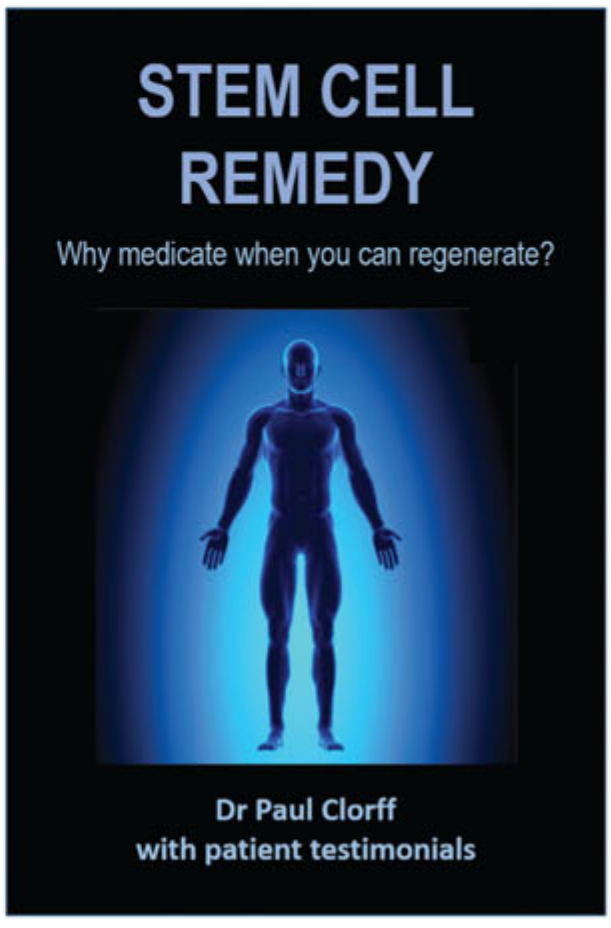


Figure 10.4 Promotional material for stem cell therapy

Table 10.2 Features of the CRAAP test

Feature	Pertinent questions	Explanation
Currency	What was the publication date?	Scientific knowledge and social attitudes evolve relatively quickly, sometimes within just a couple of years. The older the reference, the greater the risk that it is out of date. Always seek the latest publications wherever possible.
Relevance	Is the publication relevant to the investigation?	Key word searches may retrieve all sorts of articles, web pages, and social commentary that are unrelated to your study. Some may be relevant but written at a level that is inappropriate for your needs, such as a website for primary school students or a technical paper for practising clinicians. Read the opening paragraph to decide if it is worth reviewing further.
Authority	Who wrote, published, and sponsored the publication? What are the author's credentials and their affiliations?	If you have sourced publications with scientific content, it is instructive to consider whether the author is a trained scientist from a professionally recognised university or institute. Consider the author's track record in publications – do they write predominantly online content or is there evidence of publications in the peer-reviewed scientific literature? Consider how the publication might be influenced if the author is connected with a special interest or lobby group.
Accuracy	How true and reliable are the data and information contained in the publication?	Consider whether the claims made in the publication are supported by evidence and what the quality of that evidence is – is it opinion, anecdote, or drawn from primary or secondary scientific data? If it is supported by scientific evidence, how valid are the scientific data? Consider whether the publication was peer reviewed, as are those that appear in academic journals. Check whether the publication incorporates citations of other publications that you can retrieve and verify. Consider whether the language and the tone of the publication is emotive, presumptuous or discriminatory.
Purpose	What is the information meant to achieve – to evaluate, inform, teach, sell or persuade?	This will depend upon the publication's intended audience. It may be for scientists, other academics, students, consumers or the public. You need to be conscious that material is often published to promote a product or a particular point of view. Consider whether the information appears objective, or endorses a particular political, religious, commercial or ideological perspective.

Distinction between primary and secondary data

To assess the effects of a particular intervention or a biological condition, science depends on the production and analysis of data. In the scientific context, data are the results collected from an experiment or investigation that are used for analysis. Data may be gathered in different ways, depending upon the type of question being investigated. Data may take many forms, including qualitative such as observations or written survey responses, or quantitative such as measurements.

Primary data

The most obvious approach to gathering data is to produce it directly by conducting an experiment. The data in this case is described as primary data because the individual doing the analysis has personally generated the data. You will already be familiar with primary data from performing your own investigations and from reading Chapter 5.

The key advantage of primary data is that the investigation is structured to produce the data that directly answer the research question under study. The disadvantage of primary data is that they are limited in focus and cannot always be applied to answering related research questions. For example, a researcher predicts that exposing fruit flies to radiation reduces the flies' life span. The results show the life span of the irradiated flies tends to be shorter than those of the untreated group (Figure 10.5), supporting the researcher's prediction. However, the data do not answer other questions: How much radiation is enough to see the effect? How are the cells affected by the radiation? Do

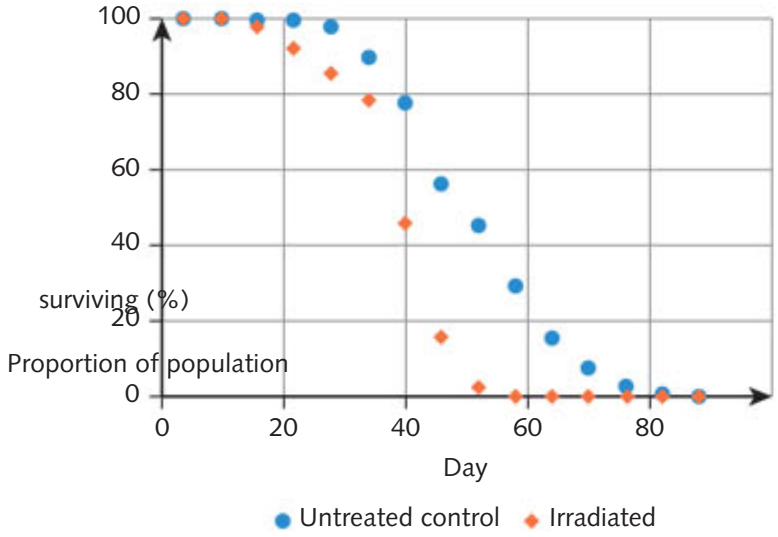


Figure 10.5 Graph depicting the life span of flies in a population exposed to radiation versus a normal, untreated population. These are primary data for the investigator who generated the data. They are secondary data for all other investigators.

the offspring of the irradiated flies show any effects? and so on. The researcher must propose and conduct other experiments to generate the primary data required to address those questions.

Secondary data

Secondary data are data that consist of facts and figures drawn from existing published or unpublished research. The secondary data may not directly answer other questions of interest. For example, it would be inappropriate for another researcher to conclude from the data shown in Figure 10.5 that all radiation, regardless of the amount, decreases the life span of flies. Instead, it would be appropriate for the researcher to ask, 'Is the decrease in life span related to the amount of radiation?' To this researcher, the data derived from the initial study are secondary data. This researcher then conducts their own experiment to generate fresh primary data to answer their own question.

WB
10.2.1 DISTINCTION BETWEEN OPINION, ANECDOTE AND EVIDENCE PAGE 236

Distinction between opinion, anecdote and evidence

Claims are classified according to the type of evidence from which they are drawn. To that end, it is worthwhile distinguishing between opinions, anecdotes and legitimate scientific claims.

Opinion describes a claim or a judgement that is formed in the absence of hard evidence. Opinions may be drawn from a combination of circumstantial evidence, experience, inference and speculation. As an extension, **anecdote** is a claim supported by a personal observation or personal experience. The evidence in support of opinion and anecdote is generally considered **weak evidence** because it was not gathered specifically to address the claim (Figure 10.6). The evidence may be circumstantial, coincidental or even irrelevant (for example, 'I notice I feel better when I drink orange juice. It must be because of the vitamin C').

Shutterst
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Figure 10.6 Social media is a rich source of opinions and anecdotes.

Opinion and anecdote are interpretations built on assumptions. The assumptions may be shaped by subjective influences, such as personal perception or the claimant's social, moral or emotional disposition. In extreme cases, individuals may choose to ignore evidence that disproves their claim. Their position is steered more by ideological belief, or **dogma**, than by evidence. Claims that fail to account for evidence are fundamentally flawed. Even with honest intentions, an individual's experience may be limited, or their observation may have focused on some aspects of a situation and overlooked others. Another weakness of opinion and anecdote is that they may be drawn from a set of circumstances under which many external influences confound the outcome or are simply unknown. In general, both personal and external factors prejudice claims based on opinion or anecdote.

WB
10.2.2 DISTINCTION BETWEEN SCIENTIFIC AND NON-SCIENTIFIC IDEAS PAGE 237

EXAM TIP

When analysing scientific evidence, demonstrate your understanding of the principles of the controlled experiment by making comparative statements. The effect of a treatment is determined by comparison with the untreated control.

Distinction between scientific and non-scientific ideas

Scientific evidence is based on the data that are systematically collected in order to specifically support or refute a claim. As far as possible, claims based on scientific evidence are detached from any emotional investment. Scientific evidence may take many forms; however, the cornerstone of scientific evidence is the controlled experiment. (Refer to Chapter 5.) Ideally, all the variables in a controlled experiment are measurable so that they are quantified and accounted for (Figure 10.7). The data obtained enable a logical interpretation about the relationship between the dependent and independent variable, free of personal prejudice or external influences. The power of scientific evidence is that it can also provide support for a mechanism to explain how a biological event occurs.

Scientific evidence is even more reliable if the outcomes of controlled experiments are reproducible when conducted independently by different researchers working in different laboratories. Moreover, the mechanistic explanation for a scientific process becomes more credible if multiple unrelated lines of experimental evidence all converge on the same conclusion.

Getty Images/Hiya Images/Corbis/VCG

Figure 10.7 Controlled experiments ideally provide substantiated and measurable evidence for claims.

Scientific and social studies

When it comes to emotionally charged issues, such as those related to genetic modifications or stem cell therapies, it is instructive to conduct both biological and social studies.

The scientific study is devoted to assessing the efficacy, or effectiveness, of the scientific or medical intervention of interest. If the evidence supports the intervention having the intended biological or therapeutic effect with minimal or manageable side effects, then it shows promise of becoming used in commercial or clinical settings.

Public opinion research is a form of social science that complements the scientific study. It may be qualitative studies based on interviews, case studies or an investigator's observations. Alternatively, it may be quantitative studies that, for example, involve surveying people to assess public understanding and attitudes about an issue (Figure 10.8). As these studies aim to describe and quantify attitudes, they are subject to the same rigorous standards of conduct, data collection and data analysis as would be expected for a scientific study. For example, to represent the public accurately, these studies must include a representative cross-section of the population by gender, age, geographical location, education background, occupation, socioeconomic status and so on. Public opinions may change over time so it is often necessary to conduct studies periodically.

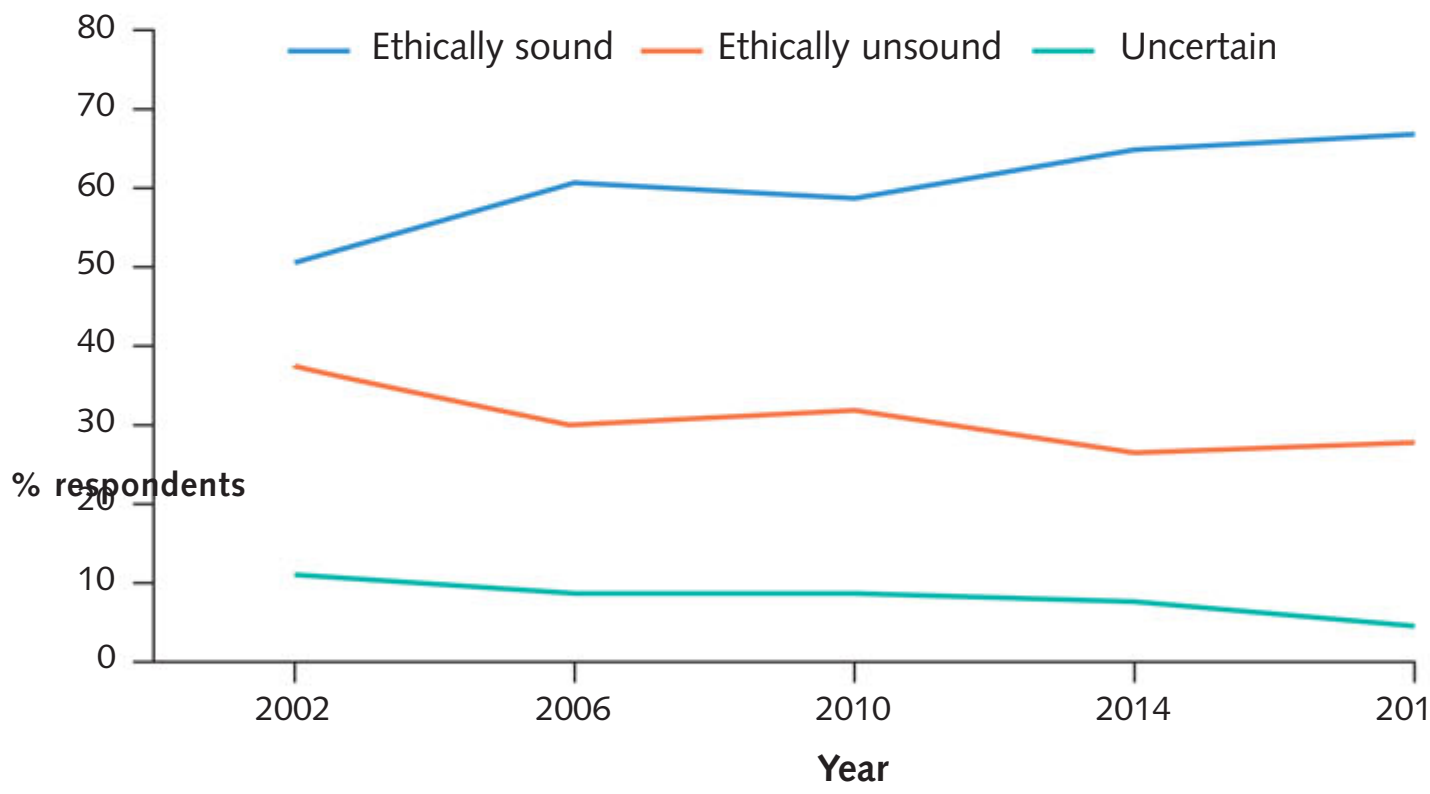


Figure 10.8 Survey data showing public attitudes to medical research using stem cells from human embryos

Public opinion studies are valuable for formulating policy on implementing a new biological or medical technology. They can inform policy makers about public perceptions, misconceptions and preparedness for adopting new technology.

Quality of evidence

WB
10.2.3 QUALITY OF EVIDENCE PAGE 237

One of the most challenging aspects of analysing risks associated with a biological issue is that the risks may be uncertain or unknown. Critically evaluating such risks requires some imagination but the evaluation also needs to be built on evidence. It is tempting to suppose that data from scientific investigations are reliable but they may be undermined by prejudice. Where scientific evidence is used to support a claim, it is necessary to evaluate the credentials of the investigator, the purpose of the investigation, the quality of the evidence and how the data were acquired.

Authority

Authority refers to the authors' credentials, their affiliations and their independence. An investigation conducted by a professionally trained scientist working at a university or accredited institute is authoritative. A study conducted by a self-proclaimed expert working at an unrecognised institute funded by a lobby group is not authoritative and is most likely unreliable.

Validity of data and sources of errors or bias

Valid data may be collected by certain methods but they may not genuinely represent the system being investigated. Put simply, we may ask: do the data actually measure what was intended to be measured? The answer to this question addresses the concept of scientific validity. If the investigation is faulty in some way so that the data do not accurately reflect the true situation, the results are invalid.

In scientific contexts, the term 'error' has a very specific meaning. Error refers to the degree with which collected data truly reflect the value of what is being measured. The results of an investigation may be invalidated by systematic errors. Systematic errors are not simply a question of the accuracy of measurement. There are many forms of systematic error that are due to prejudicing factors, or bias, that can skew an investigation in favour of one outcome over others.

CONNECT
Refer to Chapter 5 pages 197–199 for a detailed discussion of validity, error and bias.

Theories and models

In lay language, the word 'theory' is often used to describe an unsubstantiated set of beliefs. The word is prone to being misused, however, because it has a different but very significant meaning in science. A *scientific* theory is a description or explanation of some aspect of the natural world that has become established through repeated experimentation and testing. Embedded within the definition is that the theory is the coherent culmination of experimental data; it must be testable and verifiable by experiment.

A model is a simplified representation of a complex system. The model may be dynamic, such as a computer simulation that evolves over time. It may be a static description that accounts for the interactions between different features of a system. It may be as simple as a mathematical equation that depicts a relationship between variables. Whatever the form, a model is limited by which features are taken into account and which features are omitted. For example, a food web is a model that describes the feeding interactions among animals in an ecosystem (Figure 10.9). The model is a useful way to explore the effects of eliminating an invasive species (the rabbit) on the populations of other species. However, species populations may be affected by factors outside the scope of the model, such as local climatic or environmental conditions that may change over time.

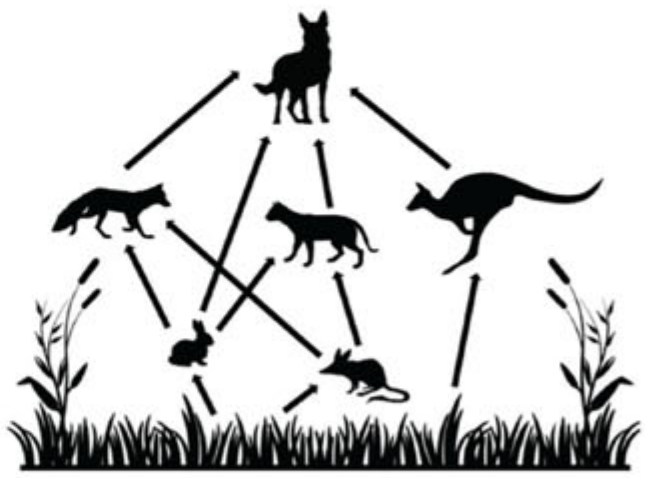


Figure 10.9 This food web is a model of the feeding interactions between native and invasive species in an arid Australian ecosystem.

Models can be refined as more variables and more data are fed into them to increase their accuracy. They may be mutually supportive if different models created by different researchers lead to the same conclusion. Predictive models become credible if, in time, natural conditions reproduce those in the simulation and the simulation has accurately predicted the outcome in the natural world. Refer to Chapter 5 for more on theories and models.

KEY CONCEPTS

- Opinion and anecdote are claims based on weak evidence; they are shaped by experience, inference and assumptions.
- Primary data are generated directly by the investigator analysing them, whereas secondary data are any data drawn from previous research.
- Scientific evidence is based on data collected systematically to address a specific question. The validity of scientific evidence depends on the degree to which it has limited errors and bias.
- It is instructive to evaluate scientific evidence against models and theories. Models are simplifications of the natural world, whereas scientific theories are reliable descriptions of the natural world.

Concept questions 10.2

1 Distinguish between opinion, anecdote and scientific evidence.

2 **a** What is the CRAAP test used for?
b Describe the features of the CRAAP test.

3 What is meant by authority?

4 **a** Describe how reproducibility strengthens scientific evidence.
b Describe an advantage and a disadvantage of primary data.
c When does primary data become secondary data?

5 Describe the similarities and differences between scientific research and public opinion research.

HOT Challenge

6 The exponential growth in number of infections in Australia during the coronavirus pandemic that began in 2019 was forecast by a model based on a number of assumptions. The model was revised over time.
a Describe the limitations of a model.
b Confusion in the non-scientific community over revisions to the models used were amplified in the press, by politicians, on social media and within communities. One of the greatest communication challenges for scientists all around the world was that a predictive model was exactly that – a prediction, not a fact. How can scientists get the message to the public that, although scientific models are based on evidence, they can be refined when more evidence becomes available?

WB
10.3 EVALUATING A BIOETHICAL ISSUE PAGE 241

10.3 Evaluating a bioethical issue

Aside from the purely scientific considerations, there are many other consequences of implementing a biological intervention. These consequences are legal, political, economic, social, moral and ethical. They are often controversial, bringing into conflict the interests of different stakeholders. Investigating a bioethical issue requires identifying, analysing and arriving at a decision on a conflict between various stakeholders' competing goals or values.

The legal and economic aspects of the issue may already be regulated by law. The law therefore provides a guide. However, the issue may be beyond the scope of the law so it becomes a moral or ethical issue. What is socially or morally acceptable to one individual or group may be unacceptable to another. We must weigh the possible consequences, the competing motives of different stakeholders, and the legal and economic framework in which they act. Ultimately we must decide, supported by evidence and reason, where our priorities lie in implementing, managing or prohibiting a biological intervention. These considerations are the focus of bioethics, the ethics of biological issues.

Legal, political and economic considerations

How is the issue you are investigating affected by legal, political or economic factors? Do government laws prohibit certain biological applications under particular circumstances? Do laws protect certain species or environments from commercial activities? Is exclusive ownership of a biological technology by a company resulting in a conflict of interest between social benefit and corporate profit?

Federal, state and territory laws regulate the development and eventual application of a biological intervention (Figure 10.10). It is sometimes the case that the scientific development of a technology outpaces its legal regulation. This happens especially when the technology is highly experimental and the bounds of what is or is not possible are not well understood. On the other hand, where experiments have demonstrated that a biological technology is effective, policy makers consult the expertise of scientists, lawyers and community leaders to develop a set of laws that control how and under which circumstances the technology is tested and eventually applied.

Shutte
Tap10

Figure 10.10 Canola is one of the few genetically modified crops legally approved for cultivation in Australia.

Government regulation

Online searches will help you to locate government regulators pertinent to your issue. Just a few are mentioned here. There are many Australian federal government authorities that regulate the application of genetically manipulated organisms (Table 10.3). For convenience, these are brought together under the Office of the Gene Technology Regulator (OGTR). The OGTR is guided by the federal *Gene Technology Act 2000*, which sets out as its objective 'to protect the health and safety of people, and to protect the environment, by identifying risks posed by or as a result of gene technology, and by managing those risks through regulating certain dealings with genetically modified organisms (GMOs)'.

Weblink
Genetically modified food

Table 10.3 Examples of regulatory areas and the Australian federal government authorities that regulate them

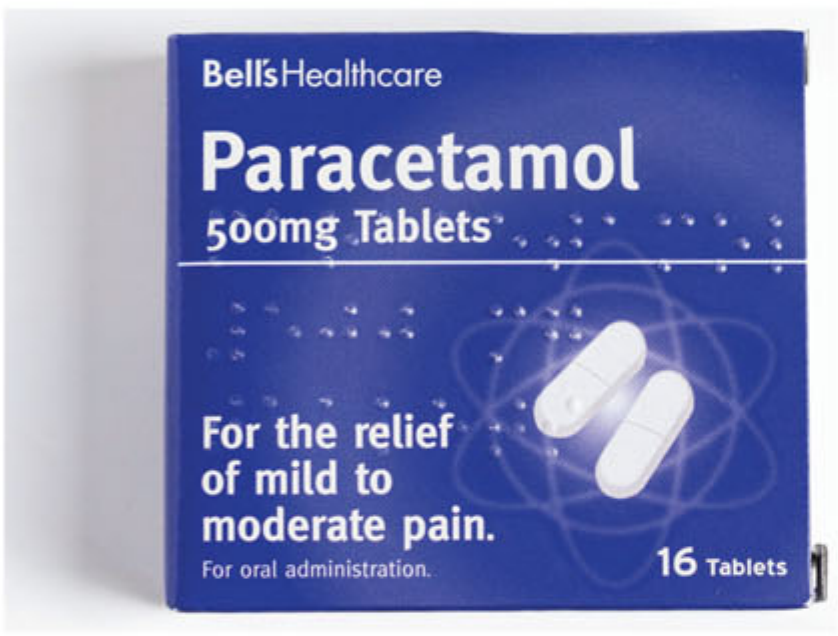
Area of regulation	Federal department with regulatory oversight
Genetically manipulated organisms	Office of the Gene Technology Regulator (OGTR)
Medicines, medical devices and other health products	Therapeutic Goods Administration
Food safety	Food Standards Australia and New Zealand
Human health and wellbeing, aged care and sport	Department of Health
Profitability, resilience and sustainability of agriculture	Australian Government Department of Agriculture and Water Resources
Environmental sustainability	Australian Government Department of the Environment and Energy
Agricultural and veterinary chemical products	Australian Pesticides and Veterinary Medicines Authority
Protection of **individual rights** from discrimination against gender, age, race, LGBTIQA+ status or disabilities	Australian Human Rights Commission
Indigenous affairs	Department of the Prime Minister and Cabinet
Indigenous heritage laws	Department of Environment and Energy

Biological technologies usually impact on many fields so several regulators across those fields need to be engaged. For example, protecting the genetic information of Aboriginal and Torres Strait Islander peoples falls under the Australian Human Rights Commission, as well as under the agencies concerned with the direct application of the technology.

Intellectual property

Laws exist to provide a measure of economic protection to inventors for their inventions. This is regarded as fair reward for the creative and financial investment that went into developing the invention. Such laws are intended to provide incentive for innovation.

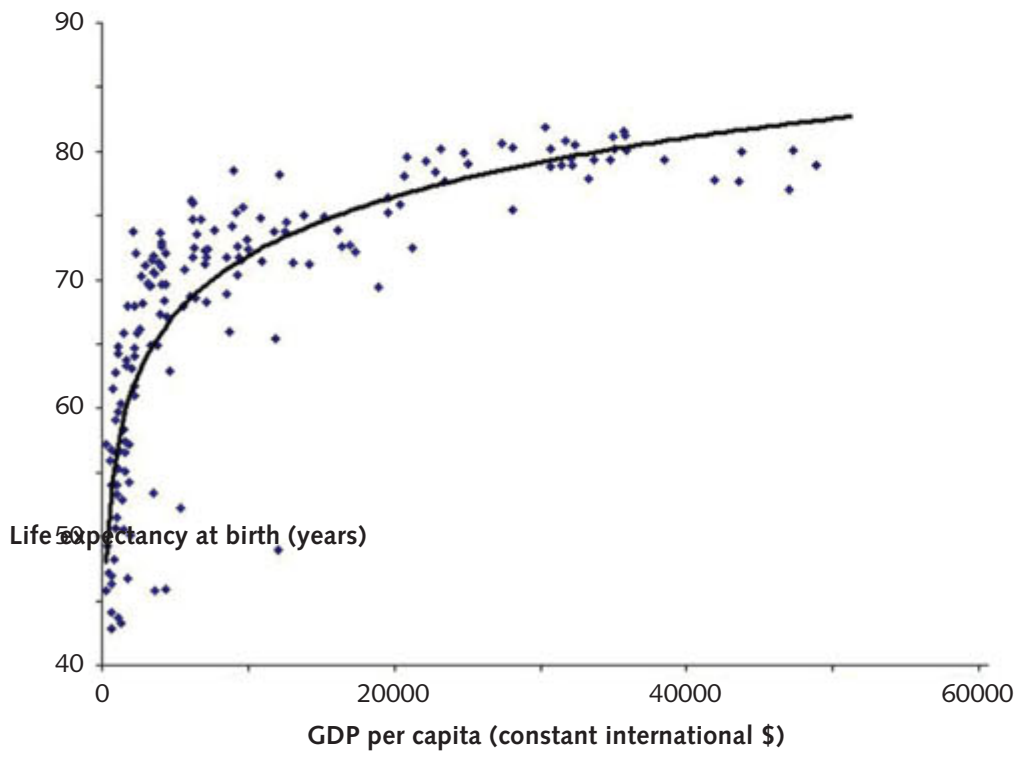
Intellectual property is the legal ownership of a novel idea, with the expectation that the owner can profit from the idea. Patents are a special type of intellectual property. A **patent** is a licence awarded for exclusive ownership of a registered new invention for a limited period of time. Each nation has its own patenting laws. Consequently, inventors must obtain separate patents in different countries to ensure their intellectual property is protected around the world. Inherent in the patent is that only the inventors or patent owners can profit from the invention for the duration of the patent. Once the patent ends, however, anyone can use the intellectual property for profit. It is for this reason, for instance, that generic medications have become widely available (Figure 10.11).



Shutterstock.com/Maddie Reed

Figure 10.11 When patents that once protected brand-name medicines have expired, other suppliers are allowed to copy and sell the formulations.

Patenting biological material is sometimes controversial. One core principle of a patent is that the 'property' is novel and not already in the public domain. This has proved disputable in the case of genetic material. For example, patents had been previously awarded for alleles of the *BRCA1* and *BRCA2* genes that predispose women to breast cancer. Following a protracted legal battle over the patents, the High Court of Australia ruled in 2015 that patents could not be granted on naturally occurring DNA sequences. While it is important to protect the commercial interests of inventors, the High Court ruling also took account of broader social and commercial implications. The patents discouraged other companies and institutes from conducting medical research on genes for commercial reasons. They also risked raising healthcare costs for individuals who carry potential disease-causing alleles.



Wikipedia Author

Figure 10.12 A plot of life expectancy against economic output (as gross domestic product per capita) based on 2005 data. Each dot represents a different country.

Equity of wealth distribution

It is usually accepted without much argument that economic prosperity is a virtue. For example, data show a relationship between the economic wealth of a nation and the life expectancy of its citizens (Figure 10.12). These data suggest that the richer a nation is, the healthier its citizens are, at least up to a point. Questions arise, however, over how equitably economic benefit is distributed, and who or what bears the cost.

Bioprospecting is the pursuit of biological resources for potential sources of new medicines, food additives or environmentally hardy food crops. Bioprospecting depends on controlled experiments for identifying biological organisms or compounds of

interest. Conflicts arise, however, when bioprospecting is guided by Indigenous knowledge. Indigenous peoples are the traditional custodians of the knowledge that culturally bound them to their land. This knowledge includes the physical, nutritional, medicinal and spiritual properties of their local plants and animals. Australian Indigenous customary law dictated that outsiders must be granted permission from the local Traditional Owners for access to their knowledge and resources.

Biopiracy refers to the situation in which Indigenous knowledge leads to a patent on a biological resource but the patent restricts the use of the organism and fails to share the economic benefits with the Indigenous communities whose knowledge it was. There are many patents that validate or build on Indigenous knowledge without acknowledging or compensating the traditional custodians. The Nagoya Protocol of 2010 is an international agreement that addresses biopiracy. It proposes that inventors are obliged to seek prior informed consent from Indigenous peoples for the use of their knowledge. The ideal is a mutually agreed contract for sharing wealth generated from the application of Indigenous knowledge. Australia and many other countries are still in the process of ratifying the Nagoya Protocol. The ambiguous state of the law raises the risk of opportunistic exploitation.

Weblink
HeLa cells

Online Worksheet
HeLa cells

Effective analysis of bioethical issues

Prior to the 1970s, decisions about medicine and scientific research were largely left to doctors and scientists. Concerns emerged about research being conducted on minority groups such as prisoners, orphans and the mentally unwell, and on unwary citizens by the military. In response, the field of bioethics was established to address ethical questions concerning morals, values and social responsibilities relating to research and practices in biology.

A paper called the Declaration of Helsinki was released in 1964, setting out ethical principles for the protection of human subjects in biomedical and behavioural research. These principles are professional integrity, respect, beneficence, non-maleficence and justice.

Professional integrity

The principle of professional integrity describes an open, truthful and transparent approach to research, irrespective of the results. It emphasises that all information pertaining to an investigation is obtained and reported honestly and is available for scrutiny. All sources must be acknowledged appropriately and plagiarism is avoided. Professional integrity captures the standards discussed earlier about the validity of scientific evidence and clarity of reporting.

Respect

The principle of respect recognises the inherent worth of humans and other living organisms. Researchers must pay regard to the wellbeing and freedoms and rights of the individual. They must also pay regard to the individual's beliefs, culture and customs. The principle emphasises that people have the right to make their own decisions. They must not be coerced into doing something they do not want to do.

In practice, this means scientists must inform prospective participants of the benefits, expectations and risks of participating in a study. It must come with the assurance that the participants' privacy and confidentiality are protected. Scientists also require the participants to give their informed consent to participate in an investigation (consider Figure 10.13). Animals do not have the capacity to express their consent. However, scientists can presume that animals wish to avoid suffering.

Beneficence

Beneficence seeks to maximise the benefits of a particular course of action. It draws on the qualities of kindness and goodwill. Beneficence can apply to an individual or a group.


Alamy Stock

Figure 10.13 **HeLa cells are grown and used throughout the world to study cell biology and cancer. The cells were first obtained in 1951 from a biopsy of a cervical cancer of a patient named Henrietta Lacks (pictured above). Ms Lacks was unaware that her tissues would be used this way and so never gave informed consent. The situation raises a modern ethical dilemma in biology.**

Non-maleficence

Non-maleficence means literally 'no evil'. Complementing beneficence, the commitment of non-maleficence is to do no harm. In practice, some harm may be unavoidable in the study of a medical intervention. The aim then is to minimise harms so that they are outweighed by the benefits.

Justice

The principle of justice champions fair and equal treatment for all. It promotes equitable access to opportunities and benefits, as well as a fair distribution of the risks and responsibilities. The course of action should not advantage one particular group at the expense of others.

A guide to bioethical analysis

The bioethical principles of the Helsinki Declaration were drawn to address scientific research involving human and animal subjects. However, the principles are applicable to analysing bioethical issues in other contexts. Table 10.4 outlines how these ethical principles are applied, providing a framework for analysing issues in biology. Ethical considerations address questions of individual rights and impacts – how might the individuals directly affected by the biological intervention benefit or be harmed, and what say should they have in the matter? Social considerations are about the effect on broader society, such as the economic costs of supporting the biological intervention, or the legal implications of regulating the biological intervention.

EXAM TIP
When responding to questions about ethical issues, it helps to distinguish between ethical considerations and social considerations.

Table 10.4 Ethical principles as a framework for analysing issues in biology

Guiding principle	Description	Key questions
Integrity	Honesty and transparency	Are the consequences for the technology or intervention supported by scientific evidence? Are stakeholders' claims supported by scientific evidence? How reliable is the evidence?
Respect	Every individual has the right to autonomy and to choose their own course of action	Are the individual rights of all individuals (stakeholders) considered and respected? Is informed consent provided? Is there respect for privacy and confidentiality?
Beneficence	A duty to do good	Who will benefit from this technology or intervention? How will they benefit (can include physical, psychological, economic or social benefit)? How many will benefit?
Non-maleficence	The duty to minimise harm	Who might be harmed by this technology or intervention? How are they harmed (can include physical, psychological, economic or social harm)? How many are harmed? Is it possible to minimise the harm?
Justice	Fair treatment for all	Does everyone have equal access? How can discrimination be avoided? Are competing stakeholders given equal hearing?

Approaches to bioethics as they apply to the issue

Decisions about the ethical application of biotechnology or a biological intervention are often difficult to make because of conflicts between different individuals' values, beliefs and cultural experiences. Such decisions are informed by science but cannot be made purely by scientific study and observation. Three major approaches are recognised in seeking to make a decision or judgement about a bioethical issue. The key difference between them is the philosophical perspective that they take.

Consequences-based approach

The **consequences-based approach** is focused chiefly on the outcome or the result of implementing the decision. It is a pragmatic approach that proposes that the action is moral and right if the consequences of the action are mainly beneficial and not harmful. Figure 10.14 illustrates one such dilemma.

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Figure 10.14 Palm oil plantation or native forest? A consequences-based approach to reaching a decision depends on which consequences different stakeholders value most.

We would assume that the best course of action to take is the one that does the most good for the most people. This is not as straightforward as it seems. The consequence-based approach might be described informally as 'the end justifies the means'. For example, one individual might argue that economic prosperity is the goal on grounds of the effects wealth has for people's wellbeing. To that individual, it is justifiable to cut down a native forest and replace it with a lucrative palm oil plantation that benefits the local community. Another individual would disagree with that proposal, arguing for protecting the native environment for its aesthetics, ecosystem services or health benefits. Aiming for the best outcome is therefore dependent on a value judgement or different people's interests. Achieving a consequences-based decision on a bioethical issue is complicated if different stakeholders have different opinions about what the best outcome is.

Duty- and/or rule-based approach

The **duty-based approach** or 'rule-based' approach relies on making a decision or choosing a course of action that aligns with an approved set of rules. The consequences are not the main consideration but they are still important. For example, it is in the interests of a biotechnology company to make money. The company must abide by a restrictive set of laws to test its genetically modified crops. These laws require measures to contain the crop to a specified field and testing to ensure pollen from the crop does not escape to neighbouring farms. These practices come at considerable cost to the company but compliance with the law is the chief consideration. Observing the law protects against accidental release and spares the company from prosecution.

The scientific process is fundamentally a duty-based approach. The process of acquiring data in an unbiased and dispassionate way is a superior concern to the outcome. The results may disprove a much cherished hypothesis.

The duty-based approach sometimes leads to conflict. For example, doctors and medical scientists take the Hippocratic oath at the beginning of their professional career (Figure 10.15). This binding oath obliges them to practise according to principles of beneficence and non-maleficence. Many experimental treatments, such as those in the field of stem cell therapy, are yet to be proven. Clinical trials are required to assess if the experimental treatment is effective and safe. Medical practitioners expect treatments to be tested through clinical trials before they can recommend the therapy in good faith. The observance of duty and their resistance to recommending unproven treatments are sometimes met with frustration and anger from desperate patients who have exhausted other possibilities. These patients argue it is their individual right to access the experimental treatment and bear the risk.

Alamy Stock Photo/Enigma

Figure 10.15 Medical practitioners take a Hippocratic oath at the start of their career, obliging them to act according to principles of beneficence and non-maleficence.

Virtues-based approach

A **virtues-based approach** focuses primarily on the moral character of the individual carrying out the action. A decision is made on the basis of an individual acting according to what it means to be virtuous, whether that means being honest, generous, courageous, compassionate or something else. For example, an inventor who is awarded a patent for an invention may be legally entitled to profit from it by themselves. However, he recognises the helpful advice he received from a colleague, which led to the breakthough. Even though the colleague was not directly involved with the invention, the inventor decides that the virtuous course to take is to reward his colleague with a share of the profits.

Taking a virtues-based approach can also lead to conflicts. For example, consider a patient suffering from a painful and aggressive terminal illness. The patient expresses the wish to die and invites a doctor to administer the act of euthanasia. The doctor respects the patient's wishes to die with dignity and agrees to act, guided by the virtues of mercy and compassion. However, the decision to act contradicts other ethical codes, such as the doctor's Hippocratic oath.

Selecting an ethical approach

There is no single right answer to selecting the ethical approach to apply for any particular bioethical issue. For example, if laws regulate a bioethical issue, a duty-based approach may be used to judge the issue. However, applying the law may result in undesirable outcomes. A consequences-based approach may be used instead and perhaps lead to a recommendation to change the law.

When deciding which approach to use, take account of the bioethical principles, the values and goals of the stakeholders, and your own values and goals.

KEY CONCEPTS

» Laws and economic considerations affect the judgement you make about a biological issue. Conversely, your judgement may reflect a need to amend existing laws or regulation.
» Bioethics concerns the ethics related to a biological technology or intervention. The ethics requires identifying, analysing and making a decision on a conflict between various stakeholders' competing goals or values.
» Bioethical principles include professional integrity, respect, beneficence, non-maleficence and justice.
» Approaches to making a decision on a bioethical issue include those that are consequences-based, duty-based and virtues-based.

Concept questions 10.3

1 Explain the relationship between intellectual property and a patent.
2 Define biopiracy.
3 Describe each of the guiding principles of bioethics.
   a Professional integrity
   b Respect
   c Beneficence
   d Non-maleficence
   e Justice
4 Describe each of the following approaches to making a judgement about a bioethical issue.
   a Consequences-based approach
   b Duty-based approach
   c Virtues-based approach
5 Henrietta Lacks was an African-American woman who lived and died in the United States in the mid 20th century. If Henrietta Lacks had lived and died in the Australia of today and researchers wished to obtain samples of her biopsied cervical cancer tumour, what responses could be applied to key questions under the guiding principles of bioethics? Refer to Table 10.4 (p. 404).

HOT Challenge

6 Bioethics is a relatively new field of research that has emerged in the last few decades. Another relatively new field related to medicine is that of health and human rights. This field is less developed in Australia because many aspects are already covered by laws that apply to and protect all Australians. Nevertheless, Australia is signed up to seven international human rights treaties.
   a What is the difference between the field of bioethics and the field of health and human rights?
   b Are human rights in relation to health the same all over Australia?
   c 'Bioethics is underpinned by social, legal and medical developments that juxtapose the contesting of life, death and the purpose of medicine. Public discourse involves itself in what goes on behind closed doors.'

The reproductive technology behind in vitro fertilisation (IVF) is considered the birthplace of bioethics in Australia in the 1980s. Consider IVF in light of the statement in quotation marks above and discuss what features of practising IVF technology to help infertile couples have babies might have led to the development of bioethics.

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10.4 Preparing a report

How you prepare your report depends on your intended audience and your chosen method of communication, such as oral or written. It will benefit also from basic principles of science communication. Communicating scientific data is crucial for demonstrating how you arrived at informed decisions about the biological issue. Scientific information must be communicated to and absorbed by a variety of audiences for different purposes. These include scientists deciding on the direction of their research, governments determining public policy, and individuals who may be weighing the possible consequences of a medical test or procedure.

Appropriateness for purpose and audience

Communicating ideas to an audience can only be done well when you have a clear outline of what you want to communicate and who you want to communicate with. Ask yourself: What do you hope to achieve through this communication – do you want to inform, educate or advise? What is your message? Who is your audience? Once these are decided, you need to consider the expertise of your audience, why they want the information, and their attitude towards you and the subject matter.

Some examples of audiences include:

» Experts in the field – have a shared understanding of scientific terminology relevant to their area of study, so it is not necessary to explain all biological terms. You may be adding new data to the field or providing a review of current knowledge. Highlight any gaps, conflicts or biases in existing secondary data.

» Community members – will have mixed expertise, so it is important to clearly translate and explain biological terms and concepts. Use narratives to provide context and to help your audience engage with the topic. Scientific concepts can be conveyed with analogies of familiar experiences. Help them to distinguish between opinion, anecdotes and claims supported by scientific evidence.

» Politicians and businesspeople – require clear reporting of data from valid and reliable studies, with explanations of why these data should be used rather than data from less rigorous studies. Evidence and predictive models are used to support recommendations.

Prepare an outline to construct a clear argument for your audience. Indicate where evidence is required to support any claims you make. Include alternative views and an analysis of bias, validity and reliability of claims.

Biological concepts specific to the investigation

Different audiences vary in their understanding of scientific terminology and concepts. Professional experts are already familiar with those that are specific to their field but they may require descriptions for those that are outside their discipline. Members of the public generally need more explanation of scientific terms and principles in a vocabulary they can understand. Once introduced, the new term is used consistently.

Keep your communication professional and use the appropriate biological conventions and representation. Examples of these conventions include:

» The use of scientific names for organisms (for example, *Escherichia coli*)

» Accepted abbreviations (for example, DNA for deoxyribonucleic acid)

» Standard biological representations (for example, the use of capital and lower case letters to label alleles for dominant and recessive phenotypes).

Characteristics of effective science communication

Whenever discussing biological information, it is essential that the descriptions and the details are accurate. Chapter 5 discusses essential features of science communication. Some additional aspects relevant to a bioethical issue are discussed here.

Conciseness

Conciseness and coherence are two strategies for clear science communication. Conciseness refers to expressing as much information as possible in as few words as possible. It also emphasises the need to be focused and avoid 'padding'. Include only material that addresses your investigation and exclude material that does not. Wherever practical, summarise data in succinct, visual representations such as figures, diagrams or tables.

Coherence

Coherence refers to the structure of the communication so that your audience can follow the thread of the narrative. Use subheadings to chunk the information. You will already be familiar with this approach to writing practical reports (refer to Chapter 5). In a similar way, your report on a bioethical issue benefits from separating the information into sections. What these sections are depends on your topic and how you investigate it, but they will conceivably follow a similar pattern (Table 10.5).

Table 10.5 A guide to structuring a report on an issue

Section title	Purpose
1 Introduction	Provides the context for the investigation
2 Method	Describes how the secondary data were sourced and analysed; uses text or constructs a flow chart or diagram to describe the study method
3 Results	Presents, contrasts and analyses the scientific evidence (secondary data) and outlines the key findings
4 Discussion	Evaluates the quality of the scientific evidence; evaluates the legal, economic and bioethical aspects relevant to the issue
5 Conclusion	Presents your judgement of the issue or a proposal for a course of action; summarises your argument in support of your judgement or proposal
Reference list	Records references for all the sources used to compile your report

Introduction and contextual clarity

Contextual clarity describes the circumstances, the significance and the motivation for you to investigate the issue. Your problem statement helps frame the context of your investigation. This contextual information is normally incorporated into the Introduction of your report. It addresses why your investigation is important, who is affected by it and what the benefits are for pursuing it. It provides the background to your investigation, such as the positions or proposals put forward by different stakeholders and the prior research that informs the issue. It highlights any gaps or conflicts in the positions of the stakeholders which lead to the purpose and the aims of your investigation.

Methods

Describe the databases and key words you used. Describe how you scrutinised the sources (for example, the CRAAP test) and any other ways you filtered the sources or the secondary data.

Results

Present your analysis of the evidence in the sources for opinion, anecdote or scientific evidence. Summarise, paraphrase and quote ideas from each source. Present secondary data using tables, graphs and models wherever possible. You may take these directly from a study and acknowledge the source or construct your own. (Refer to Conventions of data representations on page 410.)

Discussion

Present your evaluation of the quality of the sources and the scientific evidence for error, bias, validity and reliability. Describe the legal and economic implications and your evaluation of the bioethical issue. Discuss whether laws apply to the issue and how they affected your evaluation. Use bioethical principles to analyse the ethical dilemmas relating to the issue under investigation.

Conclusion

Outline your judgement and justification. Explain which bioethics approach you used to formulate your judgement. When weighing the significance of your findings, refer back to the context outlined in the Introduction.

Acknowledging sources

Conclude the report with a reference list that acknowledges the sources used.

The credibility of reports is enhanced when authorities are cited to support arguments. Quotes and paraphrasing are used when you want to provide evidence from an authority. To avoid **plagiarism**, acknowledge the original source of the ideas, data and images used from an external source. Using the APA **in-text citation** method, you provide the author (last name or organisation name) and year in parentheses, in the text. If you include a direct quote or idea you should also add the page number so the reader can verify your source. Table 10.6 shows some examples of in-text citations and their corresponding references.

Table 10.6 Examples of acknowledging references

In-text citation	Reference list
(Stockstad 2019)	Stockstad, E. (2019) New genetically modified corn produces up to 10% more than similar types. Retrieved 2020 May 10 from http://www.sciencemag.org/news/2019/11/new-genetically-modified-corn-produces-10-more-similar-types#
(Hsu et al. 2014)	Hsu, P.D., Lander E.S. and Zhang F. (2014) Development and applications of CRISPR-Cas9 for genome engineering. *Cell* 157(6): 1262–1278.
(Cormick and Mercer 2017)	Cormick, C. and Mercer, R. (2017) *Community Attitudes to Gene Technology*. Canberra, Australia: The Office of the Gene Technology Regulator.

Conventions of data representations

When presenting data, you may choose to summarise the data in a table or a visual representation, such as a graph, a chart, a photographic image or a diagram. These visual representations are collectively referred to as figures. Number tables and figures in sequence as they appear in your report and label them with a concise caption that explains what information is presented in them. If you are using figures, it is essential to select figures that are fit for purpose (Figure 10.16).

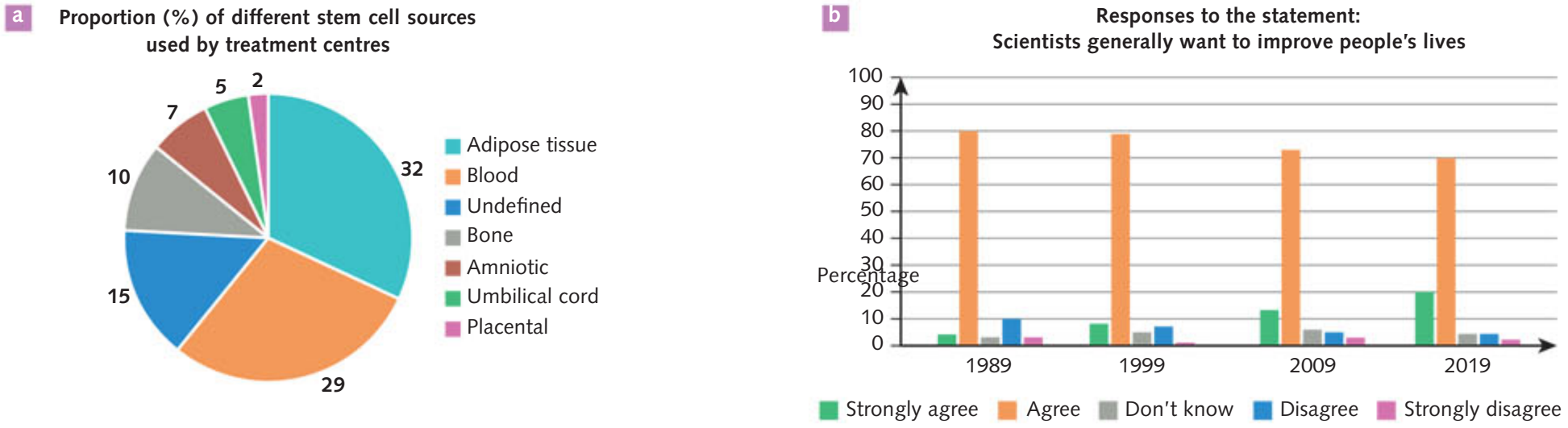
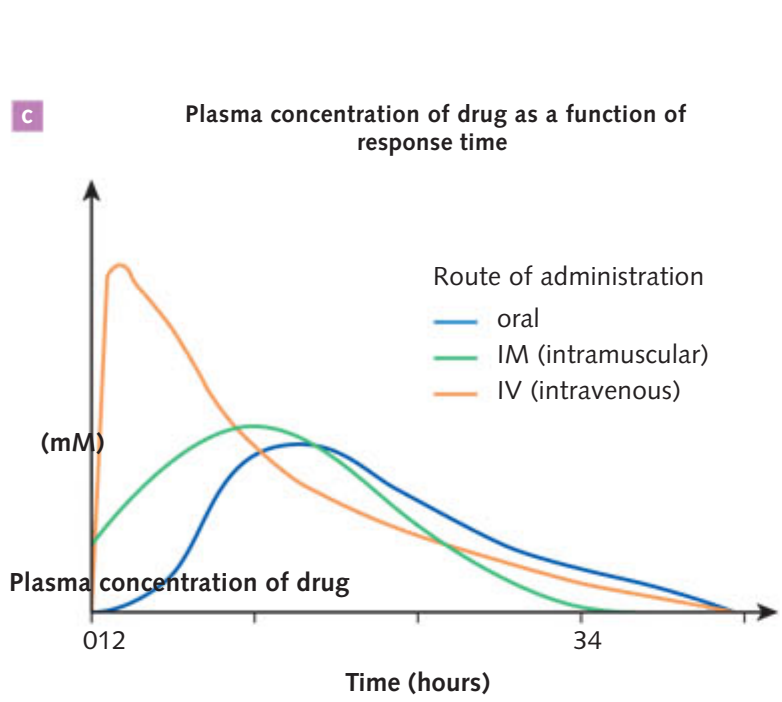
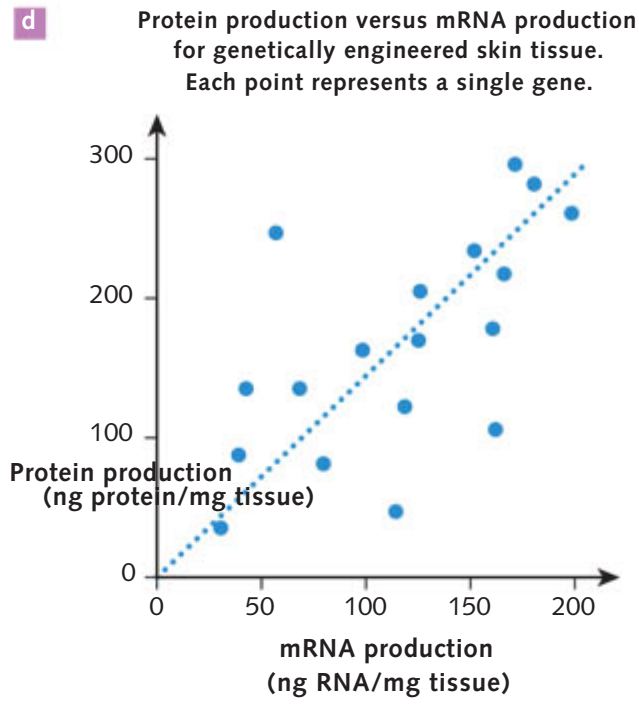


Figure 10.16 Examples of figure types and their uses. a Pie charts are ideal for showing proportions of categories within a single population of data. b Bar charts are useful for comparing quantities that belong to independent categories.





c Line graphs are suitable for depicting the relationship between an independent variable (*x*-axis) and a dependent variable (*y*-axis). d A scatter plot presents the relationship between two measurable variables that may or may not be related. In this example, a line fitted to the data points shows a positive correlation. A correlation suggests, but does not prove, the two variables are connected.

Your figures may include microscopy images, in which case adding a scale bar gives the viewer a sense of the size of the subject in the image (Figure 10.17).

Alamy Stock Photo/SDym Photography

Figure 10.17 Tiny fruit fly (about 2.5mm in length)
Drosophila melanogaster

Units of measurement (for example: μm, %, gmL^{-1}, number per m^2) must be displayed for all quantitative values. When presenting graphs, ensure the axes are properly labelled with units shown as required. It is advisable to cross-check definitions and units of measurements to ensure accuracy.

KEY CONCEPTS

- The style and terminology used for science communication depends upon the purpose and the audience.
- Structure your communication by dividing it into separate sections for coherence.
- Use figures, diagrams and tables wherever possible for conciseness.

Concept questions 10.4

1 Describe what is meant by contextual clarity.
2 Contrast how the style of writing differs when communicating with scientists and communicating with the community.
3 Describe the types of data that can be represented by a pie chart, a bar chart and a line graph.
4 What types of data should be placed in tables?
5 Table 10.5 (p. 409) outlines a basic format to follow when constructing a report. What does coherence in reporting mean when applied to Introduction, Method and Conclusion?

HOT Challenge

6 Correlation does not prove causation. What does this mean? Provide an example to illustrate your explanation.

INVESTIGATION 10.1

Making the punishment fit the crime gene

'Not guilty by reason of insanity' is a legitimate defence in criminal court. So how about 'not guilty by reason of genotype'? Judgement in criminal law has long recognised that some offenders have more control over their actions than others. For example, a youth raised in an abusive environment will usually receive a more lenient sentence than will an adult with a secure upbringing who commits the same crime.

It is a biological principle that people's characteristics are the product of their genes and the environment. Children do not choose their environment; nor do they choose their genes. If environment is a legal consideration, why not also genes (Figure 10.18)?

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Figure 10.18 If a defendant's life circumstances are a legal consideration, why not also their genes?

One gene implicated in criminal behaviour is the *MAOA* gene located on the X chromosome. The gene codes for monoamine oxidase A, an enzyme that breaks down a neurotransmitter (monoamine) in the brain. A particular allele of this gene, *MAOA-L* (long form of the gene), results in reduced expression of the enzyme. The *MAOA-L* allele is associated with impulsive aggression and is relatively more common in male prisoners than in the general population. Evidence is mounting that males with the *MAOA-L* form of the gene are more vulnerable to the effects of childhood abuse (Baum 2013).

The idea that an offender could blame their actions on 'crime' genes is gaining some traction. In 2009, for example, an Italian court reduced a convicted murderer's jail term by one year primarily on the evidence that he tested positive for *MAOA-L* (Baum 2013). The notion is upsetting for some, however, who regard it as an insult to victims of crime by absolving a perpetrator's guilt on the basis of biology (McCay 2013). Such outcomes also bring into sharp focus the purpose of punishment. Law breakers who have the 'crime' gene and a troubled upbringing may still be dangerous. Should judges condemn offenders with *MAOA-L* to harsher sentences to discourage future crime? Should such high-risk offenders be locked up for extended periods to protect the public?

Aim

To evaluate the application of genetic testing for the 'crime' gene

Method

A routine genetic test is available for *MAOA*, so there is no technical limitation to detecting whether an individual has *MAOA-L*. An international law conference has invited you to submit a report on the use of the 'crime' gene in criminal law. Your report should be 850–1000 words, and may be in the form of a digital presentation, an oral communication or a written report.

The report is divided into three parts. Part 1 is an analysis of the science behind the testing and interpretation of the 'crime' gene. Part 2 addresses the ethical implications of using the 'crime' gene for making legal decisions. Part 3 is a presentation of your conclusions based on the outcomes of Parts 1 and 2.

Respond to the following questions for your presentation.

Part 1 How feasible is it to genetically test individuals for their propensity to commit crime?

(300–400 words, for a scientific audience)

1 Draw on your understanding of inheritance to explain why *MAOA-L* apparently affects more males than females. Use a model to support your explanation.
2 What kind of variation is implied by inheritance of the *MAOA* gene? Are you satisfied that this kind of variation best describes variation in human behaviour? Explain your reasoning.
3 Use your response to question 2 to evaluate the validity of the model of inheritance proposed in question 1.
4 Do you believe 'criminal behaviour' is a valid phenotype? Outline two reasons in support of your answer.
5 Discuss how both the *MAOA* gene and the environment may affect an individual's potential to commit violent crime.

Part 2 How could information about an individual's 'crime' gene be used or misused?

(300–400 words)

6 Consider a proposal to genetically test individuals for the 'crime' gene. Write a problem statement outlining the conflict to be evaluated.
7 Evaluate the application of this genetic test in criminal law by providing a comprehensive analysis of the ethical issues, using the guiding bioethical principles of integrity, respect, beneficence, non-maleficence and justice.

In your analysis, consider the prospect of testing all individuals, accused suspects, and convicted individuals. Consider the consequences for individuals who have tested positive for *MAOA-L*, victims of crime, and the broader community.
8 Consider a situation where two first-time offenders were convicted of the same type of crime. If one of the offenders was shown to have a 'criminal' genotype, would you argue the punishment should be more lenient, the same or more severe, compared with the other convicted offender? Explain your reasoning.

Part 3 Conclusion

(150–200 words)

9 Discuss at least two benefits and two concerns associated with using a convicted criminal's genotype as a basis for determining their sentence.
10 Adopt an ethical approach to deciding on the issue (consequences-based, duty-based or virtues-based). Briefly explain why you believe that approach is most appropriate for the issue. Draw a conclusion about who should be tested for the 'crime' gene – the whole population, selected individuals or no one at all. Support your conclusion with reasons derived from your analyses in Parts 1 and 2.
11 Construct a reference list of sources used to compile your report.

References

Baum, M. (2013) The monoamine oxidase A (MAOA) genetic predisposition to impulsive violence: Is it relevant to criminal trials? *Neuroethics* 6: 287–306.
McCay, A. (2013) Evil gene would make punishment a tricky business. *The Age*, 22 April. Online http://www.theage.com.au/comment/evil-gene-would-make-punishment-a-tricky-business-20130422-2ia09.html.

INVESTIGATION 10.2

Do we have a moral obligation to invest in de-extinction?

A number of scientists have proposed that extinction rates for animal and plant species have increased dramatically in the past 10000 years. The major cause is suggested to be the increase and spread of human populations linked to developments in technology and society. Wildlife species have become threatened, endangered or extinct through human activities, including overhunting, pollution, habitat destruction and the introduction of invasive species. De-extinction has been advocated by some scientists as a moral imperative to redress past extinction events attributed to human activities (Sandler 2013). It has also been promoted as an 'insurance' strategy against future extinctions, a means to restore lost biodiversity (Sandler 2013).

Science Source/Micha

Figure 10.19 What are the prospects for resurrecting extinct species, such as the gastric-brooding frog (*Rheobatrachus silus*)?

De-extinction refers to resurrecting a lost species, such as the gastric-brooding frog (Figure 10.19), by cloning. The basic premise is a variation of somatic cell nuclear transfer in which the genome, if not the nucleus, of the donor is that of the extinct species. The recipient zygote and surrogate mother are from a closely related, living species.

Aim

To evaluate what proportion of conservation funds should be invested in de-extinction

Method

Imagine that the Federal Government is considering how best to allocate funding for conservation projects, which have traditionally been aimed at minimising environmental impact. They are interested in the concept of de-extinction and are questioning whether conservation funds should be redirected to de-extinction projects. They have called you in as a consultant to advise them. Your brief is to:

A Determine how feasible de-extinction is. You will communicate your findings to an expert scientific committee.

B Evaluate how socially responsible de-extinction is as a strategy. Use this evaluation and the feasibility study (part A) to propose what proportion of the conservation funds to allocate to de-extinction projects. You will communicate your findings to a minister, who is not a scientific expert.

Part A: Scientific evaluation: Determine how feasible de-extinction is

1 To consider the technical issues, investigate one extinct Australian species from Table 10.7.

Table 10.7 Some extinct Australian species

Scientific name	Common name	Distribution	Last recorded
Chaeropus ecaudatus	Pig-footed bandicoot	Arid and semi-arid regions of mainland Australia	1926; unverified reports to 1950s
Dromaius ater	Dwarf King Island emu	King Island, Bass Strait	1802
Macropus greyi	Toolache wallaby	South-eastern mainland Australia	1939
Macrotis leucura	Lesser bilby	Central Australia	1931
Psephotus pulcherrimus	Paradise parrot	South-eastern Queensland	1927
Rheobatrachus silus	Gastric-brooding frog	South-eastern Queensland	1981
Thylacinus cynocephalus	Tasmanian tiger	Tasmania	1936

For this investigation, consider the questions that need to be asked in order to address the technical issues for your selected extinct species (Table 10.8).

Table 10.8 Technical issues: questions to ask

Technical issue	Questions to direct your research
Reconstructing the genome	Is the genome already sequenced? If not, how well preserved is the material from which the DNA must be recovered?
Generating intact chromosomes	Can chromosomes be recovered intact from preserved material? If not, can chromosomes be made artificially? If the genome is incomplete, how might the sequence gaps be filled in?
Choosing a surrogate zygote and mother	Which species might be the best candidate surrogate zygote and mother? How similar are the genomes of the candidate surrogate organism and the donor organism?

Record the sources of information you used to assist your investigation (e.g. websites, news articles, scientific reports etc.).

2 Write a 400–500 word report to the scientific expert committee that advises Australia's Threatened Species Commissioner. In your report, deliver a verdict about how achievable de-extinction is for your selected organism, and support your conclusion with arguments drawn from your analysis in step 1. Use language appropriate for the scientific committee. Cite the sources of information that assisted in your analysis and provide a brief assessment (1–2 sentences) of their reliability.

Part B: Bioethical evaluation: Determine how socially responsible de-extinction is as a conservation strategy

3 Write a problem statement outlining the dilemma for allocating resources between conservation and de-extinction. Your problem statement should also address possible differences in scientific and community opinion.

4 In your evaluation, consider the relative diversion of resources between extinct and living species, and answer the questions in Table 10.9.

Table 10.9 Guiding principles: questions to ask

Guiding principle	Questions to ask yourself
Integrity	Does the evidence support the prospect of resurrecting the species? Is there any additional evidence that could be sought?
Respect	What are the expectations for the welfare of resurrected animals? Are the animals intended to be used for scientific research, public exhibition or reintroduction into the wild?
Beneficence	Which species stand to benefit by pursuing this strategy? How many species stand to benefit? Do people stand to benefit? How do people stand to benefit?
Non-maleficence	Which species could be harmed by pursuing this strategy? How many species may potentially be harmed? Could people be harmed? How might the harm come about? Can the harm be minimised?
Justice	Is the strategy fair for all species? How can fairness be maximised?

5 Choose an ethical approach to deciding on the issue (consequences-based, duty-based or virtues-based). Justify why you believe this approach is most appropriate for the issue. Draw a conclusion about the proportion of conservation funds (between 0 and 100%) to be diverted to the de-extinction project.

6 Using appropriate language, write a 400–500 word letter of recommendation to Australia's Threatened Species Commissioner, who is not a scientific specialist. Outline your assessments of the (A) technical and (B) ethical considerations. Express your opinion as to whether de-extinction should or should not be pursued in principle, and support your opinion with arguments based on your answers to questions **4** and **5** above. Provide a recommendation for whether conservation funding should be re-allocated away from conservation efforts towards de-extinction, supported with reasons derived from your analysis.

7 Add a reference list for all the sources used to compile the recommendation.

References

Sandler, R. (2013) The ethics of reviving long extinct species. *Conservation Biology* 28: 354–60.

Online Key Concepts
Chapter 10 summary of key concepts

10 Summary of key concepts

10.1 Beginning an investigation

KEY CONCEPTS

p. 391

- Bioethical issues are ethical issues concerned with implementing a biological technology, intervention or process.
- Investigating a bioethical issue requires identifying the issue and the conflict; analysing the evidence in support of claims; analysing the legal and economic context for the issue; and evaluating the ethical concerns and responsibilities of the stakeholders.
- A problem statement helps to organise secondary data.
- Maintaining a logbook and using APA referencing helps to record the details and your evaluation of secondary data.

Getty Images Plus/E+/Rep

Figure 10.3 Bioethical issues arise as a consequence of progress in biological technology and social attitudes.

10.2 Evaluating evidence

KEY CONCEPTS

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- Opinion and anecdote are claims based on weak evidence; they are shaped by experience, inference and assumptions.
- Primary data are generated directly by the investigator analysing them, whereas secondary data are any data drawn from previous research.
- Scientific evidence is based on data collected systematically to address a specific question. The validity of scientific evidence depends on the degree to which it has limited errors and bias.
- It is instructive to evaluate scientific evidence against models and theories. Models are simplifications of the natural world, whereas scientific theories are reliable descriptions of the natural world.

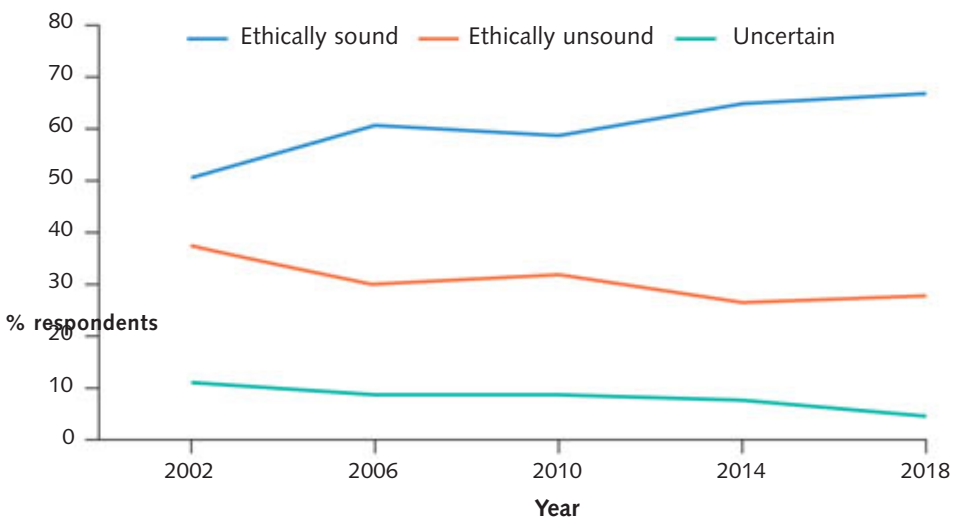

Figure 10.8 Survey data showing public attitudes to medical research using stem cells from human embryos

10.3 Evaluating a bioethical issue

KEY CONCEPTS

p. 400

- Laws and economic considerations affect the judgement you make about a biological issue. Conversely, your judgement may reflect a need to amend existing laws or regulation.
- Bioethics concerns the ethics related to a biological technology or intervention. The ethics requires identifying, analysing and making a decision on a conflict between various stakeholders' competing goals or values.
- Bioethical principles include professional integrity, respect, beneficence, non-maleficence and justice.
- Approaches to making a decision on a bioethical issue include those that are consequences-based, duty-based and virtues-based.

Shutterstock.com/apiguide

Figure 10.14 Palm oil plantation or native forest? A consequences-based approach to reaching a decision depends on which consequences different stakeholders value most.

10.4 Preparing a report

KEY CONCEPTS

p. 408

- The style and terminology used for science communication depends upon the purpose and the audience.
- Structure your communication by dividing it into separate sections for coherence.
- Use figures, diagrams and tables wherever possible for conciseness.

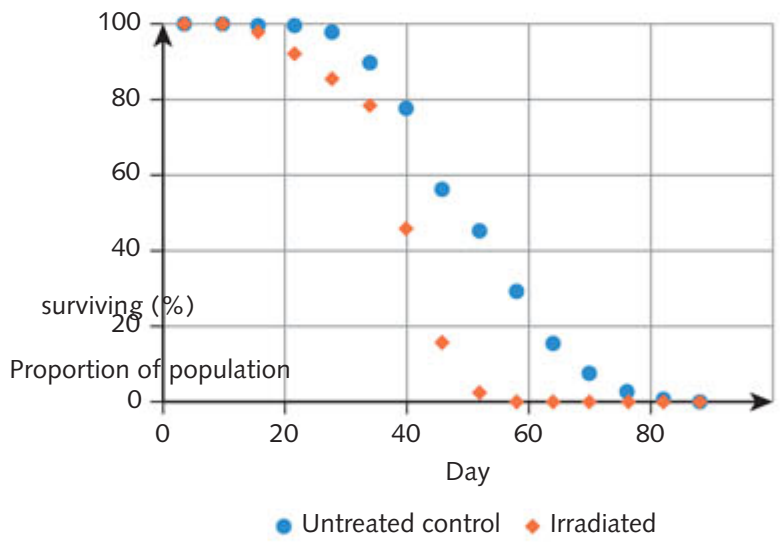

Figure 10.5 Graph depicting the life span of flies in a population exposed to radiation versus a normal, untreated population. These are primary data for the investigator who generated the data. They are secondary data for all other investigators.

WB
10.5.1 KEY TERMS PAGE 245
10.5.2 PRACTICE TEST QUESTIONS PAGE 246

10 Chapter glossary

anecdote personal observation or personal experience used to support a claim

authority an acceptable source as judged by the authors' credentials, their affiliations and their independence

bioethical issue an ethical issue concerned with implementing a biological technology, intervention or process

biopiracy a situation in which a patent based on Indigenous knowledge fails to share the economic benefits with the Indigenous communities whose knowledge was taken up

bioprospecting the pursuit of biological resources for potential sources of new medicines, food additives or environmentally hardy food crops

consequences-based approach an approach to making a decision about a bioethical issue that focuses on the outcome or the result of implementing the decision

contextual clarity describes the circumstances, the significance and the motivation for undertaking an investigation

dogma an opinion guided by ideological belief rather than by evidence

duty-based approach an approach to making a decision about a bioethical issue that focuses on making a decision or choosing a course of action that aligns with an approved set of rules

individual rights an individual's right to choose their own course of action

intellectual property the legal ownership of a novel idea with the expectation that the owner can financially profit from the idea

in-text citation acknowledgement of a source that appears in the body of a report or text

opinion a claim or a judgement that is formed in the absence of evidence

paraphrasing re-writing a particular passage from a source in your own words and retaining the original meaning

patent a licence awarded for exclusive ownership of a new invention for a limited period of time

peer reviewed describes scientific reports or articles that are evaluated by other scientists in the same field before they are published

plagiarism the act of misrepresenting someone else's work or ideas as your own

problem statement an outline of a conflict or dilemma that needs to be resolved

public opinion research to assess public understanding and attitudes about an issue

quoting re-writing a sentence or passage from a source word-for-word, enclosing the text in quotation marks

reference list a list of all sources used to prepare a report; normally appears at the end of the report

scientific evidence data that are systematically collected in order to specifically support or refute a hypothesis or claim

secondary data data that are drawn from existing published or unpublished research

stakeholder a person or other living organism that is affected by the issue

summarising putting the main ideas into your own words to capture a broad overview of a source

virtues-based approach an approach to making a decision about a bioethical issue that focuses on the moral character of the individual carrying out the action

weak evidence evidence that was not gathered specifically to address a claim

Glossary

A

abiotic relating to the non-living components of an ecosystem

absorption the movement of small, simple, soluble digested food molecules from the digestive tract into surrending blood and lymph vessels

abundance the number of individuals of a species in a population

accurate a measurement that is close to the true value

active transport the process whereby cells use energy in the form of ATP to transport substances across a membrane from low to high concentration

adaptation an inherited characteristic that makes an organism better suited to its environment and increases its chances of survival and reproduction

adenosine triphosphate (ATP) a high-energy compound composed of adenine and ribose and three phosphate groups attached; it releases energy for cellular reactions when its last phosphate group is removed and the compound is converted to ADP and inorganic phosphate

adhesion attraction between water molecules and the walls of xylem vessels that creates an upwards pull for water in the xylem

adhesion protein a plasma membrane protein that helps link cells together

adult stem cell a stem cell harvested from tissues such as bone marrow, that are not part of an embryo

aim the reason why you are undertaking the investigation

allele one of different versions of the same gene (at the same locus); the differences are determined by small differences in the DNA sequence of the gene

amensalism a symbiotic relationship whereby one species is inhibited or destroyed, while the other remains unaffected

amino acid a nitrogen-containing compound that is the building block of proteins

ammonia a nitrogenous-based waste produced during protein metabolism in cells

amylase a group of carbohydrate-digesting enzymes present in saliva and pancreatic juice

anaphase the division stage of mitosis where the chromatids separate at the centromere and move to either pole of the cell

anecdote personal observation or personal experience used to support a claim

aneuploidy describes a genome that varies from the conventional by the loss or addition of one or just a few chromosomes

antidiuretic hormone (ADH) a hormone that regulates water reabsorption in the collecting tubules in the kidneys

anus the end point of the gastrointestinal tract and a passage for faeces to be egested or eliminated out of the body

apoptosis a programmed series of events that lead to cell death

arrector pili muscle a small muscle attached to a hair follicle that contracts to raise the hair

asexual reproduction a form of reproduction in which offspring are produced from a single parent

authentication showing that you undertook the research and wrote the report yourself

authority an acceptable source as judged by the authors' credentials, their affiliations and their independence

autoclave a device used to sterilise equipment, reagents or contaminated waste; autoclaves work by subjecting contents to pressurised steam at 121°C for a set time

autosomal gene a gene located on an autosome or non-sex chromosomes

autosome a chromosome that is the same in both males and females of a species; autosomes do not include sex chromosomes

B

basal metabolic rate the rate at which the body uses energy to maintain vital functions while at rest

base pair two complementary nucleotide bases that are joined together by hydrogen bonding in a DNA double strand

behavioural adaptation an inherited way in which an organism acts that increases its chances of survival and reproduction

beneficence the principle that an action should be done for the benefit of others; can be done by helping prevent or remove harm or by improving the situation of others; a duty to do more good than harm

bias the pushing by a source of a particular point of view

bibliography a list of sources consulted during research but not necessarily cited in the final report, paper or poster

bile a substance produced by the liver and transported into the duodenum. It is not an enzyme; it is instead involved in mechanical digestion of fats due to its detergent-like action

binary fission the division of a cell into two without mitosis; the process by which a prokaryotic cell divides to form two cells

biodiversity the full range of different biological entities in a particular area or region; it can be described at various levels, including the range of different species, genetic diversity, or the diversity of ecosystems present in a large area

bioethical issue an ethical issue concerned with implementing a biological technology, intervention or process

bioethics ethics in the context of biological research

bioinformatics the science of managing and analysing biological data using advanced computing techniques

biopiracy a situation in which a patent based on Indigenous knowledge fails to share the economic benefits with the Indigenous communities whose knowledge was taken up

bioprospecting the pursuit of biological resources for potential sources of new medicines, food additives or environmentally hardy food crops

biotic relating to the living components of an ecosystem

blastocyst a hollow ball of cells formed during early embryonic development

bleb a balloon-like outgrowth of the plasma membrane

Bowman's capsule the structure in which the glomerulus is found, where filtration occurs at the beginning of the nephron

brown fat a type of fat involved in the rapid production of heat, especially in babies

budding the development of a new organism from an outgrowth of the parent organism

C

cancer a disease that arises when the signals that control apoptosis and cell division are disrupted, so cells survive and divide uncontrollably

capture–mark–recapture an ecological survey technique used to measure animal populations: individual animals are captured, marked and released; after a time, the population is re-sampled and the proportion of marked animals among those caught gives an indication of population size

carcinogen a cancer-causing agent

carnivore an organism that feeds on other animals

carrier a heterozygous organism carrying an allele for a recessive phenotype that may transmit the allele for the recessive phenotype to its offspring

carrier protein a protein within membranes that assists other molecules to cross the membrane in facilitated and active transport

causation where a factor (the cause) can change another factor (the effect)

cell the basic structural unit of all life forms on Earth

cell cycle the sequence of events from one cell division to the next

cell plate the structure produced by dividing plant cells where the new cell wall is to be formed

cellular respiration a series of cellular biochemical reactions and processes using glucose and producing carbon dioxide and water; the energy released is used to convert ADP and inorganic phosphate into ATP

cellulose a complex carbohydrate molecule found in cell walls

centriole a structure in animal cells that produces and organises microtubules

centromere the point of attachment of two sister chomatids; required for the movement of chromosomes during cell division

channel protein a protein that forms channels within membranes to allow the passage of hydrophobic substances across the membrane

chemical digestion a process in which large, complex molecules are broken down into small, soluble molecules by enzyme action

chemical mutagen a compound that can increase the rate of mutation

chiasmata (singular: chiasma) contact points between chromatids of homologous chromosomes that may become sites for crossing over and recombination during meiosis

chlorophyll the green pigment found in chloroplasts; it is able to absorb light energy, making it available for photosynthesis

chloroplast a membrane-bound organelle (type of plastid) found in the cytoplasm of plants and algae containing the green pigment chlorophyll; its main function is photosynthesis and storage of carbohydrates

chloroplast DNA (cpDNA) DNA contained in a chloroplast

cholesterol part of the structure of the plasma membrane where it alters fluidity of the membrane depending on temperature

chromatid one strand of a chromosome; can exist as one chromatid, or when replicated as two chromatids joined at the centromere

chromatin a complex of proteins and DNA in eukaryotic chromosomes

chromosome one of the structures that comprise the double-stranded DNA molecule that physically carry genes from one generation to the next; chromosomes occur as a circular DNA molecule in prokaryotes, mitochondria and chloroplasts and as linear DNA molecules associated with proteins inside the nucleus of eukaryotic cells

chyme 'soupy' contents of the stomach consisting of partially digested food

cleavage division of the cytoplasm in an animal cell

cleavage furrow a shallow, ring-like depression that forms at the cell surface of an animal cell undergoing cytokinesis as contractile microfilaments pull the plasma membrane inward; it defines where the cytoplasm will be divided across the two daughter cells

clone cells, tissue or an organism genetically identical to another organism or its cells

cloning the process of producing a cell, a tissue or an organism genetically identical to cells of another organism

coding DNA a sequence of DNA that codes for a protein

codominant describes a phenotype in which both alleles in the genotype are fully expressed in the heterozygote

coexistence different species living together

cohesion the strong forces that exist between water molecules and aid water movement upwards in the xylem

colon the first section of the large intestine, where water, minerals and vitamins are absorbed into the blood

commensalism a symbiotic relationship whereby one species benefits and the other is unaffected

community the sum of the different species inhabiting a particular habitat at one time

competition the struggle between members of a species or between two or more species for resources to fulfil their needs for survival

complementary bases the nucleotide bases that pair on the opposite strands of DNA; A pairs with T and C pairs with G

concentration gradient the difference in concentration of a substance between two different regions

conduction the transfer of heat energy from a relatively hot object to a relatively cool object by direct contact

consequences-based approach an approach to making a decision about a bioethical issue that focuses on the outcome or the result of implementing the decision

consumer any organism that cannot manufacture its own food and depends on others for food

contextual clarity describes the circumstances, the significance and the motivation for undertaking an investigation

contractile vacoule a specialised vacuole involved in regulating the amount of water inside a cell that pumps water from the cytoplasm to the outside of the cell

control group an experimental condition set up to compare to the condition receiving the independent variable

controlled variable a factor that is kept the same throughout an experiment so it does not influence the dependent variable

convection the transfer of heat by means of rising currents of warm air or liquid

crenation the crinkling of red blood cells when they lose water

cristae infoldings of the inner membrane of the mitochondria, forming partitions

crossing over and recombination the process during meiosis in which chromatids break and re-join to other chromatids, resulting in the chromatids swapping genes at the same loci

cuticle the waterproof wax layer that covers the leaves of plants

cyclin a type of molecule that regulates the cell cycle

cycline-dependent kinase (CDK) a type of molecule that regulates the cell cycle

cytokinesis division of the cytoplasm

cytoplasm all the cytosolic fluid, dissolved materials and organelles between the plasma membrane and the nuclear membrane

cytoplasmic streaming the mixing and movement of the cytoplasm

cytoskeleton a system of microtubules and microfilaments within a cell that supports and gives shape to it; helps movement and reproduction as well as maintaining the three dimensional shape of the cell

cytosol the part of the cytoplasm containing highly organised fluid material with dissolved substances; excluding the organelles

D

daughter cell a cell resulting from the mitotic division of a parent cell

deamination a process that separates the nitrogen-containing amine group from the rest of the amino acid

density the number of organisms of a species per unit area

deoxyribonucleic acid (DNA) an information molecule that is the universal basis of an organism's genetic material; it contains instructions, written in a chemical code, for the production of proteins by the cell

dependent variable the variable that is predicted to change as a result of changes to the independent variable; the variable that is measured

differentiation the process by which unspecialised cells develop special characteristics to suit particular functions

diffusion the passive movement of molecules from a high to a low concentration of that substance

digestion the breakdown of large pieces of food to smaller pieces (mechanical digestion) and the breakdown of large complex molecules into simple soluble molecules (chemical digestion) for absorption

digestive system the place where digestion takes place; also known as the gastrointestinal tract or gut

dihybrid cross a cross between two organisms for two different traits that involves two genes located at two different gene loci on the same or different chromosomes

dihybrid inheritance inheritance of two pairs of contrasting characteristics which involve the alleles of two different genes at two different gene loci

diploid having two haploid sets of chromosomes in each cell, represented by $2n$, the standard condition for human somatic cells

direct observation recording data on living things by looking at them in their natural habitat

distal tubule the portion of the nephron between the loop of Henle and the collecting duct

distribution the pattern of where the organisms of a species live

DNA methylation the attachment of a methyl group to nucleotides or histone proteins in the DNA molecule, thus altering the structure of the DNA molecule but not the DNA sequence

DNA sequence the order of nucleotide bases within a DNA molecule

dogma an opinion guided by ideological belief rather than by evidence

dominant describes a phenotype that requires only one copy of the allele for a dominant trait in an individual for it to be expressed

double helix the spiral shape of a DNA molecule

ductless gland a gland that has no duct or tube for exit of hormones, so the hormone is secreted directly into the bloodstream

duty-based approach an approach to making a decision about a bioethical issue that focuses on making a decision or choosing a course of action that aligns with an approved set of rules

E

ecosystem a self-sustaining unit consisting of the interactions between the community and the environment

effector an organ, tissue or cell that acts in response to a stimulus

egestion the removal of faeces from the digestive system through the anus; also called elimination

embryo the early stage of development of an organism; in humans, from fertilisation to the end of the eighth week of pregnancy

embryonic stem cell a stem cell that is cultured from an embryo

endocrine gland a ductless gland that produces hormone(s) and releases it directly into the blood

endocrine system the collection of ductless glands that produce hormones and secrete them directly into the bloodstream

endocytosis the movement of solids or liquids into a cell from the environment via vesicle formation

endoplasmic reticulum an organelle in eukaryotic cells consisting of an interconnecting system of thin membrane sheets dividing the cytoplasm into compartments and channels; involved in the synthesis, folding, modification and transport of proteins

endothermic describes an organism that maintains a relatively constant internal temperature

environment abiotic and biotic factors of an area

enzyme a specific protein catalyst that acts to increase the rate of a chemical reaction within the cell by lowering the amount of energy required for the reaction to proceed

epidermis the surface layer of cells in plants and animal cells, generally responsible for separating and protecting the organism from its external environment

epigenetics the study of chemical modifications resulting in DNA structural changes that cause changes in the expression of genes but not changes in the DNA sequence

equilibrium the point at which particles are distributed evenly throughout a system; they move at equal rates in all directions

ethics a system of moral principles to consider when undertaking scientific investigation; the principles are based on what is good and bad for society

eukaryotic describes a complex type of cell with a nucleus and membrane-bound organelles

evaporation the process in which liquid water changes to water vapour by gaining heat

excretion removal of metabolic wastes from the internal environment of the body

exocrine gland a ducted gland that secretes substances through a tube onto an epithelial surface; for example, sweat glands, salivary glands

exocytosis the movement of solids or liquids from a cell to the environment via vesicle formation

external environment (of a cell) the environment surrounding a cell outside the plasma membrane

external environment the environment surrounding an organism and inside the digestive, respiratory and excretory systems

exteroceptor a receptor that receives signals from the external environment

extinct the status of a species when there are no living members

extracellular external to the cell

extraneous variable a variable that could affect your results and that needs to be controlled

F

facilitated diffusion a form of diffusion that requires a substance to be attached to a specific carrier molecule to move across a membrane

faeces the waste material eliminated from the body through the anus

falsifiable able to be disproved

feedback mechanism a mechanism in which the output or response affects the input or stimulus

filtrate the fluid that passes from the glomerulus through the wall of the Bowman's capsule into the tubule in a nephron

first filial generation (F_1) the first generation of offspring produced from a cross between two pure breeding parents (P) with different phenotypes for the same trait

first-order consumer a consumer that feeds directly on producers; also known as a herbivore

flaccid floppy; describes the condition of a plant cell that has lost water

fluid mosaic model explains the fluid character of the plasma membrane

foetus the developing individual after the second month of pregnancy

food chain a sequence of trophic levels in which an organism is consumed by an organism in a higher trophic level, creating a chain in which energy and matter are passed to progressively higher levels

food web a network of feeding relationships that shows flow of energy and matter through complex pathways

fragmentation division of a parent organism into pieces, with each piece then giving rise to a complete organism

G

G_0 phase the non-proliferating state where cells undergo an extended G_1 phase

G_1 phase an intermediate phase in the cell cycle from the end of cytokinesis to the beginning of DNA synthesis

G_2 phase an intermediate phase in the cell cycle from the end of DNA synthesis to the beginning of mitosis; involves a time of cell growth

gall bladder the organ that stores bile

gastric juice liquid containing substances produced due to the presence of food in the stomach; contains mucus, water, hydrochloric acid and protease enzymes such as pepsin

gastrointestinal tract *see* digestive system

gene a unit of heredity that transmits information from one generation to the next; a segment of DNA that codes for a protein

genetic diversity the range of genotypes of individuals in the population of a species or the entire species

genetic predisposition an increased risk of developing a particular disease, based on a person's genetic makeup

genetics the study of the mechanism and patterns of inheritance through the transmission of coded chemical instructions from one generation to the next

genome all the genetic material contained in an organism or a cell; in eukaryotes, includes the chromosomes within the nucleus and the DNA in mitochondria and chloroplasts

genome size the total number of base pairs of DNA in a prokaryotic cell or in the haploid set of chromosomes of a eukaryotic cell

genomics the study of the genome – how genes interact with each other and the environment, and the resultant proteins produced; it requires a knowledge of an organism's entire DNA sequence, so studies rely on powerful sequencing technologies and bioinformatics

genotype a specific combination of alleles for a locus belonging to an individual or cell

glomerulus a network of capillaries located in the Bowman's capsule and site of filtration of the blood in the nephron

glucagon a hormone formed in the pancreas by the alpha cells in the islets of Langerhans that promotes the breakdown of stored glycogen to glucose in the liver and muscles

glycogen an energy-storing carbohydrate in animals, usually in the liver and muscles

glycoprotein protein that has carbohydrates attached

Golgi apparatus a collection of membranes that package and store substances into vesicles in preparation for their release from the cell

grafting the process of artificially attaching part of one plant to another plant

grana a stack of thylakoid discs within a chloroplast

H

habitat an area or environment in which an individual or species lives within an ecosystem

haemolysis the bursting of red blood cells

haploid the condition of gametes having a single set of chromosomes, represented by *n*

heat balance a balance between heat gain and heat loss

herbivore a first-order consumer that feeds on plants

heredity the study of inheritance; the genetic transmission of characteristics from one generation to another

heterosome non-identical chromosomes that pair up at meiosis (e.g. the X and Y chromosomes in human males)

heterotroph an organism that cannot make its own complex organic food molecules and so must take in food from other organisms

heterozygous a genotype with two different alleles for a single gene locus

histone a protein around which DNA winds in eukaryotic cells

homeostasis the maintenance of a relatively constant internal environment within narrow limits, despite changes in the external environment

homologous chromosomes a pair of chromosomes that have the same size, shape and genes at the same locations

homozygous a genotype with two identical alleles for a single gene locus

hormone an organic compound produced in one part of the body, which is transported in the bloodstream to another part of the body, where it produces a response

host an organism that another organism lives on or in

hydrogen bond a weak molecular chemical bond

hydrophilic tending to interact with and dissolve in water

hydrophobic avoiding association with water

hyperglycaemia a condition in which a person has elevated blood glucose levels above the set point

hyperthermia a state in which the internal temperature rises above the set point

hyperthyroidism a state in which there is an excess of thyroxine produced by the thyroid gland

hypertonic a solution with a higher solute concentration compared with another solution

hypoglycaemia a state in which the blood glucose level drops below the set point

hypothalamus a small region located at the base of the brain that plays a crucial role in releasing hormones, temperature control and water balance

hypothermia a state in which the internal temperature falls below the set point

hypothesis a tentative prediction, usually based on an existing model or theory

hypothyroidism a state in which there is too little thyroxine in the body

hypotonic a solution with a lower solute concentration compared with another solution

I

incomplete dominance the state in which a heterozygous individual has a phenotype that is intermediate or a blend between those of the corresponding homozygous individuals; also known as partial dominance

independent assortment when alleles of gene pairs redistribute independently into different combinations in gametes during meiosis

independent variable the variable that is altered or manipulated in a scientific investigation

individual rights an individual's right to choose their own course of action

ingestion the taking in of complex organic compounds

inheritance the genetic acquisition of characteristics by offspring from their parents

insulin a hormone produced in the pancreas by the beta cells in the islets of Langerhans; it increases glucose absorption into cells from the blood

integrity an ethical concept that means being honest, transparent and professional about one's actions; a scientist shows integrity by reporting their data (even if it doesn't fit their hypothesis) and acknowledging all sources of information

intellectual property the legal ownership of a novel idea with the expectation that the owner can financially profit from the idea

intercellular occurring between cells

internal environment (of a cell) all material contained within the plasma membrane

internal environment all the fluids that surround and bathe the cells, including extracellular (tissue) fluid, blood and lymph

International System of Units (Système International d'Unités, SI) a modern form of the metric system; a standardised worldwide system of measurements used in science and commerce

interoceptor a receptor that receives signals from the internal environment

interphase the stage of the cell cycle between nuclear divisions

interstitial fluid fluid that lies in the spaces between cells; also known as extracellular or tissue fluid

in-text citation acknowledgement of a source that appears in the body of a report or text

intracellular occurring within a cell

ion a particle with either a positive or a negative charge

isotonic describes fluid with an equal solute concentration to another fluid

J

justice the moral obligation to consider competing claims, not to place an unfair burden on a particular group and to fairly distribute or allow access to the benefits of an action

K

karyotype a display of the number and appearance of the chromosomes of an organism or cell observed at late prophase and metaphase

keystone species a species that has a disproportionately large effect on other organisms within an ecosystem and is important for maintaining balance within the ecosystem

kidney an organ that removes cell metabolic wastes and helps to control the body's fluid balance

L

lacteal a blunt-ended lymph capillary that absorbs fatty acids and glycerol in a villus of the small intestine

large intestine the final length of the gut; consists of the colon and the rectum. It functions to absorb water and some salts back into the blood and to compact undigested food material to form the faeces, which are temporarily stored

law a general rule that explains repeated experimental observations and is usually in the form of a verbal statement or a mathematical statement

law of independent assortment the principle that genes on different homologous chromosomes separate independently into gametes during meiosis; the combination of genes (and alleles) that occurs in each gamete is therefore the result of chance

law of segregation the principle that half the gametes formed during meiosis contain one member of each gene pair and half contain the other member**locus** the position a gene occupies in a chromosome

lignin a complex polymer substance found in xylem cell walls where it provides strength and structure to the cell wall and the plant

linkage group a segment of genes close together on the same chromosome that are inherited together

linked genes genes that are inherited together because they are located close together on the same chromosome

locus the position a gene occupies in a chromosome

logbook the record of an experiment or investigation kept by the scientist performing the experiment; it is a legal record of the experiments and their results

loop of Henle the portion of a nephron that connects the proximal convoluted tubule to the distal convoluted tubule and where much reabsorption occurs

lymph a colourless fluid that circulates through the lymphatic vessels and delivers excess tissue fluid back into the blood; it transports fatty acids and glycerol from the villi where they are absorbed

lymphatic system a drainage system in the body that assists in the maintenance of a balanced fluid level

lysosome an organelle within the cytoplasm containing digestive enzymes

M

M phase the phase of the cell cycle when the nucleus undergoes a series of steps to divide, leading to two daughter cells

macrophage a phagocytic white blood cell

mean the central value of a set of data points; also known as the average

mechanical digestion the process of breaking large pieces of food down into smaller pieces of food

membrane a thin, pliable sheet or layer acting as a boundary

Mendelian genetics an explanation of patterns of inheritance based on the discoveries of Gregor Mendel and his statistical analysis and breeding experiments on pea plants

metabolism the sum of all chemical reactions that occur within an organism's cells to maintain life

metaphase the stage in mitosis when all the chromosomes are fully condensed and attached by a spindle fibre at their centromere

method the numbered steps taken to carry out an investigation

methodology the broader framework of approach taken in the investigation to test your research question or hypothesis

microfilament a solid contractile protein; involved in movement and cell shape

microtubule a hollow, cylindrical tube in cells that acts as scaffolding to determine cell shape and aid movement

microvilli tiny projections on the surface of villi that increase the surface area of the gut for absorption

mitochondria organelles within the cytoplasm that are the site of aerobic cellular respiration, releasing energy for the cell

mitochondrial DNA (mtDNA) DNA contained in mitochondria

mitochondrial matrix gel-like material within the mitochondria

mitosis a type of nuclear division that maintains the parental number of chromosomes for daughter cells; it is the basis of bodily growth and asexual reproduction in many eukaryotic species

model a representation of a system or phenomenon that explains the system or phenomenon; it may be mathematical equations, a computer simulation, a physical object, words or in some other form

monoculture the agricultural practice of growing a single crop or plant species over a wide area for a large number of consecutive years

monohybrid cross a cross between two organisms for one trait involving the alleles of one gene located at one specific locus on a chromosome

monoploid describes a cell or organism that has a functional genome consisting of one copy of each chromosome, represented by $1n$

monosomy the condition in which somatic cells contain one copy of a particular chromosome

multicellular describes an organism consisting of more than one cell

multipotent stem cell a stem cell that is able to give rise to a limited number of other cell types; for example, blood stem cells will give rise to red blood cells, white blood cells and platelets

mutagen an agent that can induce or increase the frequency of mutation in DNA

mutation a change or mistake in the copying of a DNA sequence in chromosomes

mutualism a symbiotic relationship whereby each species in the relationship benefits from the other

N

nanometre (nm) one-thousand-millionth of a metre

necrosis unprogrammed cell or tissue death

negative feedback a response to a stimulus that counteracts the stimulus and reverses the direction of the change

nephron one of the millions of small units of each human kidney where filtration and reabsorption occur

nitrogenous base a structural component of nucleotides; DNA has adenine (A), cytosine (C), guanine (G) and thymine (T)

non-coding DNA DNA that does not code for a protein but may have other functions in chromosome structure or regulating production of proteins from genes

non-disjunction the failure of paired chromatids in mitosis or homologues in meiosis to separate and go to opposite poles

non-maleficence the principle that we should act in ways that do not cause harm or inflict suffering upon others; a duty to minimise harm

nuclear envelope/membrane the membrane surrounding the nucleus

nucleoid the region within a prokaryotic cell that contains the genetic material

nucleolus a site for assembling protein and RNA that will later form ribosomes; visible in a non-dividing cell

nucleotide the basic building block of DNA, made up of a five-carbon sugar, a phosphate group and a nitrogenous base

nucleus the organelle containing DNA in a eukaryotic cell; it functions to coordinate cellular activities

O

oesophagus the muscular tube that transports food from the mouth to the stomach

omnivore an organism that feeds on a range of foods, including plant and animal matter

oncogene a gene that can promote cancer

opinion a claim or a judgement that is formed in the absence of evidence

optimum range the narrow range within the tolerance range for a specific factor at which the organism functions best

organ a structure made up of different types of tissues working together

organelle a specialised structure or compartment within a cell that has a specific function

osmoreceptor a receptor that responds to changes in the osmotic pressure of the blood

osmoregulation processes by which internal water and solute concentrations are maintained at relatively constant values, despite fluctuations in the external environment

osmosis the movement of water across a selectively permeable membrane from a region of low solute concentration to a region of high solute concentration

outlier a data point that does not fit the pattern shown by other measured data points

P

p53 gene a gene that monitors DNA and is activated when DNA damage is detected or there is cell injury

pancreatic juice the secretion from the pancreas into the duodenum that contains amylase, lipase, protease and bicarbonate

paraphrasing re-writing a particular passage from a source in your own words and retaining the original meaning

parasite an organism, such as a bacterium, virus, fungus, worm or arthropod, that lives on or in another host organism

parasitism a symbiotic relationship in which one species benefits to the detriment of the other

parenchyma large, thin-walled cells that make up the cortex of a plant

parent cell a cell before it divides by mitosis to produce two daughter cells

parental generation (P) two organisms that represent the start of a breeding experiment; their offspring are the F_1 generation

parthenogenesis a form of asexual reproduction where growth and development into a complete organism occurs from an unfertilised egg

partial dominance *see* incomplete dominance

passive transport the movement of molecules that does not require input of energy

patent a licence awarded for exclusive ownership of a new invention for a limited period of time

pedigree analysis a way of finding out the pattern of inheritance of the alleles of a gene for a specific characteristic by following the inheritance pattern over several generations

pedigree chart a chart that uses accepted symbols and shows the inheritance of a particular trait over several generations

peer reviewed describes scientific reports or articles that are evaluated by other scientists in the same field before they are published

peristalsis waves of muscular contractions that push food down the oesophagus and through the length of the gut to the anus

permeable able to pass through

personal error a mistake made by the investigator

pH a scale from 0 to 14 used to measure acidity and alkalinity of solutions, where 7 is neutral

phagocyte a scavenging cell that engulfs and absorbs cell particles and bacteria

phagocytosis the bulk transport of solids into a cell inside a vesicle; a type of endocytosis

phenotype the characteristics expressed in an organism determined by their genotype and influenced by factors in their environment and epigenetic factors

phloem vascular tissue in plants composed of living cells that is responsible for the transport of sugars and other plant substances in all directions around the plant

phospholipid a type of lipid that forms part of the plasma membrane

phospholipid bilayer two layers of phospholipids that form the plasma membrane with the hydrophobic end facing inwards and hydrophilic end facing outwards

photosynthesis a chemical reaction using energy from the Sun to convert carbon dioxide and water into glucose and oxygen

physiological adaptation an inherited characteristic in the functioning of an organism that increases its chances of survival and reproduction

physiological stress impact on physiological functioning caused when an organism experiences external and internal environmental conditions outside its tolerance range

phytoplankton the collective term for the tiny photosynthetic organisms present in bodies of water

phytosterol similar to cholesterol, found in plasma membrane

pinocytosis the bulk transport of liquids into a cell inside a vesicle; a type of endocytosis

placenta the organ that supplies nutrients to, and removes wastes from, the foetus

plagiarism the act of misrepresenting someone else's work or ideas as your own

plasma membrane the insoluble boundary of all living cells that maintains the contents of the cell and regulates movement of substances into and out of the cell

plasmid extrachromosomal circular DNA found in prokaryotes

plasmolysis the cytoplasm pulling away from the cell wall because of water loss

plastid an organelle in a plant cell containing coloured pigments

pluripotent stem cell a stem cell that is able to give rise to many, but not all, of the cell types necessary for foetal development

pole one end of a cell

polypeptide a chain of many amino acids linked together forming a protein or part of a protein

polyploidy describes a cell or organism that has a genome comprising three or more copies of each chromosome, represented by $3n$, $4n$, $5n$, $6n$ etc.

population a group of individuals belonging to the same species living in a particular area at the same time

precise describes repeated measurements that are close to each other

predator an organism that hunts another organism for its food

prey an organism that is hunted by another organism for food

primary data data that you have measured or collected yourself

primary source a report of original research, such as an article in a scientific journal

problem statement an outline of a conflict or dilemma that needs to be resolved

producer autotrophic species that produce complex organic matter from simple inorganic molecules, predominantly using light energy from the Sun, in photosynthesis or chemical energy in chemosynthesis

prokaryotic describes a simple type of cell that lacks a nucleus and membrane-bound organelles

prophase the first phase of mitosis where the DNA condenses to form the chromosomes

protease a protein-digesting enzyme

proteomics the study of the entire protein content produced by a cell, tissue or organism

proto-oncogene a gene that can promote cancer

proximal tubule the section of the tubule in the nephron that leads from the Bowman's capsule to the loop of Henle and where much reabsorption occurs

public opinion research to assess public understanding and attitudes about an issue

Punnett square a grid used to graphically predict the outcome of a cross or breeding experiment

pure breeding describes a line of organisms that, when crossed with each other, always produce offspring with the same phenotype

purebred refers to an organism that has identical alleles for a gene (homozygous) and produces offspring with the same phenotype as the parent over many generations (true breeding)

pyloric sphincter the small muscular ring at the lower end of the stomach that controls the amount of food that can leave the stomach and enter the small intestine

Q

quadrat a method used in population sampling where a square is placed on the ground to count each individual of a species and determine its density; useful for stationary organisms

qualitative data descriptive or non-numerical results

quantitative data measurements or results with numerical values

quiescent cell an inactive cell

quoting re-writing a sentence or passage from a source word-for-word, enclosing the text in quotation marks

R

radiation the transfer of heat from a hot object by infrared waves

random error an error caused by an unknown and unpredicted factor

receptor a cell component that detects changes in the surrounding environment

receptor protein a protein that binds hormones and other signal molecules

recessive describes a phenotype that requires two copies of the allele of the gene for it to be expressed

recognition protein a protein that acts as a marker on membranes

recombinant gametes new combinations of genes in the gametes that are not found in either parent, resulting from crossing over between linked genes

recombinant offspring offspring with combinations of alleles that are not found in either parent and result from crossing over and recombination of segments of chromatids

rectum the final section of the large intestine, where faeces are stored prior to egestion

reference list a list of all sources used to prepare a report; normally appears at the end of the report

reference the source of a specific piece of information or quotation that you have used in writing your report

regulatory elements segments of non-coding DNA with a role in switching on or switching off the production of protein from a gene

reliable highly likely to be true; a trustworthy source of information or reproducible data

renal artery the blood vessel that brings blood from the heart to the kidney

renal pelvis the section of the kidney where urine is collected and directed to the ureter

repeatable giving the same result, within uncertainty limits, when repeated measurements are made by the original investigator

replicate one of several experimental samples subjected to all the treatment combinations to be compared in an experiment; for example, duplicate refers to two repetitions of the conditions, triplicate to three repetitions

reproducible giving the same result, within uncertainty limits, when repeated measurements are made by other researchers

research question the specific question that a particular experiment or investigation is attempting to answer

respect an ethical concept that considers the rights of an individual or group (person or other living organism); for example, respect for animals considers their welfare

response structural, behavioural or physiological action that results from a stimulus

ribonucleic acid (RNA) the single-stranded nucleic acid that functions in transcribing and translating information from DNA into proteins

ribosome a small structure in all cells that builds amino acids into complex proteins; this organelle is not bound by a membrane

risk assessment the process of evaluating potential risks involved in an investigation and how to manage them

root hair cells a root cell with an elongated tubular extension to increase water and mineral ion absorption

root pressure the force that contributes a small amount of force to push water up the stem from the roots

rough endoplasmic reticulum endoplasmic reticulum with ribosomes attached

S

S phase the phase of the cell cycle where DNA is replicated

sample a small group of organisms selected from the total population; is representative of the whole population

scavenger a consumer that feeds on dead and decaying flesh or remains

scientific evidence data that are systematically collected in order to specifically support or refute a hypothesis or claim

second filial generation (F_2) offspring of the F_1 generation; the second generation produced from a cross between two homozygous parents (P)

secondary data data that are drawn from existing published or unpublished research

secondary source a summary, review or analysis of primary sources; a report, article, web page, person, institute or group from which background information was gathered

selectively permeable describes a membrane that allows some substances but not others to pass across it

set point optimal level

sex chromosomes the pair of chromosomes that determines the sex of an individual

sex-linked describes genes that are found on the sex chromosomes

sex-linked gene a gene located on either the X or the Y chromosome

sex-linked inheritance the inheritance pattern shown by a gene located on a sex chromosome

small intestine the longest part of the gastrointestinal tract, where digestion is completed and most absorption of digested food occurs

smooth endoplasmic reticulum endoplasmic reticulum with no ribosomes attached

solute a substance that can be dissolved in another substance

solution a mixture of solute and solvent

solvent a substance in which another substance can be dissolved to produce a solution

somatic cell a normal body cell, as compared with a germ-line cell from which a gamete (sperm or ovum) is derived

sphincter a circular muscle that when constricted closes a natural body passage and relaxes as required to allow the flow of substances through the passage

spindle the framework of microtubules that radiates out from the poles of a cell during cell division

spindle fibres microtubules, produced during cell division, that move chromosomes in precise directions

spore a reproductive body able to withstand harsh environmental conditions

stakeholder a person or other living organism that is affected by the issue

standard abbreviations shorter forms of a word or term that are conventionally used in scientific communication

stem cell a cell that has the ability to produce a different type of body cell

stimulus (plural: stimuli) a signal that causes a response

stimulus–response model a model that explains how the cells and organ systems of the human body respond to changes in the external and internal environments

stomata (singular: stoma) the holes or openings in leaves and some stems that open and close to control the movement of gases into and out of the plant and control water loss

stroma colourless fluid in a chloroplast

structural adaptation an inherited feature of an organism's anatomy that increases its chances of survival and reproduction

subjective capable of being interpreted differently by different people, for example blueness of the contents in a test tube

summarising putting the main ideas into your own words to capture a broad overview of a source

surface-area-to-volume ratio (SA : V) the mathematical ratio of the size of the surface area (in two dimensions) compared to the volume of an object (in three dimensions)

symbiosis the relationship between individuals of two or more species that interact together whereby at least one organism benefits from or is harmed by the relationship

synapsis the state of homologous chromosomes laying side by side during prophase I of meiosis

synthesise to make

system a number of organs that work together to perform a function

systematic error a predictable error that arises through imperfections in the equipment used to take the measurements

T

telophase the final stage of mitosis where the nuclear material has been evenly and equally separated to opposite ends of the parent cell and the two daughter cells begin to take shape

teratogen an agent that causes developmental abnormalities in a developing foetus

terminally differentiated cell a cell that has lost the ability to replicate

terrestrial land dwelling

test cross a cross using an organism with a recessive phenotype to determine the genotype of an organism with a dominant phenotype or to determine if two gene loci are linked closely on the same chromosome or are present on different chromosomes

tetraploid having four haploid sets of chromosomes in each cell, represented by $4n$

theory a collection of models and concepts that explain specific systems or phenomena; scientific theories allow predictions to be made and hence are falsifiable

thermoregulation temperature regulation

thylakoid membrane the system of interconnected membranes in a chloroplast

thyroid-stimulating hormone (TSH) hormone produced by the pituitary gland that triggers thyroxine synthesis and secretion

thyrotrophin-releasing hormone (TRH) hormone produced by the pituitary gland that stimulates the production of TSH

thyroxine a hormone produced in specialised secretory cells in the thyroid gland that is responsible for controlling the basal metabolic rate of cells and is particularly important in growth

thyroxine a hormone produced in the thyroid gland in the neck, important in three main physiological processes – cellular differentiation, growth and metabolism

tissue a group of specialised cells working together to perform a specific function

tolerance range the range of external and internal environmental conditions within which an organism can function efficiently

tonoplast the membrane surrounding the vacuole

top consumer the last link in a food chain

totipotent stem cell a stem cell able to create any of the types of cells necessary for embryonic development

tracheid an elongated dead cell in the xylem of plants that is involved in water and mineral salt transport

trait a heritable characteristic; phenotype

transect a method used in population sampling whereby a line is drawn through a community and information gathered along it is used to determine the distribution of species; can be used in conjunction with quadrats and is useful for stationary organisms

translocation movement in the phloem that transports sucrose, along with some amino acids and some mineral salts, from a site of synthesis to a site of use or storage

transmembrane protein a type of integral protein that spans the entire thickness of the plasma membrane

transpiration the loss of water from plants through evaporation from the moist inside cells of a leaf and diffusion of water vapour out of open stomata

transpiration stream the continuous columns of water in the xylem that run the length of the plant, from roots to leaves

transpirational pull the force arising from the evaporation of water from leaves that is transmitted down the xylem

transport protein a protein that carries molecules across membranes

triploid having three haploid sets of chromosomes in each cell, represented by $3n$

trisomy the condition in which somatic cells contain three copies of a particular chromosome

trophic level a feeding level in the food chain of an ecosystem

true value a value that would be obtained in an ideal measurement where there are no errors

tumour a lump in any part of the body caused by the abnormal growth of cells or tissue

tumour suppressor gene a gene that inhibits cell division

turgid describes a cell that is tight and rigid from absorbing water

U

uncertainty the doubt associated with the value derived from measuring a variable

unicellular describes an organism made up of a single cell

unlinked genes *see* independent assortment

urea the compound into which most nitrogenous wastes (produced from the oxidation of amino acids) are converted; it is excreted in water as urine

!!

V

vacuole a membrane-bound fluid-filled space within a cell

valid describes results that are affected by only a single independent variable and hence are reproducible

vascular bundle a combined group of xylem and phloem tissues in plants

vascular plant a plant containing vascular tissue: phloem and xylem

vascular tissue (in plants) the plant tissue for the transport of water, nutrients, sugars and other substances in the xylem and phloem

vasoconstriction a decrease in the diameter (narrowing) of blood vessels, particularly arterioles, to decrease blood flow near the skin surface to reduce heat loss

vasodilation the widening of blood vessels, particularly arterioles, to increase blood flow near the skin surface and allow increased heat loss

vasopressin a specific name for an antidiuretic hormone (ADH) responsible for increased permeability of the distal tubules of the kidney, increasing water reabsorption and reducing urine volume

vegetative propagation to grow a new plant from a fragment of a parent plant

vesicle a small, membrane-bound sac in the cytoplasm that transports, stores or digests substances

villi the finger-like projections on the internal surface of the small intestine that greatly increase the surface area available for absorption of digested food

virtues-based approach an approach to making a decision about a bioethical issue that focuses on the moral character of the individual carrying out the action

W

water potential the capacity of water to do work based on the kinetic energy of its individual molecules; the work is done as water moves across selectively permeable membranes due to osmosis

weak evidence evidence that was not gathered specifically to address a claim

X

X-linked related to a gene located on the X chromosome

xylem one of the vascular tissues in plants, mainly composed of dead cells, responsible for transport of water and dissolved mineral salts from the roots to the leaves

xylem vessel element a type of cell comprising xylem tissue of vascular plants that are dead lignified cells that join end-to-end to form tubes for transport of water

Y

Y-linked related to a gene located on the Y chromosome

Z

zygote the diploid cell that results from the fusion of two haploid gametes

Answers

Unit 1 Area of Study 1 review

Multiple choice

1 D
2 B
3 C
4 A
5 A
6 D
7 D
8 C
9 C
10 B
11 C
12 D
13 B
14 C
15 B

Short answer

16 a E, D, C, F, G, A, B
b metaphase
c DNA replication
d any somatic cell is accepted
e i Checks are made on the spindle for defects in chromosome attachment.
ii To ensure that chromosomes are attached to the spindle before anaphase so the daughter cells have the correct number of chromosomes. If the chromosomes are not attached correctly to the spindles then daughter cells can have missing or extra chromosomes.

17 a As it has many mitochondria, which produce ATP for cell activities, the cell's function requires high energy input, for example for protein synthesis.
b Cell C, because it does not contain membrane-bound organelles such as a nucleus, mitochondria and chloroplasts.
c Cell wall made of cellulose, large vacuole
d Cells A and B
e Sister chromatids

Unit 1 Area of Study 2 review

Multiple choice

1 A
2 C
3 B
4 D
5 C
6 B
7 C
8 C
9 C
10 D
11 D
12 D
13 B
14 D
15 B
16 C

Short answer

17 a The maintenance of a relatively constant internal environment, even when there are changes in the external and internal environments.
b Blood glucose levels have risen in the first 30 minutes after the meal is eaten. This is detected by receptors in the pancreas. Beta cells are stimulated to release insulin, which circulates in blood and targets cells to take up glucose, resulting in the blood glucose levels falling after 30 minutes.
c Emily is unable to produce enough insulin to signal to her cells to take up glucose from the blood, therefore Emily's blood sugar increases to higher levels and still remains higher than Grace's after 5 hours. In contrast, Grace is able to produce enough insulin when blood glucose levels rise above the body's set point and therefore her body cells can take in glucose to lower the blood sugar level back to the set point.

d Grace's graph. Up to 4 hours without a meal, her blood sugar level drops to below the level before the meal. Between 4–5 hours after the meal there is a small rise in blood glucose. This is due to the glucagon being released from the alpha cells of the pancreas in response to this drop; it signals liver and muscles cells to convert stored glycogen to glucose and release it into the bloodstream. This is evident by the small increase in blood glucose levels beginning 4 hours after the meal.

e Yes, this can be considered negative feedback as the initial stimulus – increase in blood glucose level – stimulates a series of events that bring about a response that changes the direction of the initial stimulus; that is, it decreases the blood glucose level. This results in the concentration of blood glucose remaining within a narrow range and homeostasis is maintained.

f Body temperature, water balance. Mammals require a stable body temperature for the optimal conditions for chemical reaction in cells. Mammals require a constant water concentration in order to maintain movement of nutrients and wastes across membranes.

18 a Mammal H is lying outside in the sun and gaining heat by absorbing radiant heat.

b Mammal G could have an increase in sweating onto its skin. The evaporation of sweat from the skin cools the blood that is in capillaries near the surface of the skin.

c Mammal H is able to tolerate a greater range in its internal temperature. By not maintaining a raised metabolic rate to keep its body temperature within a narrow range, when the environmental temperature drops to 20°C, it is able to conserve energy. When the environmental temperature rises to 40°C, the mammal is potentially still able to be active and not have to seek shelter in order to not heat up. This could enable the mammal to avoid predators and still obtain food.

Unit 2 Area of Study 1 review

Multiple choice

1 B
2 B
3 B
4 D
5 A
6 D
7 A
8 B
9 B
10 B
11 C
12 D
13 A
14 C
15 D
16 C

Short answer

17 a X-linked recessive

b 50%
Mother X^HX^h, Father X^HY
Molly is a female so male offspring are not considered.

Gametes	X^H	Y
X^H	X^HX^H female homozygote 50%	X^HY
X^h	X^HX^h female heterozygote 50%	X^hY

c Carrier

18 a Pups with the phenotype R could have the genotype *bbTT* or *bbTt*. They could be heterozygous *Tt* or homozygous *TT* for gene 2 and still have the same phenotype.

b Cross dog M with a dog with a grey coat and white area on its coat (the recessive phenotype) because you know its genotype is *bbtt*. If any recessive phenotype is present in the offspring you can conclude that dog M is heterozygous. If dog M was homozygous at both loci, that is, *BBTT*, then all offspring with the test cross would be *BbTt* and therefore black with no white on their coat.

Dog M heterozygote					
Gametes		*BT*	*Bt*	*bT*	*bt*
Dog for test cross *bbtt*	***bt***	*BbTt* Black No white on coat	*Bbtt* Black White areas on coat	*bbTt* Grey No white on coat	*Bbtt* Grey White areas on coat

c If the genes are on different chromosomes, you would expect the four possible combinations of coat in the ratios of 1:1:1:1. If the genes are linked, then due to the possibility of recombinant gametes due to crossing over, you could get offspring in different ratios, and could then infer that the genes loci are on the same chromosome.

d No. With these small numbers it would not be possible to make the conclusion because each fertilisation to produce a pup is an independent event, and with so few fertilisations you may not see the expected patterns.

Unit 2 Area of Study 2 review

Multiple choice

1 D
2 B
3 C
4 A
5 D
6 B
7 D
8 C
9 A
10 D
11 D
12 C
13 C
14 A
15 D
16 D

Short answer

17 a

Characteristic	Advantage	Disadvantage
Lack of genetic diversity	The offspring have inherited the characteristics from their parent that made the parent successful in the particular environment, so they too will have the same characteristic and be able to survive in the environment.	As the offspring are identical to their parent, if any of the environmental conditions change and the population are not able to survive the change due to a lack of adaptations that suit the new environmental conditions, then the whole genetically identical population may not survive and they can be wiped out.
Large number of offspring produced	Large number of offspring are produced quickly so can colonise an area quickly when environmental conditions are favourable.	If offspring are close together then they will be competing for resources.

b Greater genetic diversity in a species means there is greater diversity in genotypes and therefore phenotypes. If there is a change in a species' environment, one of the different phenotypes may be better suited to this change. This phenotype is more likely to survive, reproduce and then pass on the genes that produce the beneficial phenotype to its offspring.

18 a The enucleated egg is used as a carrier of the genetic material of the donor dog, which is the dog that is to be cloned. The enucleated egg with the donor nucleus will develop into an embryo identical to the donor. Therefore the genetic material originally in the egg, a haploid set of chromosomes, needs to be removed.

b A somatic cell is a body cell with a diploid set of chromosomes. This cell is fused with the enucleated egg cell, so that when the egg cell is stimulated to divide like a fertilised egg the cells will be genetically identical to the somatic cell from the donor dog.

c Snuppy is male because it is genetically identical to Dog B, which is a male dog. The genetic material in the egg that develops into Snuppy came from Dog B because the egg had been enucleated.

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9780170452465

NELSON

VICscience

biology

VCE UNITS 1 + 2

Xenia Pappas
Ann Cathcart
Tony Chiovitti
Amanda Clarke
Adrianne Harrowfield
Susan Ryan

4E

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