CAMBRIDGE
UNIVERSITY PRESS

VCE UNITS
1&2

Cambridge Senior Science

# Biology

Simon **Maaser**
Brett **Drummond**
Ben **Elliott**
Kylie **May**
Victoria **Shaw**

ISBN 978-1-108-88711-3

CAMBRIDGE
UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom

One Liberty Plaza, 20th Floor, New York, NY 10006, USA

477 Williamstown Road, Port Melbourne, VIC 3207, Australia

314–321, 3rd Floor, Plot 3, Splendor Forum, Jasola District Centre, New Delhi – 110025, India

79 Anson Road, #06–04/06, Singapore 079906

Cambridge University Press is part of the University of Cambridge.
It furthers the University's mission by disseminating knowledge in the pursuit of education, learning and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org


First published 2021

20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

Cover designed by Cate Furey
Text designed by Shaun Jury
Typeset by QBS Learning
Printed in China by C&C Offset Printing Co. Ltd.

*A catalogue record for this book is available from the National Library of Australia at* www.nla.gov.au

ISBN 978-1-108-88711-3 Paperback

Additional resources for this publication at www.cambridge.edu.au/GO



*Please be aware that this publication may contain images of Aboriginal and Torres Strait Islander peoples now deceased. Several variations of Aboriginal and Torres Strait Islander terms and spellings may also appear; no disrespect is intended. Please note that the terms 'Indigenous Australians' and 'Aboriginal and Torres Strait Islander peoples' and 'First Australians' may be used interchangeably in this publication*

# About the authors

Simon Maaser is Lead Author of the VCE Biology team. He has held roles as both Head of Science and Director of Curriculum across various schools. He has also been involved in leading VCAA Biology Exam assessing and Study Design reviews.

Brett Drummond is a science communicator and co-founder of MStranslate, an organisation that communicates research summaries on multiple sclerosis. He has been a private tutor for VCE Biology and Chemistry.

Ben Elliott has been a Years 7–10 Science Co-ordinator and a VCE Biology teacher for a number of years. He also taught Science and A-Level Biology in the UK.

Kylie May has taught VCE Biology for the last 14 years. She has held the positions of Head of Science and Head of Biology at various schools throughout her career. She has also been a VCAA assessor for Biology and completed studies with the Harvard Graduate School of Education.

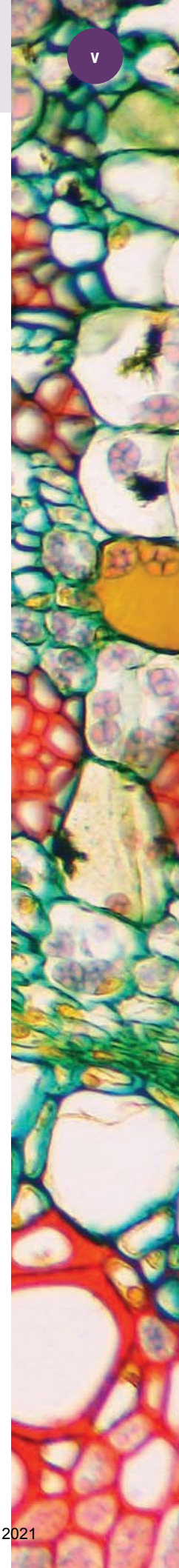
Victoria Shaw has been committed to sharing her love for science with Year 7–12 students for the past 21 years. She was Head of Science at an independent school for several years and has been an assessor for both the VCAA and IBO.

ISBN 978-1-108-88711-3

# Contents



ISBN 978-1-108-88711-3



UNIT 2

## How does inheritance impact on diversity?



Answers are available in the Interactive Textbook and the teacher resources.

ISBN 978-1-108-88711-3

# Overview: How to use this resource

> *Go to* **cambridge.edu.au/education/vcescience** *for more information and demos.*

This overview guides you through all the components of the **print and PDF textbooks**, the **Interactive Textbook (ITB)**, and the teacher resources in the **Online Teaching Suite (OTS)**. Users of the award-winning *Cambridge Science 7–10 for the Victorian Curriculum* will recognise some similarities with this senior science resource, including the hosting of the digital material on the Edjin platform, which was developed from *Cambridge HOTmaths* and is already being used successfully by thousands of teachers and students across Victoria.

## Print book features

### Learning intentions

In the Curriculum table at the start of each chapter, the Study Design dot points are translated into Learning Intentions, describing what students should be able to do by the end of the chapter:

Black text indicates the portion of the dot point covered by the section shown in the second column

White text indicates the portion of the dot point covered by other sections

**Curriculum**

**Area of Study 1 Outcome 1**
**Cellular structure and function**

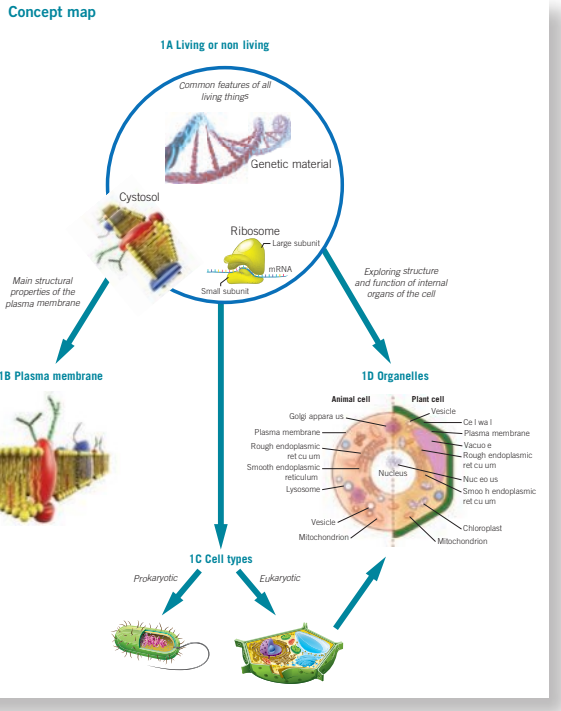
| Study Design | Learning intentions – at the end of this chapter I will be able to: |
|---|---|
| • Cells as the basic structural feature of life on Earth, including the distinction between prokaryotic and eukaryotic cells | **1A** **Living or non-living**<br>**1A.1** Recall the four common factors for all organisms<br>**1A.2** Define the following key terms: abiotic, biotic, multicellular, unicellular<br>**1A.3** Outline the functions of the four common factors for an organism |

Learning intentions are turned into Success Criteria (achievement standards) at the end of the chapter and are assessed in the Chapter review and tracked in the Checklists

Relevant Study Design dot points are repeated at the start of each section in the chapter, and an overall curriculum grid is provided in the teacher resources.

### Concept maps

Concept maps display each chapter's structure with annotations emphasising interconnectedness, providing a great memory aid. The versions in the ITB are hyperlinked and offer an alternative way of navigating through the course. An overall concept map of Units 1&2 is also provided after this overview.




### Links

The interconnectedness of topics in Biology is demonstrated through links between sections, displayed in the margins. In the ITB, these are hyperlinks that provide an alternative way of navigating through the course.

2D ROLE OF CHLOROPLASTS AND MITOCHONDRIA LINK

**Comparison of plant and animal cells**

Plant cells and animal cells have many organelles in common, but there are some differences (Figure 1D–4).

A misconception is that plant cells only perform photosynthesis and do not respire. In fact, plant cells perform both photosynthesis and aerobic cellular respiration, and so a plant cell has both mitochondria and chloroplasts. Not all the cells in a plant photosynthesise (e.g. root cells do not photosynthesise), but they do all respire. In contrast, animal cells do not have any chloroplasts, and do not photosynthesise.

ISBN 978-1-108-88711-3

## Chapter sections

Chapters are divided into numbered sections each with a consistent set of features.

## Engage

At the start of each section, these boxes provide points of interest for the topic emphasising its place in Biology. This material, though not assessable, can be used as examples of applications.

## Explain

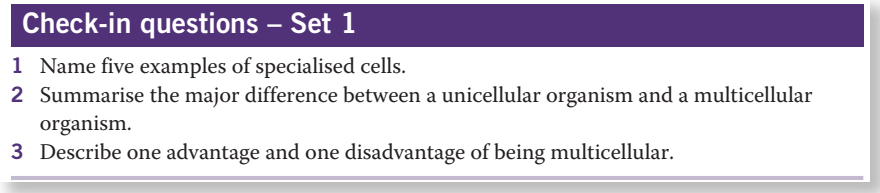
This icon marks the start of essential content that is assessed.

## Glossary

Scientific terms are highlighted in the text, definitions are given in the margin of the print and PDF textbooks, or on mouseover in the ITB, and the terms are listed at the start of each chapter and section.

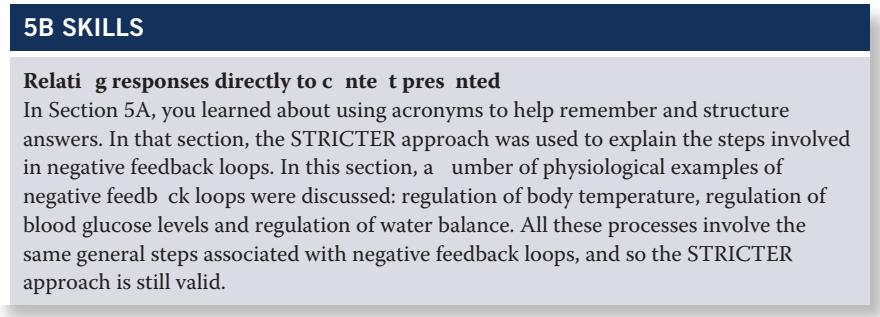

## Check-in questions

Each section in the chapter has one or more sets of check-in questions, for formative assessment. Full answers are provided in the digital resources.



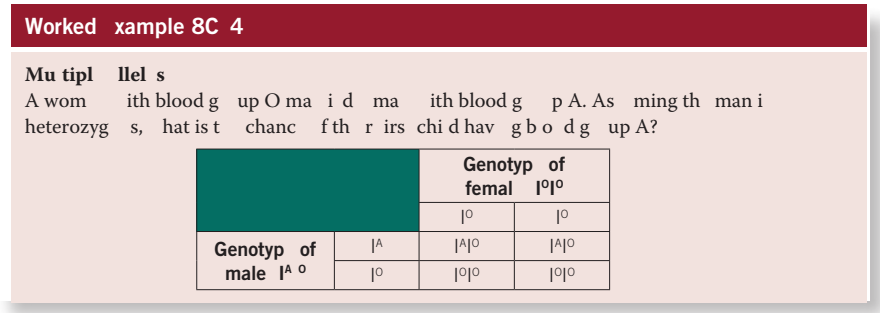

## Skills

Skills boxes in every section provide advice and guidance on how to answer and prepare for questions, especially in examinations. The ITB has video versions of these guided by experienced teachers which provide extra comments and an alternative medium of delivery.




## Worked examples

Worked examples are provided for questions requiring computation; for example, in genetics.




ISBN 978-1-108-88711-3

## Charts, diagrams and tables

Detailed charts integrating text and diagrams, and illustrated tables, feature throughout the print books. In the ITB, most of these are available as animated slide-show presentations for students to use, with copies for teachers to display on data projector or whiteboard.

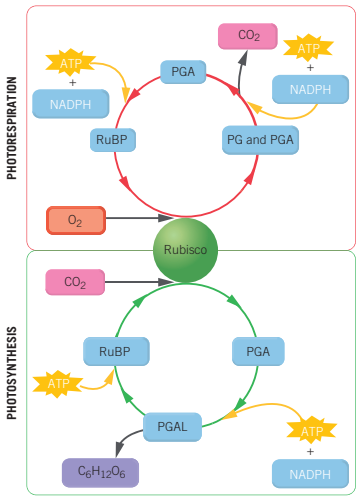



**Figure 5B–6** A comparison of the Calvin-Benson cycle in photosynthesis (when Rubisco binds to $CO_2$) and photorespiration (when Rubisco binds to $O_2$)

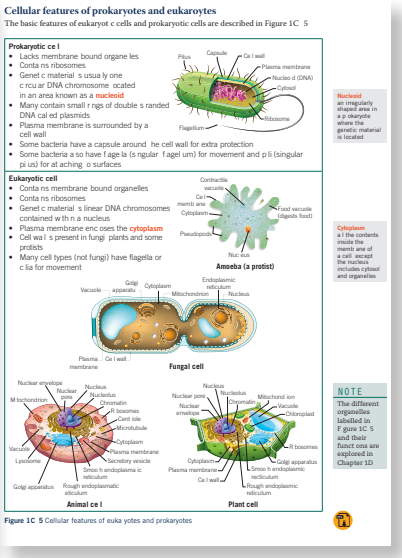



**Figure 1C 5** Cellular features of eukaryotes and prokaryotes

## Section questions

Summative assessment is provided at the end of each section, again with full answers provided in the digital resources.

### Section 5B questions

1 What two hormones are involved in the maintenance of blood glucose homeostasis? Explain the action of both of these in the circumstances when they are required.
2 What property of proteins makes body temperature homeostasis particularly important?

## Chapter reviews

**Summaries:** Students are encouraged to make their own set of summary notes, to help them assimilate the material. Model summaries are provided in the teacher resources, to be given to those who need help. Creating summaries can also be turned into an assessment task, with the models serving as the answer.

**Checklists** and **Success criteria:** The learning intentions from the front of the chapter are listed again in the form of success criteria linked to the **multiple-choice** and **short-answer questions** that follow. The checklists are printable from the ITB, and students can tick off their achievement manually. If they do the questions in the ITB, they are ticked automatically when the questions are marked.

### Chapter 5 review

#### Summary

Create your own set of summary notes for this chapter on paper or in a digital document. A model summary is provided in the Teacher Resources which can be used to compare with yours.

#### Checklist

In the Interactive Textbook, the success criteria are linked from the review questions and will be automatically ticked when answers are correct. Alternatively, print or photocopy this page and tick the boxes when you have answered the corresponding questions correctly.

| Success criteria – I am now able to: | | Linked question |
|---|---|---|
| 5A.1 | Recall the five stages of a stimulus–response model | 9 ☐ |
| 5A.2 | Describe the stimulus–response model | 9 ☐ |

#### Multiple-choice questions

1 Which hormone is responsible for lowering blood glucose levels?
A glucagon
B glycogen
C TSH
D insulin

2 Which of the following is a response to an increase in body temperature?
A shivering
B thirst

3 The objective of homeostasis is best defined as
A maintaining levels within a constant range.
B maintaining levels at a constant value.
C increasing levels that are too low.
D decreasing levels that are too high.

4 Which of the following processes is about maintaining water balance in animals?
A transpiration
B perspiration

#### Short-answer questions

11 You are working as a doctor, when a woman comes in presenting with bulging eyes. You immediately suspect that she might have Graves' disease.
a First, you tell her your suspicions. What type of disease would you tell her Graves' disease is? (1 mark)
b Second, you explain to her what the normal process is for the regulation of thyroid hormones in her body. What type of mechanism maintains homeostatic levels of these hormones? (1 mark)
c Would treating this woman with synthetic TSH be appropriate? Explain. (2 marks)

## Unit revision exercises

Each Unit has a revision exercise in the print book, with both multiple-choice and short-answer questions.

ISBN 978-1-108-88711-3

## Special content

Two aspects are highlighted here:

- **Chapter 6 Scientific Investigations** features modelling of logbook development for students' own practical investigations, with detailed examples.

VIDEO 6A–1 LOGBOOK EXAMPLE

**Title**
the research question under investigation; includes information about what is being tested

**Introduction**
a detailed but succinct explanation of the reason for undertaking an investigation; includes key biological concepts, aim and hypothesis

*Logbook*

**Title**

1 What temperature do enzymes work at?

2 What is the optimal temperature for the enzyme catalase to break down hydrogen peroxide into oxygen and water?

**Introduction**

1 Enzymes are essential to help reactions proceed more efficiently, in order to sustain life. They are made of proteins, which are coded for by an organism's DNA, and they are specific to the substance they act on.

2 The enzyme catalase reacts with the substrate hydrogen peroxide ($H_2O_2$), breaking it down into water and oxygen (products) in a catabolic reaction. Catalase is primarily found in the liver and is important in protecting the organism from damage caused by hydrogen peroxide, which is constantly produced by mammals.

**Notes**
The title should include reference to the variables being changed (independent variable) and measured (dependent variable), along with enough detail for the reader to decide whether they want to continue reading.

In the introduction (to a poster) it can also be appropriate to present a labelled diagram of the concept/idea being investigated.

- **Chapter 7 Reproduction** includes Aboriginal and Torres Strait Islander peoples' knowledge and perspectives in understanding adaptations of species and their interdependence, with examples, and guidance for student activities.

**Indigenous**
the original or earliest known inhabitants of an area; also referred to as First Peoples or First Nations

1A LIVING OR NON-LIVING LINK

### Aboriginal and Torres Strait Islander knowledge and perspectives in understanding adaptations

While modern scientific studies have helped us better understand how organisms adapt to their environment, much of this knowledge has existed within **Indigenous** cultures for a very long time.

Aboriginal and Torres Strait Islander peoples' knowledge and perspectives in understanding adaptations of species come from a variety of cultures some of which date back over 60 000 years. This understanding is based on observations of their environment, both abiotic and biotic factors, and experience of what is needed by humans, plants and animals to survive in Australian environments.

Today, knowledge of plant and animal adaptations to habitat and season is still essential for finding food and materials in Australian environments. Knowing likely places and times to hunt kangaroos, collect bogong moths and gather certain fruits are essential for survival, and Aboriginal and Torres Strait Islander peoples completed this for thousands of years. In the context of life on Earth, this makes them very successful.

**Figure 7C–9** An Aboriginal elder on Cave Hill, Pitjantjatjara Community, Central Australia pointing out features of the landscape

This knowledge of the adaptations of plants and animals has not just been u ed for hunting and gathering. In recent decades, researchers have found, through sources such as Aboriginal and Torres Strait Islanders oral histories, archaeological evidence and early colonists' records, that Aboriginal and Torres Strait Islander peoples used their knowledge to manage the land, till the soil, sow seeds and harvest crops. They managed, and continue to manage, the land, encouraging animals to populate certain areas where they may be hunted sustainably, constructing weirs and traps on waters to sustainably harvest eels, fish and other aquatic life, and using fire to create beneficial ecosystems.

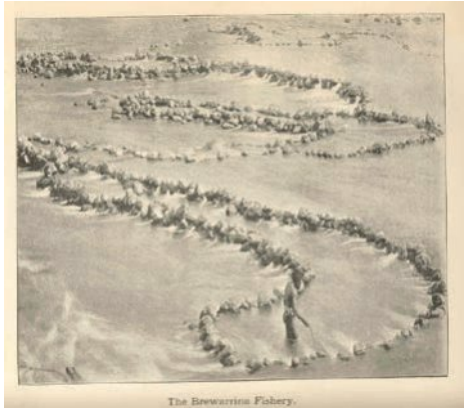



**Figure 7C–10** The Brewarrina fish traps on the Barwon River in New South Wales are an example of Aboriginal Australian aquaculture. They are a series of dry-stone weirs and ponds arranged across the river to create fish traps, where fish were herded into the ponds and the openings quickly shut with a few rocks. The walls of the traps are different heights, allowing them to be used at different water levels. According to the Dreaming an ancestral being called Baiame, threw his net across the Barwon, creating their design. The place is extremely significant to the Aboriginal people of Western and Northern NSW for whom it is imbued with spiritual, cultural, traditional and symbolic meanings.

ISBN 978-1-108-88711-3



## Interactive Textbook features


The digital version of the textbook is hosted on the Edjin platform, offering easy navigation, excellent on-screen display and multimedia assets, as well as auto-marking of multiple-choice questions, and workspaces for other questions with self-assessment and confidence rating tools. The different kinds of digital assets are listed below and are accessed by:

- Printable **Worksheets** with extra questions and activities (and content in some cases) are provided for most chapters, marked by an icon in the margin, as shown on the right.

WORKSHEET 1A–1 LIVING OR NON-LIVING?

- **Videos** are provided for all chapters, and are of two kinds: **concept videos** demonstrate or illustrate important theory, while **skills and example videos** feature experienced teachers working through the textbook's skills and example boxes, providing extra explanation and guidance. Some videos are provided in the print pages as QR codes for immediate access and review.

VIDEO 3A–1 SKILLS: DIFFERENTIATION OF GERM LAYERS

- **Animated slide-show presentations** (in PowerPoint Show format) are provided of many charts, diagrams and tables, as marked by an icon in the margin as shown at right, enabling them to be explored interactively.
- **Answers** (worked solutions) to questions are provided in pop-up windows next to the questions, or in printable PDFs for use with the print textbook.
- **Prior knowledge** can be tested with an auto-marked quiz with questions from the Year 9 and 10 *Cambridge Science for the Victorian Curriculum*.

## Online Teaching Suite features (teacher resources)

The OTS provides Edjin's learning management system, which allows teachers to set tasks, track progress and scores, prepare reports on individuals and the class, and give students feedback. The assets include:

- **Curriculum Grid** and **teaching programs**
- Editable and printable **Chapter tests** with answers
- **Checklists** with linkage to the success criteria for the chapter question sets and tests
- A **question bank** and test generator, with answers
- **Practice exams** and **assessment tasks**, with answers
- Editable versions of **Worksheets** in the Interactive Textbook, and answers to them
- Editable versions of the PowerPoint files in the Interactive Textbook
- Downloadable, editable and printable **practicals**
- Editable and printable chapter **summaries** (model answers for the chapter summary activity)
- **Teacher notes** on selected content with additional theory explanation and suggestions for further activities and resources
- **Curated links** to internet resources such as videos and interactives.

**cambridge.edu.au/education/vcescience**

ISBN 978-1-108-88711-3

# Acknowledgements

The authors and publishers wish to thank the following people for help and advice in preparing this resource:

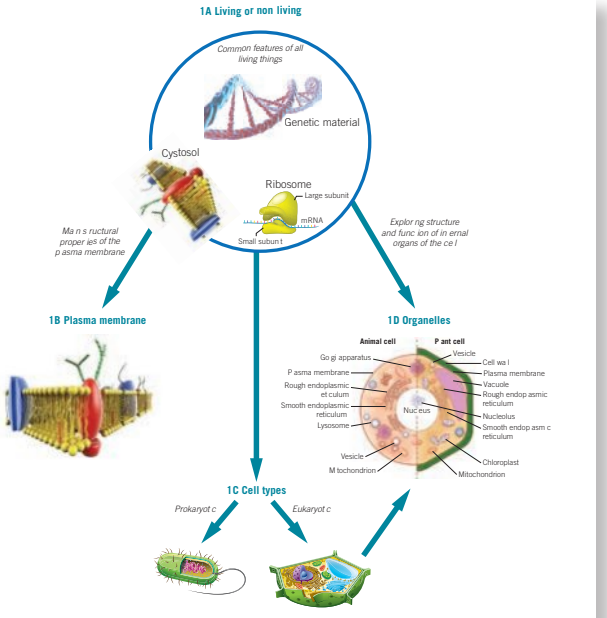
- Dr Kaye Price AM for advice on Aboriginal and Torres Strait Islander knowledge and perspectives
- Joe Sambono, Curriculum Specialist Aboriginal and Torres Strait Islander Priority and Science Curriculum, Australian Curriculum, Assessment and Reporting Authority, for providing links to resources and references
- Harry Leather and Jan Leather, authors of *Cambridge Checkpoints VCE Biology Units 1&2* for advising on aspects of the resource.

ISBN 978-1-108-88711-3

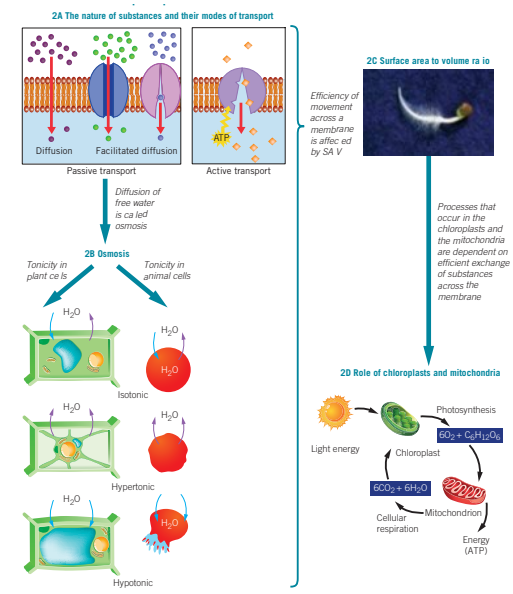
# Concept map for Units 1&2

This spread displays the concept maps for topics Chapters 1–5 and 7–9. (Chapter 6 Scientific investigations is not included as it covers skill development rather than topics.) Access the digital version of this concept map in the ITB to zoom in on the details and click on hyperlinks to explore the interconnections of the topics.

## Chapter 1 Cellular structure

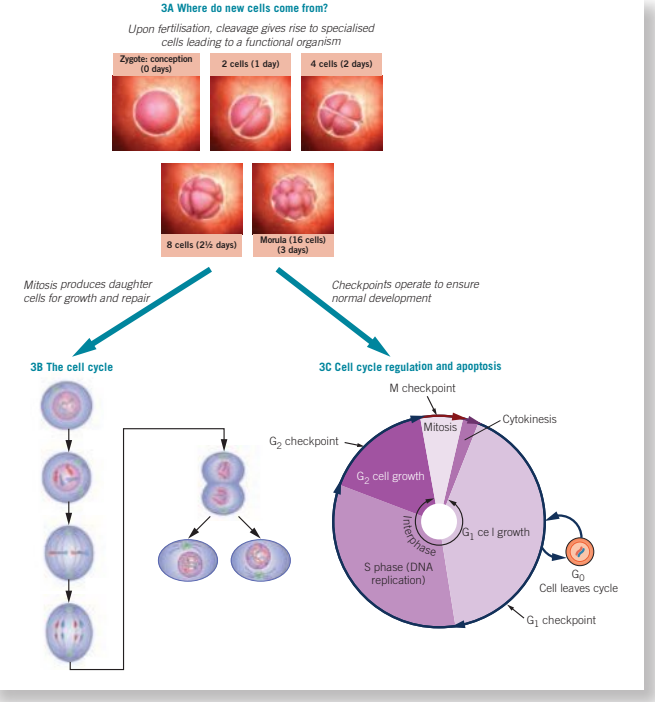



## Chapter 2 Cellular functioning

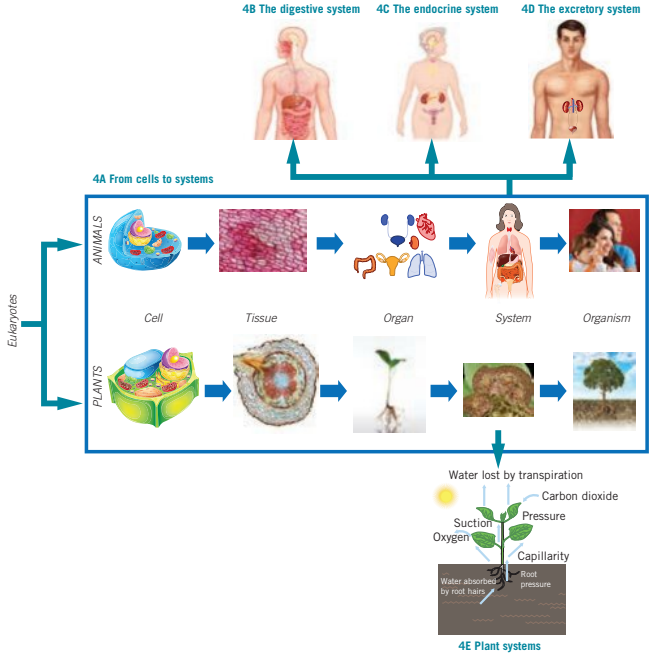



See the Interactive Textbook for an interactive version of this concept map interlinked with all concept maps for the course, and for a quiz of prior knowledge from Years 9 & 10 science

## Chapter 3 Cellular regeneration and regulation

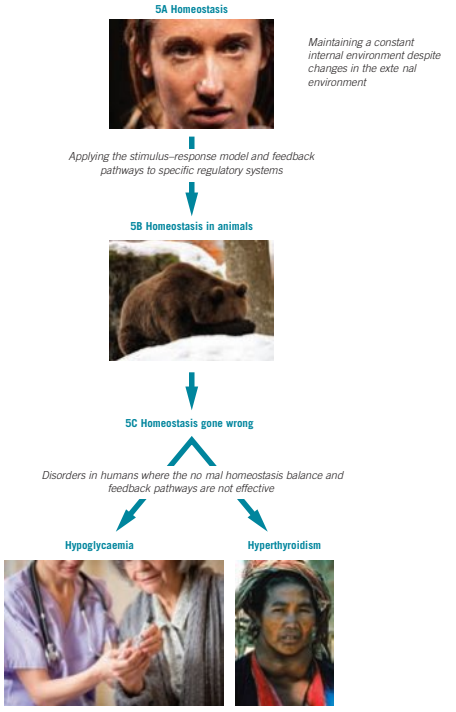



## Chapter 4 Functioning systems

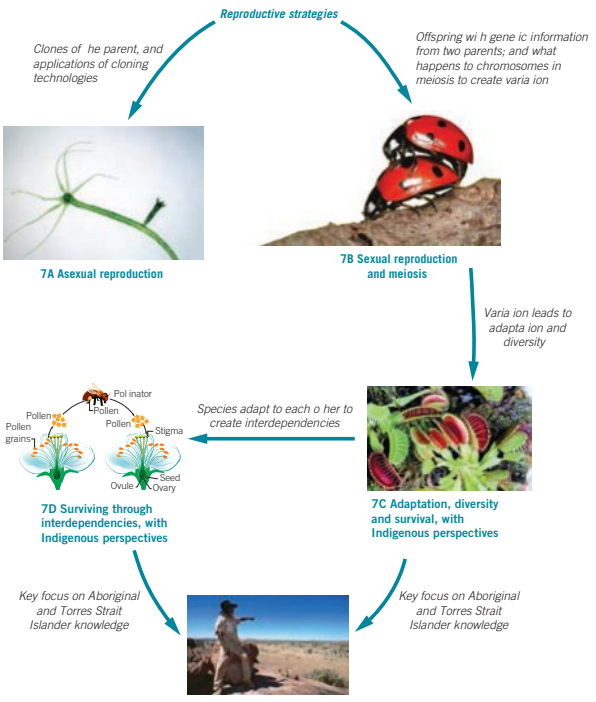



ISBN 978-1-108-88711-3

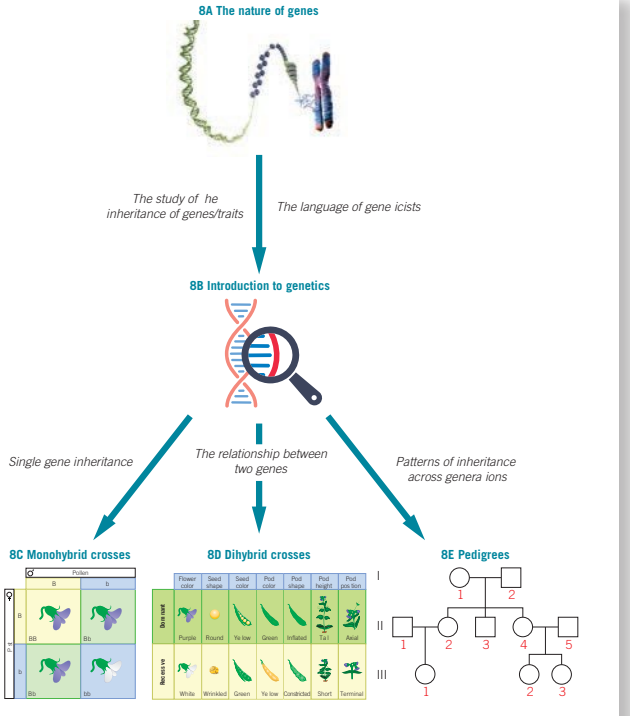
## Chapter 5 Regulation of systems



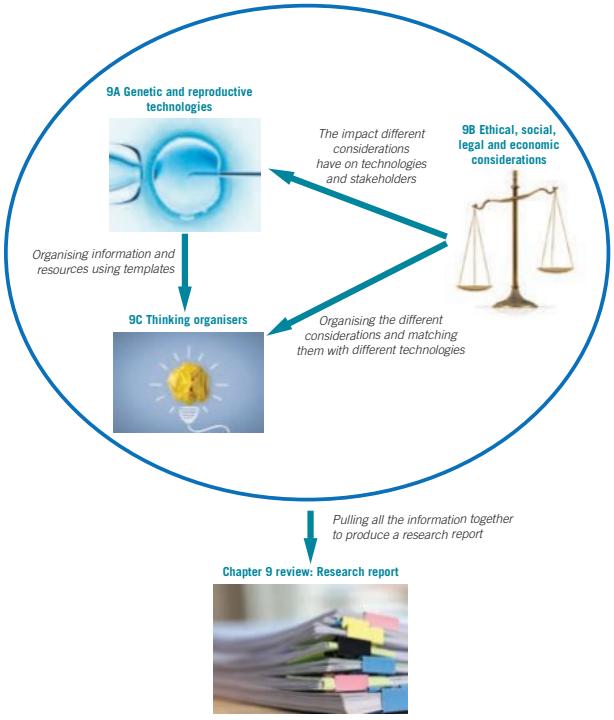

## Chapter 7 Reproductive strategies, adaptations and diversity




## Chapter 8 Inheritance




## Chapter 9 Research task strategies




ISBN 978-1-108-88711-3

UNIT 1

# HOW DO ORGANISMS REGULATE THEIR FUNCTIONS?

CHAPTER 1

# CELLULAR STRUCTURE

## Introduction

Cells are the basic structural feature of life on Earth. All cells have four features: genetic material, plasma membrane, cytosol and ribosomes. Understanding the structural components of cells will enable you to understand how different substances are processed within each cell. The plasma membrane controls what enters or leaves the cell, and this function is vital in maintaining the concentrations of reactants and products that enable the cell, and the organism, to function.

Prokaryotes and eukaryotes are the two main cell types, and being able to distinguish between them is an important skill. Plants and animals are the two main groups of eukaryotic organisms. Specialised structures within each cell are known as organelles, and in this chapter you will explore the structure and function of each type of organelle.

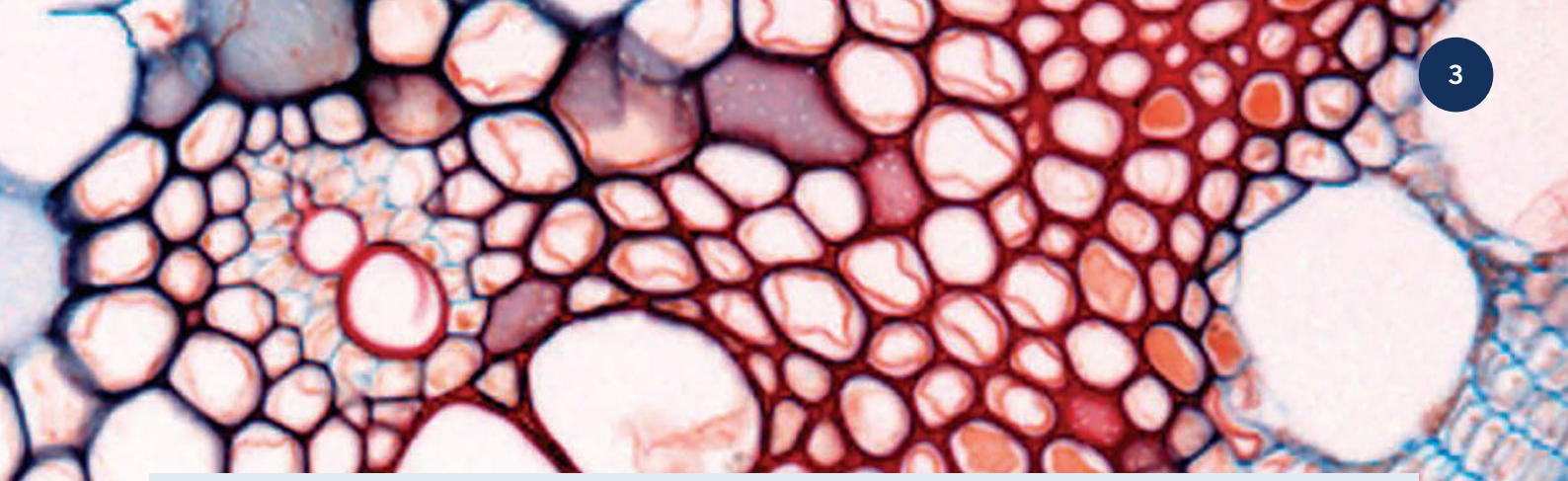
The Interactive Textbook includes a worksheet, which discusses how to look at cells by using a light microscope and how to represent cells using scientific drawings.

## Curriculum

**Area of Study 1 Outcome 1**
**Cellular structure and function**

| Study Design | Learning intentions – at the end of this chapter I will be able to: |
|---|---|
| • Cells as the basic structural feature of life on Earth, including the distinction between prokaryotic and eukaryotic cells | **1A Living or non-living**<br>**1A.1** Recall the four common factors for all organisms<br>**1A.2** Define the following key terms: abiotic, biotic, multicellular, unicellular<br>**1A.3** Outline the functions of the four common factors for an organism |
| • The structure and function of the plasma membrane in the passage of water, hydrophilic and hydrophobic substances via osmosis, facilitated diffusion and active transport | **1B Plasma membrane**<br>**1B.1** Recall and define the following key terms: fluid mosaic model, hydrophilic, hydrophobic, plasma membrane and semi-permeable membrane<br>**1B.2** Recall and define the functions of the different components of the plasma membrane<br>**1B.3** Identify the different components of a plasma membrane<br>**1B.4** Draw a plasma membrane, including the identification of the different components<br>**1B.5** Use evidence from a diagram to explain answers about the structure of the plasma membrane |

ISBN 978-1-108-88711-3



| Study Design | Learning intentions – at the end of this chapter I will be able to: |
|---|---|
| • Cells as the basic structural feature of life on Earth, including the distinction between prokaryotic and eukaryotic cells | **1C Cell types**<br>**1C.1** Recall and define the following key terms: eukaryote, nucleoid, prokaryote<br>**1C.2** Outline the cellular features for a eukaryote and a prokaryote<br>**1C.3** Draw a prokaryote, including the identification of its cellular features<br>**1C.4** Identify whether a cell is a eukaryote or a prokaryote, based on its cellular features |
| • 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<br>• The structure and specialisation of plant and animal cell organelles for distinct functions, including the chloroplast and mitochondria | **1D Organelles**<br>**1D.1** Recall and define the following key terms: cell wall, chloroplast, cilia, flagella, Golgi apparatus, lysosome, mitochondrion, nucleus, organelle, ribosome, rough endoplasmic reticulum, smooth endoplasmic reticulum, symbiosis, vacuole, vesicle<br>**1D.2** Identify the organelles present in a plant and an animal cell<br>**1D.3** Describe what compartmentalisation is<br>**1D.4** Explain the importance of compartmentalisation for cells<br>**1D.5** Draw animal and plant cells, including the identification of organelles<br>**1D.6** Compare the structures of plant cells and animal cells<br>**1D.7** Explain what organelles would be present in different cell types so that the cell can perform its particular function |

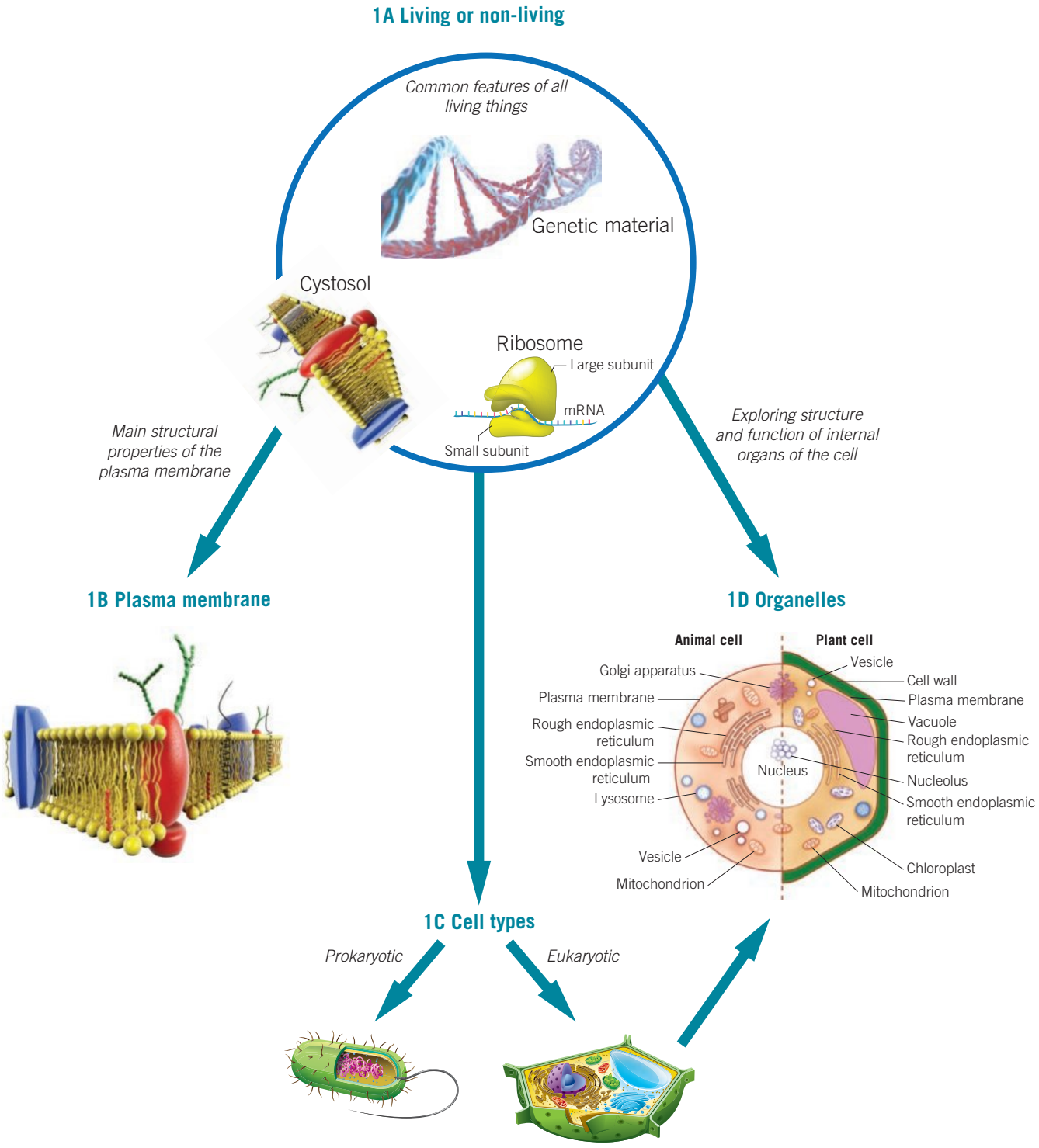


## Glossary

Abiotic
Biotic
Cell theory
Cell wall
Chloroplast
Cilia
Cytoplasm
Cytosol
Endosymbiosis
Eukaryote
Flagella
Fluid mosaic model
Golgi apparatus
Hydrophilic
Hydrophobic
Lysosome
Mitochondrion
Multicellular
Nucleoid
Nucleus
Organelle
Organism
Plasma membrane
Prokaryote
Ribosome
Rough endoplasmic reticulum
Semi-permeable membrane
Smooth endoplasmic reticulum
Symbiosis
Unicellular
Vacuole
Vesicle

ISBN 978-1-108-68711-3

## Concept map




*See the Interactive Textbook for an interactive version of this concept map interlinked with all concept maps for the course, and for a quiz of prior knowledge from Years 9 & 10 science.*

ISBN 978-1-108-88711-3

# Living or non-living

**Study Design:**
Cells as the basic structural feature of life on Earth, including the distinction between prokaryotic and eukaryotic cells

**Glossary:**

| | | |
|---|---|---|
| Abiotic | Cytosol | Plasma membrane |
| Biotic | Multicellular | Ribosome |
| Cell theory | Organism | Unicellular |

## ENGAGE

### The largest living things

What is the biggest **organism** on Earth? Did you think of a blue whale? A blue whale (Figure 1A–1) can grow to 30 metres long, and consists of about 100 quadrillion cells. Compare this to an elephant's 1000 trillion (or 1 quadrillion) cells, and a human's 37.2 trillion cells.

**Organism**
an individual that is living (biotic)

In fact, none of these examples is the biggest organism on Earth. The biggest is a fungus, *Armillaria*, commonly known as honey fungus (Figure 1A–2). The honey fungus is known to stretch up to 3.8 km across the Blue Mountains in Oregon, in the United States.

**Figure 1A–1** The blue whale, a multicellular organism

**Figure 1A–2** Honey fungus, the largest multicellular organism

The examples given so far are **multicellular** organisms. But what is the biggest **unicellular** organism? An aquatic alga called *Caulerpa taxifolia* (Figure 1A–3) is unicellular, and can grow up to three metres long.

**Figure 1A–3** The aquatic alga *Caulerpa taxifolia* is unicellular.

**Multicellular**
made up of more than one cell

**Unicellular**
made up of only one cell

ISBN 978-1-108-88711-3

## EXPLAIN

An organism is defined as something that is living. But how do you know whether something is living or not? In junior science, you learned the acronym MRSGREN (movement, reproduction, sensitivity, growth, respiration, excretion, nutrition). In VCE Biology, different criteria are used to distinguish between living and non-living. The terms **biotic** (living) and **abiotic** (not living) are used.

**Biotic**
living; made up of at least one cell

**Abiotic**
not living

**Cell theory**
the theory that living (biotic) things are made up of at least one cell, and that these cells are the basic unit of life and came from pre-existing cells

An organism is made up of at least one cell. The cell is the basic unit of life, and every cell comes from a pre-existing cell. This is known as **cell theory**.

The cells of plants, animals, bacteria and amoebas all have the following four common factors (Figure 1A–4):

- genetic material
- cytosol
- ribosomes
- a plasma membrane.

WORKSHEET 1A–1 LIVING OR NON-LIVING?

**Cytosol**
the liquid inside a cell, between the organelles (doesn't include the organelles)

**Ribosome**
a non-membrane-bound organelle involved in synthesis of proteins

**Plasma membrane**
a membrane made up of two layers (known as a bilayer) of phospholipids that encloses the contents of a cell

**Table 1A–1** Common factors for all organisms

| Feature | Function |
|---|---|
| Genetic material | Contains hereditary information, containing genes that code for proteins |
| **Cytosol** | The liquid inside cells. Consists of 80% water, salts and organic molecules. The site of many cellular reactions |
| **Ribosome** | Site of protein synthesis |
| **Plasma membrane** | Separates the interior and exterior environments, selecting what enters and leaves the cell |

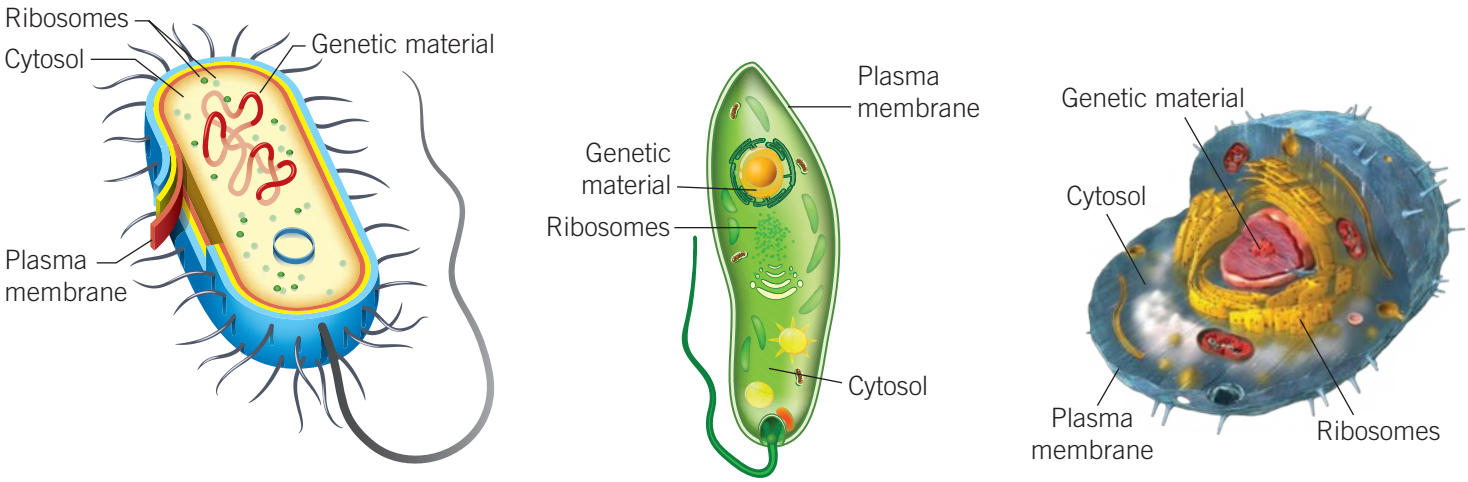



**Figure 1A–4** Different types of cells all contain four common factors.

VIDEO 1A–1 CELL TYPES AND THEIR FOUR COMMON FACTORS

## Check-in questions – Set 1

1 Define 'organism'.
2 Which of the following are biotic? Explain your answer.
bones, the Sun, water, the ocean, vegetables that have been picked
3 What is the function of the cytosol?

ISBN 978-1-108-88711-3

## 1A SKILLS

VIDEO 1A–2
SKILLS: BUILDING A GLOSSARY

**Building a glossary**

In studying Biology, you are required to remember, apply and explain many terms. Before you start applying new terms, you need to understand them. A strategy to achieve this is creating a glossary of your own, which will sharpen your skills in defining terms.

To *define* is to state the precise nature or function of something. For example:

> *Question*: Define 'biotic'.
>
> *Answer*: Living

You can elaborate on your response by explaining what 'living' means in a biological setting.

> *Improved answer*: 'Biotic' means living. A living thing consists of at least one cell, which has a plasma membrane, genetic material, ribosomes and cytosol.

In both these instances, the *define* response does not go into detail with an example. It simply explains what the term means, in the correct context.

Even if the answer is a single word, it can require you to use your understanding, as shown in this example:

> *Question*: Provide an example of a biotic factor essential for the survival of a blue whale.
>
> *Answer*: Krill

This answer requires an understanding of what 'biotic' means, and that the term does not include other things that are also essential for survival, such as oxygen, which is an abiotic factor.

To start creating your own glossary, you can use the highlighted glossary terms in this textbook or download the online document, which has a list of key terms for each chapter.

## Section 1A questions

1. Recall the four cell features common to all organisms.
2. State the function of each of the four common cell features.
3. Define 'abiotic'.
4. Compare an abiotic factor with a biotic factor.
5. Is the bark in the image on the right biotic or abiotic?
6. Provide at least three examples of abiotic and biotic factors that affect the survival of an apple tree.
7. Recall the cell theory.

ISBN 978-1-108-88711-3


# Plasma membrane

**Study Design:**
The structure and function of the plasma membrane in the passage of water, hydrophilic and hydrophobic substances via osmosis, facilitated diffusion and active transport

**Glossary:**
Fluid mosaic model
Hydrophilic
Hydrophobic
Semi-permeable membrane

## ENGAGE

### Separating internal and external

The *plasma membrane* (also known as the *cell membrane*) acts as a boundary between the internal environment of a cell and its external environment. Figures 1B–1 and 1B–2 illustrate how the plasma membrane helps to determine the two different environments. Without a plasma membrane a cell would not exist, because the survival of the cell depends on how substances are exchanged between the internal and external environments. Remember that a plasma membrane is one of four common features of all cell types.

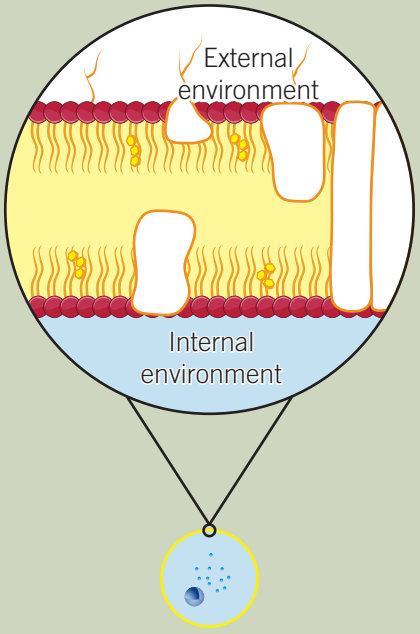



**Figure 1B–1** Zoomed-in diagram of a cross-section of a cell membrane, showing the internal and external environments

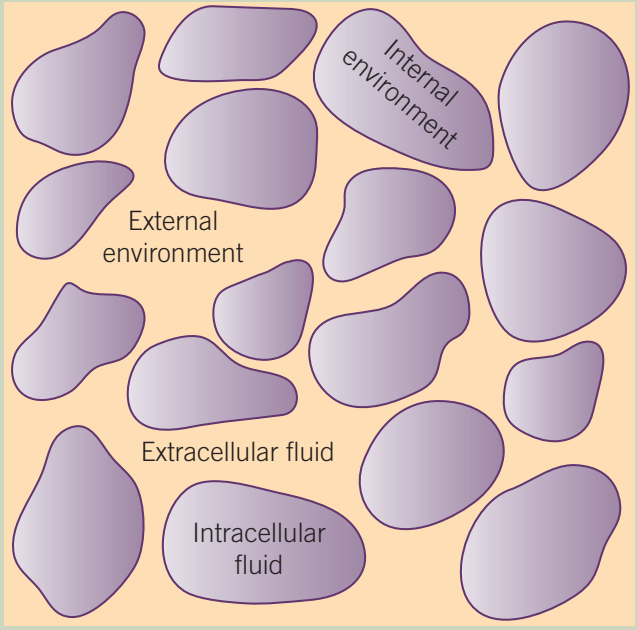
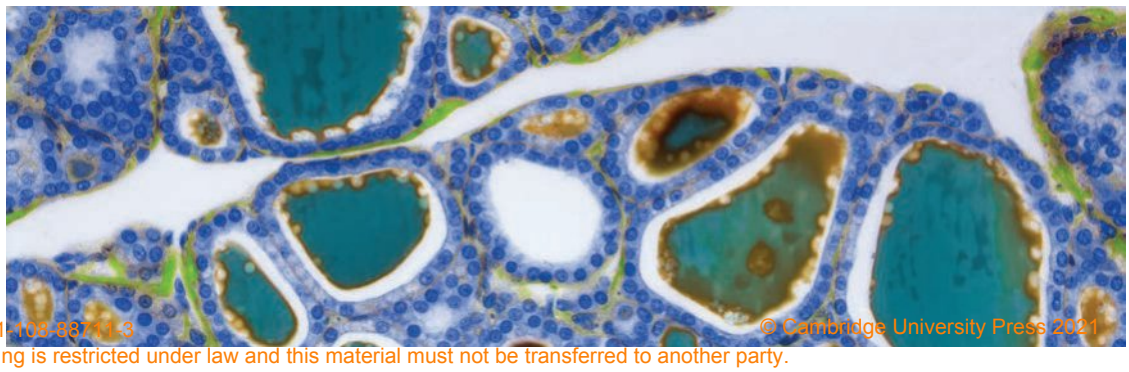



**Figure 1B–2** Simplified diagram of several cells, showing the internal, or intracellular (within each cell), and external, or extracellular (between cells), environments



ISBN 978-1-108-88711-3

## EXPLAIN

# Structure and function of the plasma membrane

The *structure* of the plasma membrane relates to its *function* and the type of cell it is in. The plasma membrane is a **semi-permeable membrane** that allows substances to be transported between the internal and external environments of the cell (Figure 1B–3). It consists of a phospholipid bilayer, proteins, carbohydrates and cholesterol.

**Semi-permeable membrane**
a membrane that only lets certain substances cross it; also called partially permeable, differentially permeable or selectively permeable

The functions of the plasma membrane include but are not limited to:

- recognising other cells when forming tissue, or determining whether cells are foreign during an immune response
- communicating with other cells
- selectively controlling which substances are transported into or out of the cell.

The process of transporting substances across the plasma membrane is explored in detail in Chapter 2.

LINK UNIT 4

LINK 2A THE NATURE OF SUBSTANCES AND THEIR MODES OF TRANSPORT

LINK 2B OSMOSIS

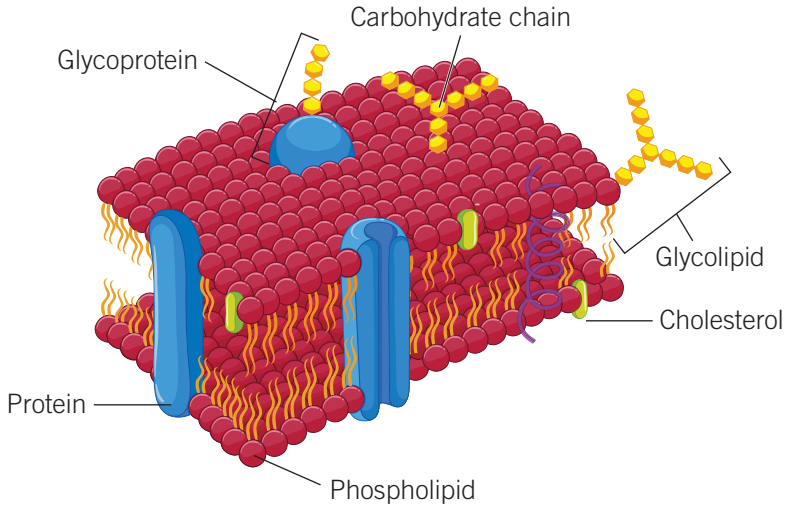
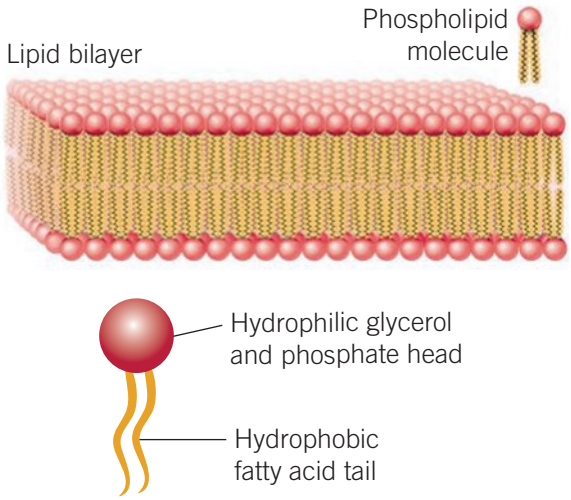


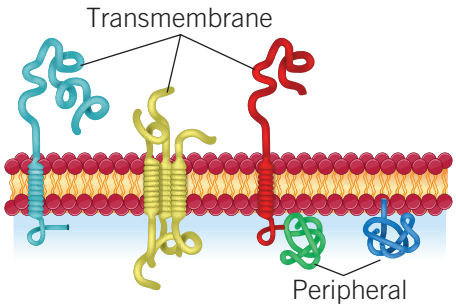
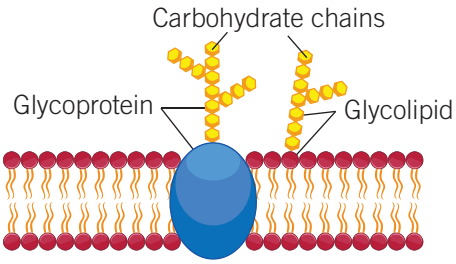
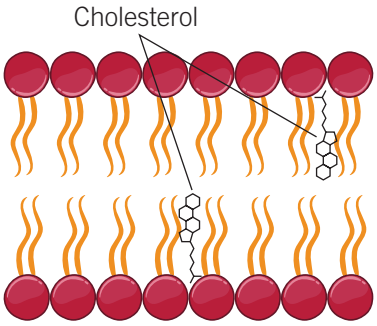

**Figure 1B–3** Structure of the plasma membrane

**Table 1B–1** Components of the plasma membrane

| Component | Diagram | Description |
|---|---|---|
| Phospholipids |   | Phospholipids are arranged in two layers, with their hydrophilic (water-attracting) glycerol and phosphate heads facing outwards, towards both the intra- and extra-cellular environments. The hydrophobic (water-repelling) fatty acid tails face inwards, towards each other. |

ISBN 978-1-108-88711-3

**Table 1B–1** *Continued*

| Component | Diagram | Description |
|---|---|---|
| Proteins |  | Proteins play a variety of roles including transport, signalling and cell-to-cell recognition. When they span the width of the membrane, they are called transmembrane proteins. When present on only one side of the membrane, they are called peripheral proteins. |
| Carbohydrates |  | Carbohydrates play a role in adhesion between cells and in cell recognition. When a carbohydrate is attached to a protein, it is called a glycoprotein. When a carbohydrate is attached to the head of a phospholipid, it is called a glycolipid. |
| Cholesterol |  | Cholesterol helps to increase the stability of the plasma membrane without affecting the membrane's fluidity (ability to move). |

**Hydrophobic** does not dissolve readily in water; also called lipophilic

The phospholipid bilayer is arranged with the **hydrophobic** (water-repelling) tails facing inwards and the **hydrophilic** (water-attracting) heads on the outsides of the membrane, towards the watery internal and external environments. Because the plasma membrane is made up of phospholipids, it is able to selectively allow different substances to enter and leave the cell. Water-soluble (hydrophilic) substances need the assistance of a protein channel to cross the phospholipid part of the membrane. Lipid-soluble (hydrophobic) substances are able to cross through the phospholipids of the plasma membrane.

**2A** THE NATURE OF SUBSTANCES AND THEIR MODES OF TRANSPORT LINK

**Hydrophilic** dissolves easily in water; also called lipophobic

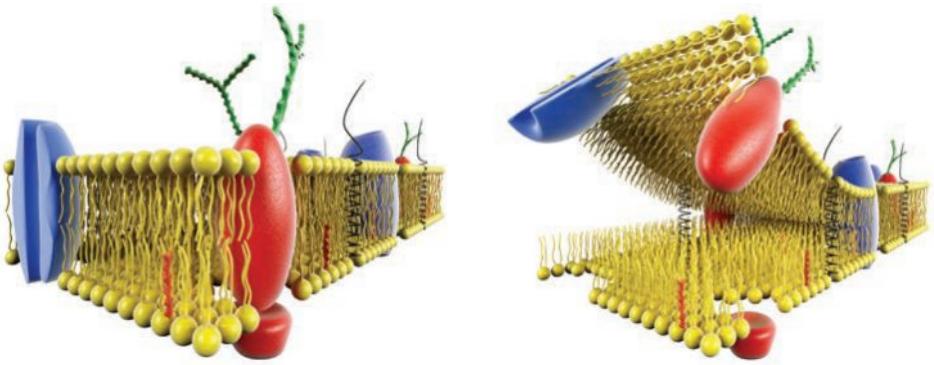


**Figure 1B–4** Plasma membrane with the same components as Figure 1B-3, shown intact (left) and with the two layers of phospholipids separated (right)

ISBN 978-1-108-88711-3

## Check-in questions – Set 1

1 What does the plasma membrane divide or separate (what is on either side of it)?
2 List the key components of a plasma membrane.
3 Which part of the plasma membrane is hydrophilic?

## Fluid mosaic model

A plasma membrane is made up of different types (a mosaic) of molecules. It is also fluid – that is, the phospholipids and proteins are able to move around within each layer. Referring to plasma membranes in this way is known as the **fluid mosaic model** (see Figure 1B–4 on the previous page).

**Fluid mosaic model** a model that represents the plasma membrane as a combination (mosaic) of phospholipids, proteins, cholesterol and carbohydrates that gives the membrane its fluid nature

Recall that a phospholipid consists of a head and two tails, and the tails consist of fatty acids. If these fatty acids only have single bonds between the carbon atoms (i.e. they are 'saturated'), then they can pack together tightly. If the fatty acids have some double bonds between carbon atoms ('unsaturated'), then they pack together less tightly. If there are unsaturated fatty acids in the tails, they have some double bonds between carbon atoms and this makes them pack together less tightly. So more unsaturated fatty acids in the tails of the phospholipids increases the fluidity of the plasma membrane (Figure 1B–5).

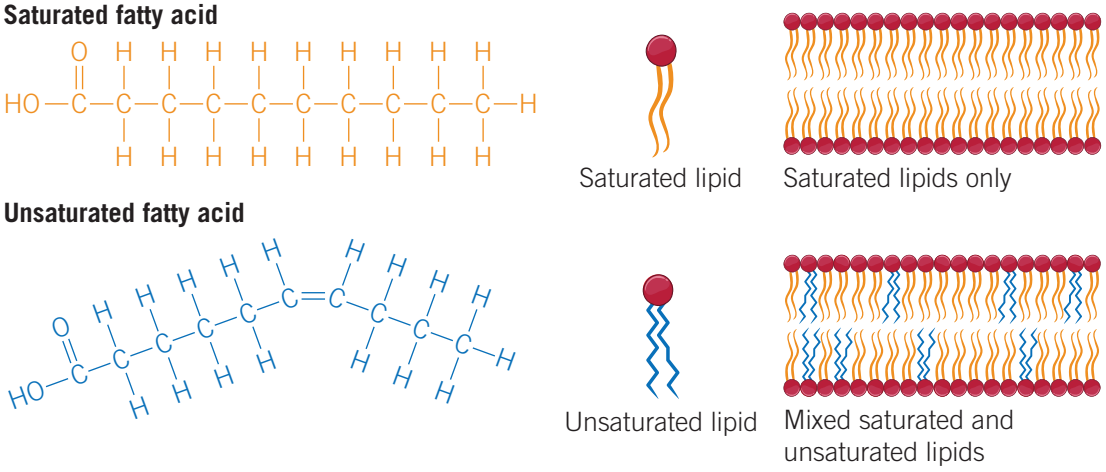



**Figure 1B–5** Double bonds between carbon atoms in unsaturated fatty acids cause the carbon chain to kink. The presence of unsaturated lipids in the bilayer increases the fluidity (elasticity) of the plasma membrane.

**VIDEO 1B–1** THE PLASMA MEMBRANE

## 1B SKILLS

### The difference between 'identify' and 'explain'

The ability to identify the components of a plasma membrane is a key skill. It is important that you become familiar with a variety of representations of the plasma membrane, as different diagrams can be used during an assessment.

Figure 1B–6 is a representation of a plasma membrane. If the question asks you to *identify* some or all of the components, be succinct and specific. If the question asks you to *explain*, this is the time to elaborate on your answer.

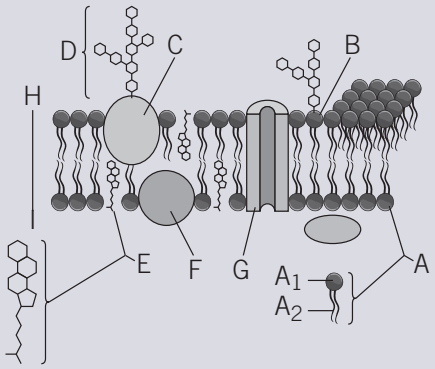



**Figure 1B–6** Unlabelled diagram of a plasma membrane. You should be able to identify all the components shown.

**VIDEO 1B–2** SKILLS: DIFFERENCE BETWEEN 'IDENTIFY' AND 'EXPLAIN'

ISBN 978-1-108-88711-3

For example:

*Question*: Identify components A and E from the diagram of the plasma membrane (Figure 1B–6).

*Answer*: A = phospholipid, E = cholesterol

This sample response has done exactly what the question required, without elaboration.

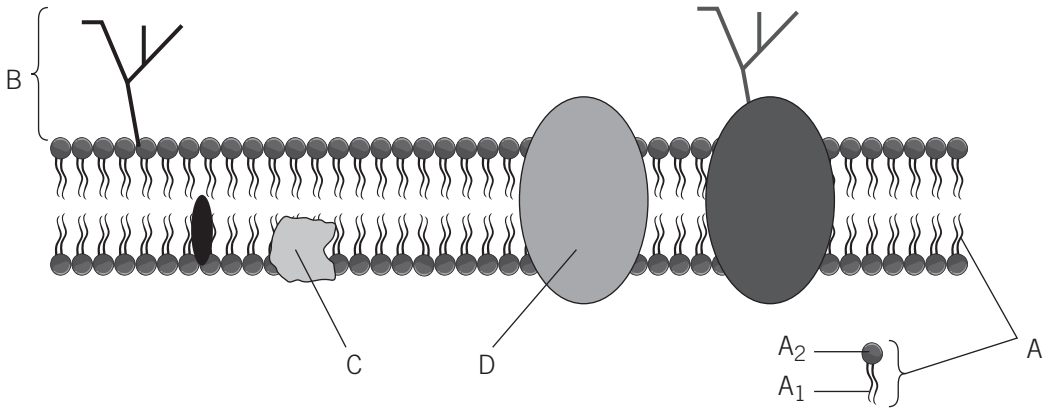
*Question*: Explain how you know whether a component of a plasma membrane is a glycoprotein or a glycolipid.

*Answer*: A glycoprotein consists of a carbohydrate chain attached to a protein molecule, as indicated by C in the diagram. A glycolipid, by comparison, consists of a carbohydrate chain attached to a phospholipid, as indicated by B in the diagram.

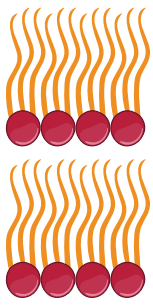
This answer gives an elaborated response that demonstrates the ability to differentiate between the two components of the plasma membrane. To ensure that the answer is clear, a comparative term is included ('by comparison'). The answer also *incorporates specific evidence from the diagram* to further demonstrate the correct understanding of the difference between the two components of the plasma membrane.

## Section 1B questions

1 Phospholipids are a component of the plasma membrane. Recall the other three components.
2 State the functions of the three components you identified in Question 1.
3 Identify the labelled components in this diagram.




4 Outline the orientation of phospholipids in a plasma membrane.
5 Explain why phospholipids have their particular orientation in a plasma membrane.
6 Identify the errors in the diagram of a phospholipid bilayer shown on the right.
7 Outline the role of ribosomes.
8 Two membranes have different levels of fluidity (ability to move). Describe the composition of the phospholipids in the two membranes to provide a reason for their different fluidity.



ISBN 978-1-108-88711-3


# Cell types

**Study Design:**
Cells as the basic structural feature of life on Earth, including the distinction between prokaryotic and eukaryotic cells

**Glossary:**
Cytoplasm
Eukaryote
Nucleoid
Prokaryote

## ENGAGE

### Bacteria

Fossil records reveal that bacteria were the first type of organism on Earth, 3.5 billion years ago. Bacteria are now the most prevalent organism on Earth – an estimated 5 million trillion trillion (that is, a 5 with 30 zeroes after it). This means there are more bacteria on Earth than stars in the universe. At any one time, you can find up to $10^{10}$ bacteria in your mouth and $10^{14}$ bacteria in your gut. Of all the bacteria, 85% are considered 'good' bacteria and 15% are considered 'bad' bacteria. Even though the bacteria in your body outnumber the cells in your body by about 10 to 1, bacteria contribute only 1–3% of your body mass. Bacteria are able to live in extreme environments, such as volcanic hot springs and hydrothermal vents.

**Figure 1C–1** A volcanic hot spring, Sunset Lake, Yellowstone National Park, United States. The colours are created by thermophilic bacteria growing in the hot water.

**Figure 1C–2** Bacteria can be found everywhere. Ultraviolet (UV) light shone onto a computer keyboard reveals bacterial contamination, through a process that causes the bacteria to fluoresce.

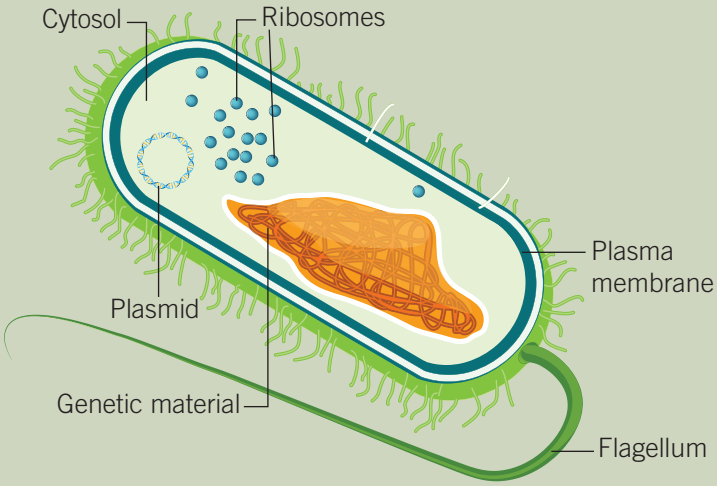



**Figure 1C–3** Diagrammatic representation of a bacterium. The bacterium has the four common features of all organisms (genetic material, cytosol, ribosomes, plasma membrane) but lacks membrane-bound organelles.

ISBN 978-1-108-88711-3

EXPLAIN

## Prokaryotes and eukaryotes

**Prokaryote**
a single-celled organism that does not have membrane-bound organelles; includes bacteria and archaea

**Organelle**
a compartment within a cell that performs specific functions

**Eukaryote**
a single-celled or multicellular organism whose cells include membrane-bound organelles; includes protists, fungi, plants and animals

Organisms can be classified into one of two groups: prokaryotes and eukaryotes (see Figure 1C–4). A **prokaryote** is a single-celled organism that is made up of prokaryotic cells. Prokaryotic cells do not contain membrane-bound **organelles**. Examples of prokaryotic organisms are bacteria and archaea.

**Eukaryotes** can be single-celled or multicellular organisms, and are made up of eukaryotic cells. Eukaryotic cells contain membrane-bound organelles. Examples of eukaryotic organisms are protists, fungi, plants and animals.

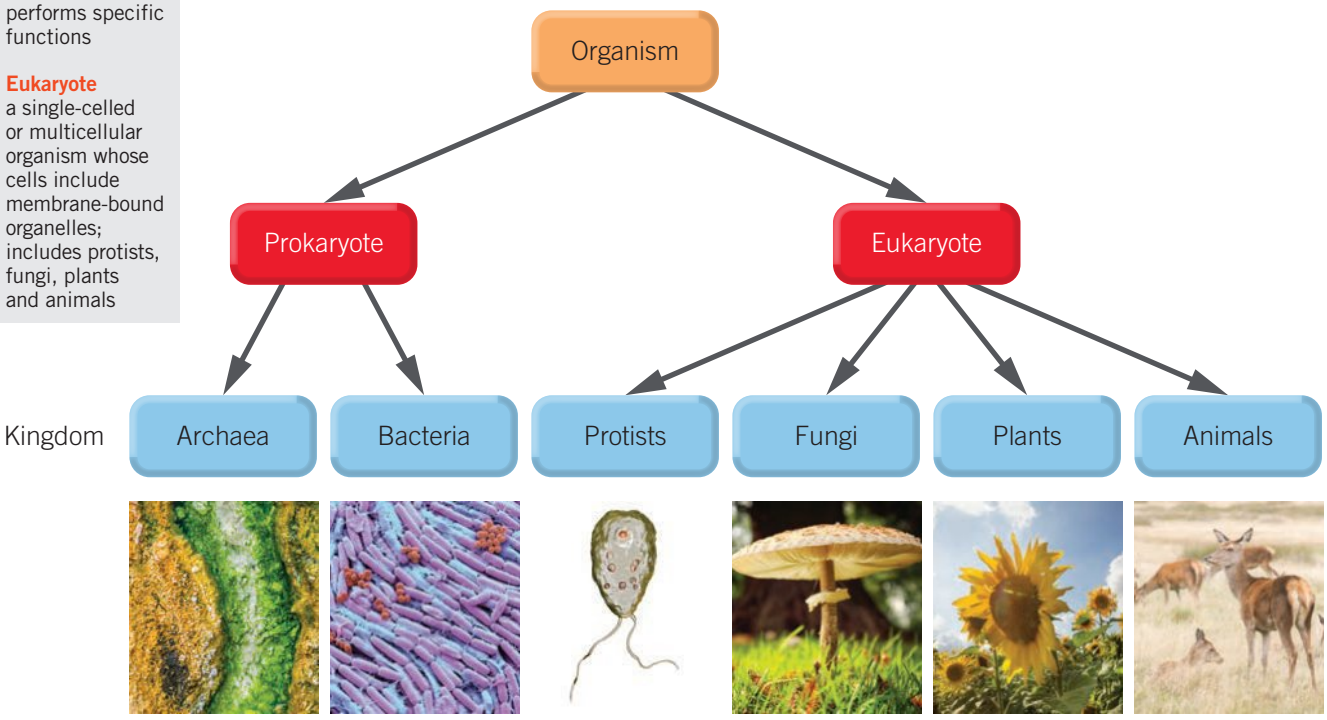



**Figure 1C–4** Organisms can be classified as prokaryotes or eukaryotes. This diagram also shows another way of classifying them: into kingdoms.

## Check-in questions – Set 1

1 Define 'eukaryote' and 'prokaryote'.
2 Which kingdoms consist of multicellular organisms?
3 Explain whether the organism in the image on the right is a prokaryote or a eukaryote.

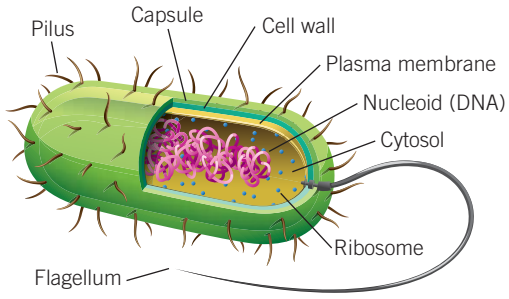
ISBN 978-1-108-88711-3

## Cellular features of prokaryotes and eukaroytes

The basic features of eukaryotic cells and prokaryotic cells are described in Figure 1C–5.

**Prokaryotic cell**

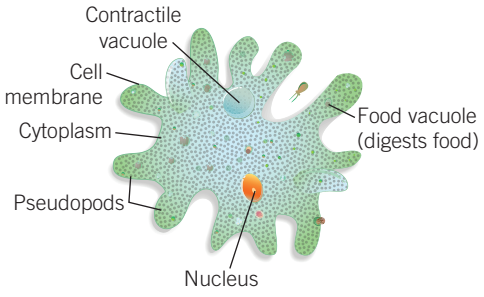
- Lacks membrane-bound organelles
- Contains ribosomes
- Genetic material is usually one circular DNA chromosome located in an area known as a **nucleoid**
- Many contain small rings of double-stranded DNA called plasmids
- Plasma membrane is surrounded by a cell wall
- Some bacteria have a capsule around the cell wall for extra protection
- Some bacteria also have flagella (singular: flagellum) for movement and pili (singular: pilus) for attaching to surfaces




**Nucleoid** an irregularly shaped area in a prokaryote where the genetic material is located

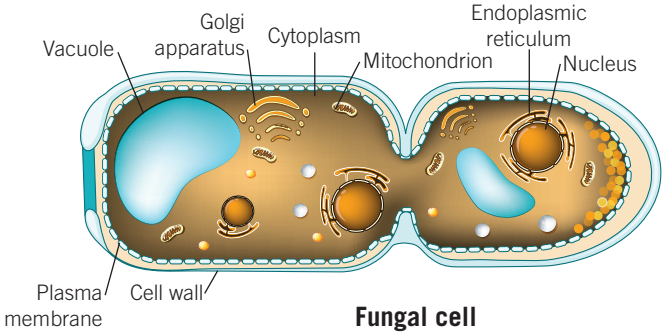
**Eukaryotic cell**

- Contains membrane-bound organelles
- Contains ribosomes
- Genetic material is linear DNA chromosomes contained within a nucleus
- Plasma membrane encloses the **cytoplasm**
- Cell wall is present in fungi, plants and some protists
- Many cell types (not fungi) have flagella or cilia for movement

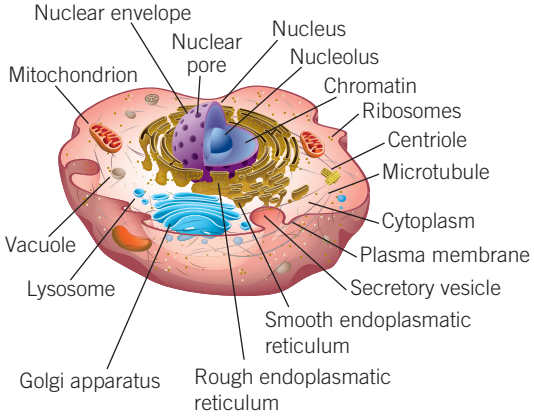



**Amoeba (a protist)**

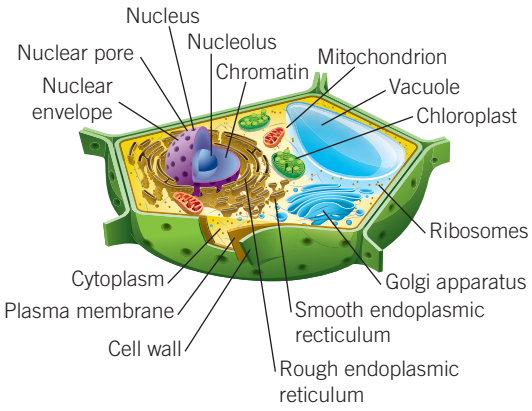
**Cytoplasm** all the contents inside the membrane of a cell, except the nucleus; includes cytosol and organelles




**Fungal cell**




**Animal cell**




**Plant cell**

**NOTE**

The different organelles labelled in Figure 1C–5 and their functions are explored in Chapter 1D.

**Figure 1C–5** Cellular features of eukaryotes and prokaryotes

ISBN 978-1-108-88711-3

## Check-in questions – Set 2

1 What is a plasmid?
2 What is the difference between the DNA structure of a prokaryote and that of a eukaryote?
3 Which kingdom's cells contain a cell wall?
4 Which type of organism has larger cells: prokaryotes or eukaryotes?

## 1C SKILLS

VIDEO 1C–1 SKILLS: USING DIAGRAMS TO ANSWER QUESTIONS

### Using diagrams to answer questions

When providing examples of organisms that are either eukaryotic or prokaryotic, it is important to use cellular features as your justification. A key cellular feature is the presence or absence of membrane-bound organelles. If the cell contains a membrane-bound organelle, then it is a eukaryote.

One type of organism that often causes confusion is protists. A protist is unicellular but it is not a prokaryote. It is important to remember that some unicellular organisms, such as paramecium, contain membrane-bound organelles, as shown in Figure 1C–6. For this reason, a paramecium is classified as a eukaryote.

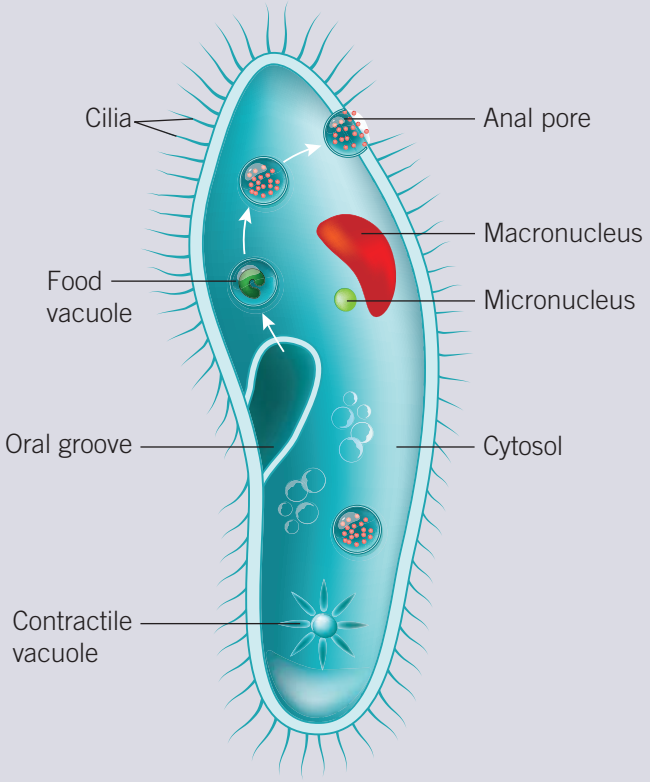


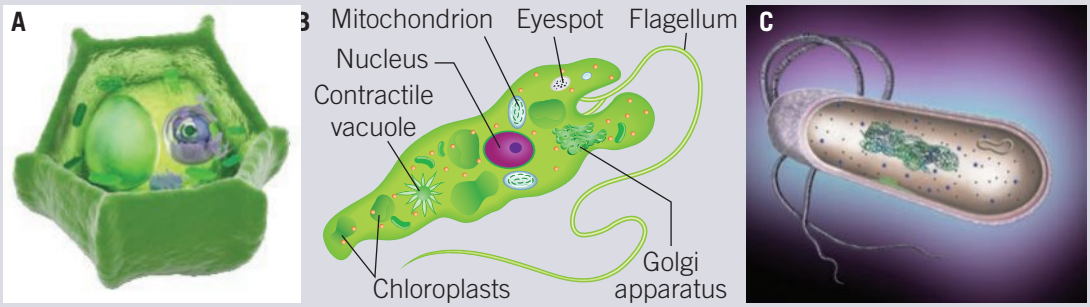

**Figure 1C–6** A paramecium is a unicellular organism that has membrane-bound organelles.

You could be asked to *identify* which of the examples are either a prokaryote or a eukaryote. When a question asks you to identify, there is no need to include a justification or explanation. All you need to do is put the example into a category, or label it as either prokaryote or eukaryote.

ISBN 978-1-108-88711-3

For example:

*Question:* Identify which of the diagrams shows a prokaryote.




*Answer*: C

As you can see, the answer consists of just the letter associated with the correct diagram. This is in contrast to a question that asks you to *justify* your choice. For example:

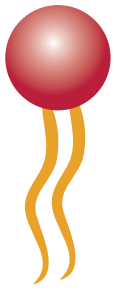
*Question:* Provide a justification for why you have identified your answer as a prokaryote.

*Answer:* C lacks membrane-bound organelles. The other two diagrams show a nucleus or another membrane-bound organelle. Hence C is a prokaryote.

Note that the answer does not repeat the question, and it gives a specific piece of evidence as the reason for the choice. The response also finishes by coming back to the context of the question, re-stating that the chosen option is a prokaryote.

## Section 1C questions

1 Draw a prokaryote.
2 Provide three examples of eukaryotic organisms.
3 State which kingdoms are eukaryotic.
4 Outline how you would correct the following statement:
Prokaryotes only have circular pieces of DNA, whereas eukaryotes only have linear pieces of DNA.
5 Explain why a prokaryote is still an organism.
6 Redraw the following image of the phospholipid and annotate it with the following labels: fatty acid tail, glycerol and phosphate head, hydrophilic, hydrophobic.



7 Where in a cell would a phospholipid be found?
8 Using a Venn diagram, compare the similarities and differences between unicellular and multicellular organisms.

ISBN 978-1-108-88711-3


# Organelles

**Study Design:**

- 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
- The structure and specialisation of plant and animal cell organelles for distinct functions, including the chloroplast and mitochondria

**Glossary:**

Cell wall
Chloroplast
Cilia
Endosymbiosis
Flagella
Golgi apparatus
Lysosome
Mitochondrion
Nucleus
Organelle
Rough endoplasmic reticulum
Smooth endoplasmic reticulum
Symbiosis
Vacuole
Vesicle

**Symbiosis**
a beneficial relationship between two organisms

**Endosymbiosis**
symbiosis where one organism lives inside another

## ENGAGE

### Symbiosis and endosymbiosis

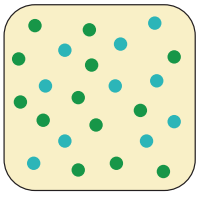
Why does a mitochondrion have a double membrane, its own ribosomes and its own set of DNA? Mitochondria are believed to have arisen as a result of one prokaryote engulfing another, aerobic, prokaryote. An aerobic prokaryote is able to use oxygen to respire. The first prokaryote – the one doing the engulfing – was then able to take on the respiratory function of the aerobic prokaryote that it engulfed. The first prokaryote did not break down the aerobic prokaryote; instead, it retained it and gained its aerobic function. This kind of beneficial relationship between two organisms is called **symbiosis**, and if one of the organisms lives inside the other it is referred to as **endosymbiosis**.

## EXPLAIN

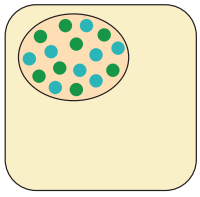
### Benefits of compartmentalisation within cells

A cell can be thought of as a 'reaction factory', a place where many molecules (reactants) interact to release new products. For a successful reaction, the molecules need to move into and around the cell at the correct rate. They also need to be in the correct concentration for specific chemical reactions to occur.

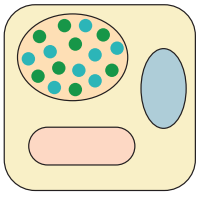
A eukaryotic cell is relatively large, making it more difficult for chemical reactions to occur efficiently within it. This problem is overcome by having smaller compartments within the cell. Organelles are membrane-bound compartments within a cell that perform specific functions. Each individual organelle (except ribosomes) has a plasma membrane. This membrane enables the organelle to maintain the concentrations of molecules at levels that allow the reactants to interact with each other at optimal rates. The compartmentalisation within organelles also allows various chemical reactions to occur simultaneously in different places without interfering with each other (Figure 1D–1).



Reactant molecules spread out in a large compartment.



If the reactant molecules are restricted to a smaller space by being enclosed in an organelle, they are more likely to bump into each other and react.



More organelles allow other specialised reactions to take place without being affected by the presence of other reactants.

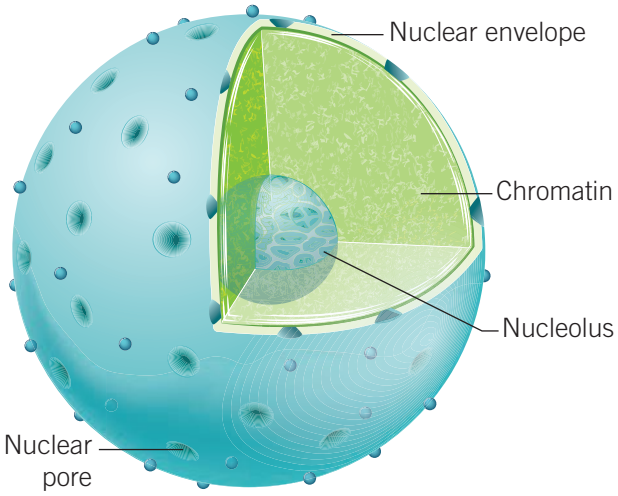
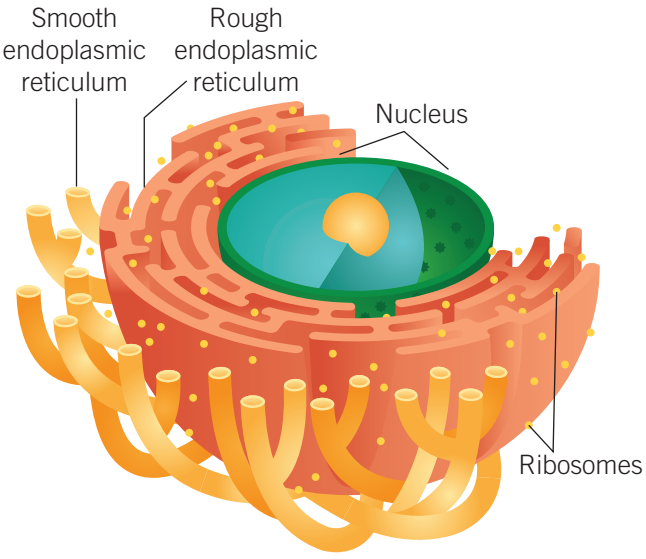
**Figure 1D–1** The benefits of compartmentalisation within a cell

ISBN 978-1-108-88711-3

## Organelles in plant and animal cells

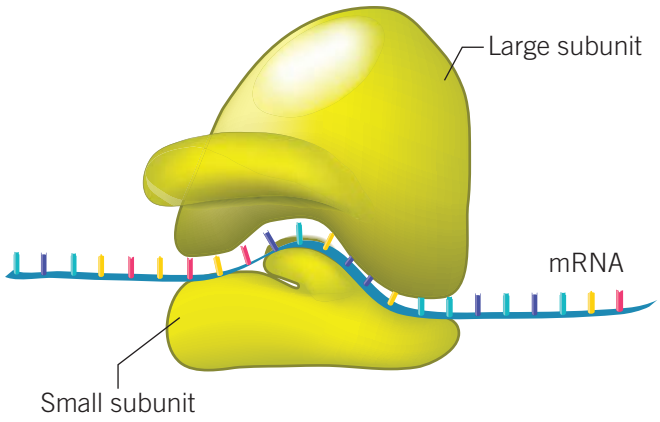
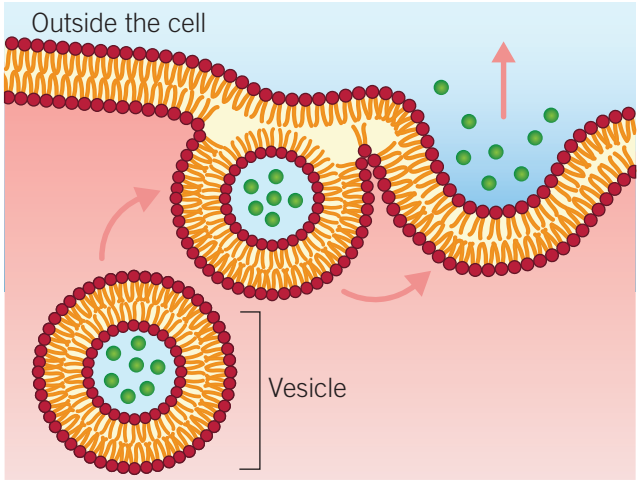
Table 1D–1 identifies the types of organelles found in plants and animals, and their structure and function.

**Table 1D–1** The structure and function of organelles in plant and animal cells

| Organelle | Structure | Function |
|---|---|---|
| **Nucleus**<br>a double-membrane bound organelle that contains genetic material (DNA, RNA)<br>  <br> | Enclosed in a double-membrane nuclear envelope<br>Contains chromatin (DNA and protein)<br>Nucleolus inside contains RNA<br>Nuclear pores allow RNA and other materials to leave the nucleus<br>LINK UNIT 3 | Stores and executes the genetic code in the DNA<br>RNA carries the code to ribosomes to synthesise the proteins that control the cell's activities<br>The DNA is passed on to daughter cells during mitosis and meiosis<br>LINK 3B CELL DIVISION<br>LINK 7B SEXUAL REPRODUCTION AND MEIOSIS |
| **Endoplasmic reticulum (smooth** and **rough)**<br>**Smooth endoplasmic reticulum**<br>an organelle that synthesises and transports lipids<br>**Rough endoplasmic reticulum**<br>an organelle that transports proteins in vesicles to the Golgi apparatus<br>  <br> | Membrane bound, with a system of tubules<br>Rough ER is studded with ribosomes<br>Smooth ER has no ribosomes | Smooth ER: synthesis and transport of lipids<br>Rough ER: transports proteins in vesicles to the Golgi apparatus |

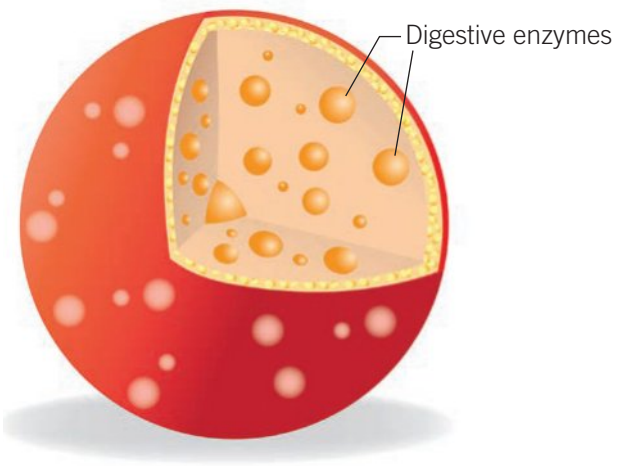
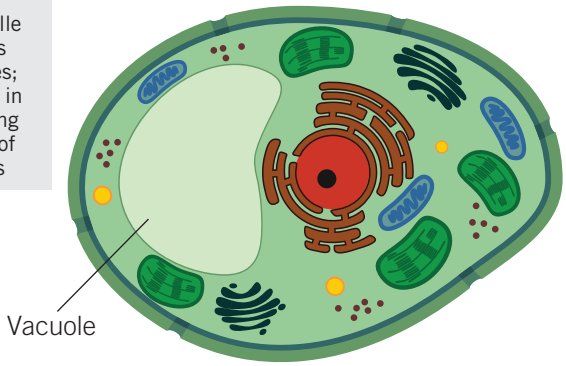
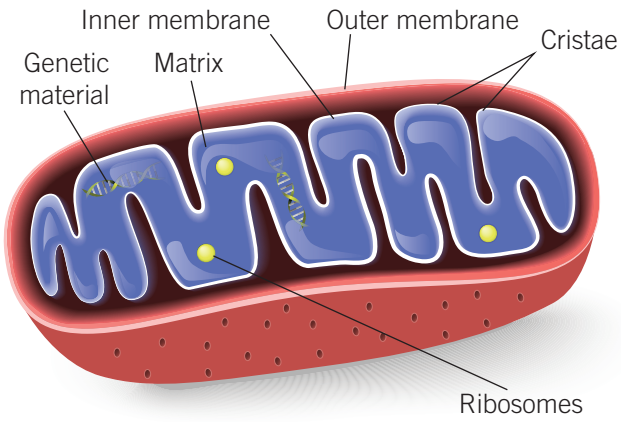
ISBN 978-1-108-88711-3

**Table 1D–1** *Continued*

| Organelle | Structure | Function |
|---|---|---|
| **Ribosome**<br>  | A non-membrane bound organelle, made up of protein and ribosomal RNA<br>LINK UNIT 3 | Synthesis of proteins, a process known as translation<br>Ribosomes in the cytosol make proteins for use inside the cell, whereas ribosomes on the rough ER make proteins for use outside the cell<br>RNA carries the code to make proteins |
| **Golgi apparatus**<br>an organelle consisting of layers that modifies and packages proteins<br>  | Layers of membrane-bound stacks | Takes in proteins from the ER<br>Modifies and packages proteins into secretory vesicles for exporting from the cell by exocytosis<br>LINK 2A THE NATURE OF SUBSTANCES AND THEIR MODES OF TRANSPORT |
| **Vesicle**<br>an organelle that transports materials between organelles and within the cell<br>  | Membrane-bound sac | Transports materials (e.g. proteins) between organelles and within the cell<br>Also exports molecules from the cell (exocytosis) and brings molecules into the cell (endocytosis)<br>Vesicles are produced and absorbed by the ER and Golgi membranes |

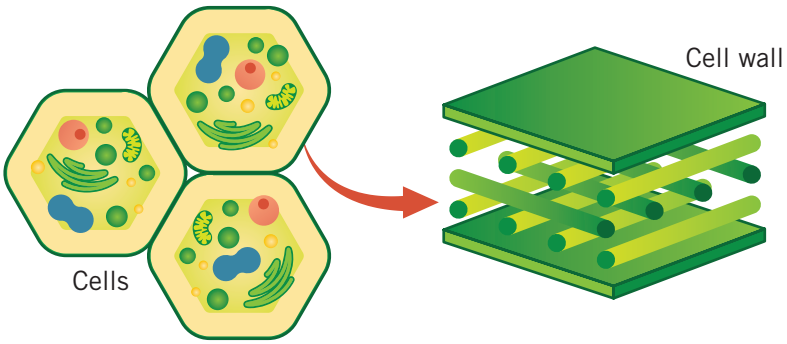
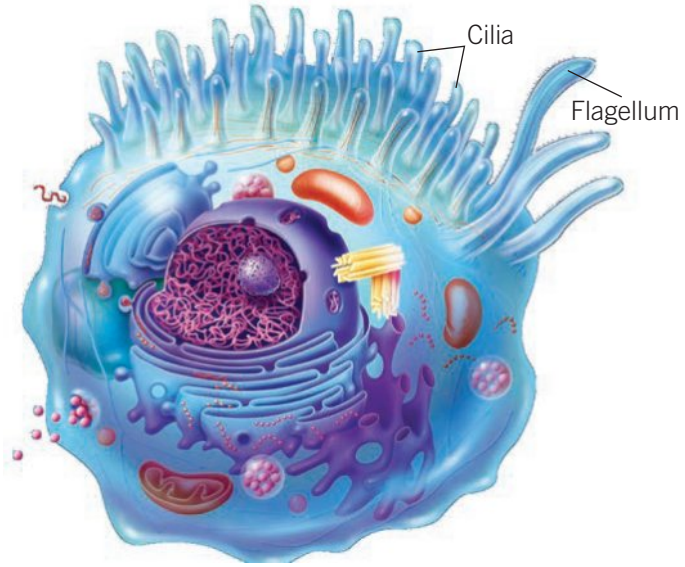
ISBN 978-1-108-88711-3

**Table 1D–1** *Continued*

| Organelle | Structure | Function |
|---|---|---|
| **Lysosome** (in animals)<br>an organelle containing enzymes that break down foreign matter or materials no longer required<br>  | Membrane-bound sacs containing digestive enzymes (lysozymes)<br>Related to vesicles and have a similar structure, but are not found in plants | Break down materials no longer required, or foreign matter |
| **Vacuole**<br>an organelle that stores substances; important in maintaining structure of plant cells<br>  | Membrane (tonoplast)-bound sac<br>Develop from vesicles | Storage of substances (e.g. water and ions)<br>Vacuoles are larger in plants than in animals and are important in maintaining plant structure |
| **Mitochondrion**<br>an organelle where stages of aerobic respiration occur, releasing energy (ATP)<br>  | Has a double membrane, with the inner membrane folded to form cristae, with matrix inside this<br>Mitochondria have their own genetic material and ribosomes | Site of stages 2 and 3 of aerobic cellular respiration, which releases usable energy in the form of ATP molecules<br>LINK **2D** ROLE OF CHLOROPLASTS AND MITOCHONDRIA |

ISBN 978-1-108-88711-3

**Table 1D–1** *Continued*

| Organelle | Structure | Function |
|---|---|---|
| **Chloroplast** (in plants)<br>an organelle where photosynthesis occurs; contains chlorophyll<br>  | Double membrane comprising grana (stacks of membrane discs called thylakoids) and stroma (fluid). Grana contain chlorophyll | Site of photosynthesis, which converts carbon dioxide and water, with the assistance of light, to glucose and oxygen<br>Animal cells do not have chloroplasts |
| **Cell wall** (plants)<br>a structure that surrounds a plant cell and provides support and protection<br>  | Surrounds the plant cell, lies outside the plasma membrane. Contains cellulose | Provides cellular structure and protection<br>Animal cells do not have a cell wall |
| **Cilia** and **flagella**<br>**Cilia**<br>short microtubules projecting from a cell that move to provide motility (movement of the cell) or movement of fluid<br>**Flagella**<br>long microtubules projecting from a cell that move to provide motility (movement of the cell) or movement of fluid<br>  | Microtubule projections from the cell. Cilia are generally shorter, flagella longer<br>Not found in fungi or plants | Provide motility (movement of the cell) or movement of fluid |

ISBN 978-1-108-88711-3

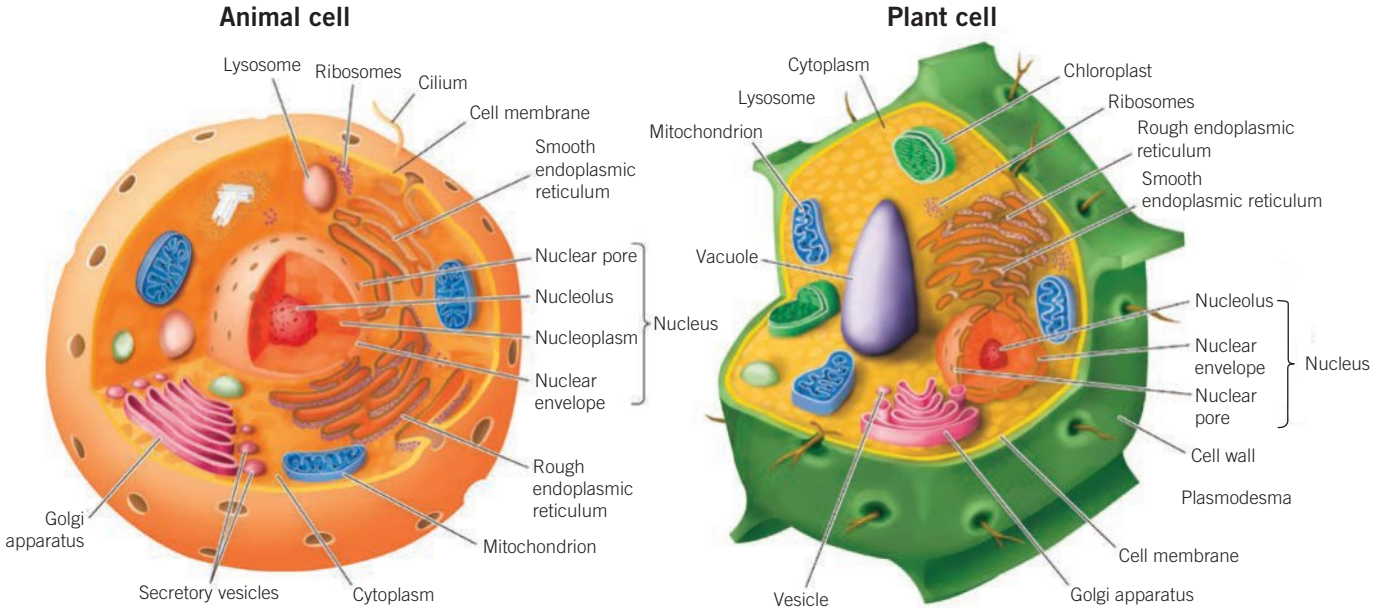



**Figure 1D–2** Generalised animal cell and plant cell, with organelles labelled

It is important to realise that cells do not all have the same types and numbers of organelles. The types and numbers of organelles present in a cell are specific to the type of tissue in which the cell is found. For example, a sperm cell requires a lot of energy, so you would expect to find a large number of mitochondria in it, as mitochondria provide energy for the cell. The secretory cells that line the stomach are part of the digestive system, and hence they require a lot of Golgi apparatus to enable them to release enzymes (proteins) that aid in the breakdown of food molecules.

**WORKSHEET 1D–1** CELLS AND THEIR ORGANELLES

**WORKSHEET 1D–2** MODELLING CELLS

LINK **5A** HOMEOSTASIS

## Check-in questions – Set 1

1 What is an organelle?
2 Provide an advantage of having organelles, for a eukaryotic cell.
3 Define ‘compartmentalisation’.
4 What is the function of ribosomes?

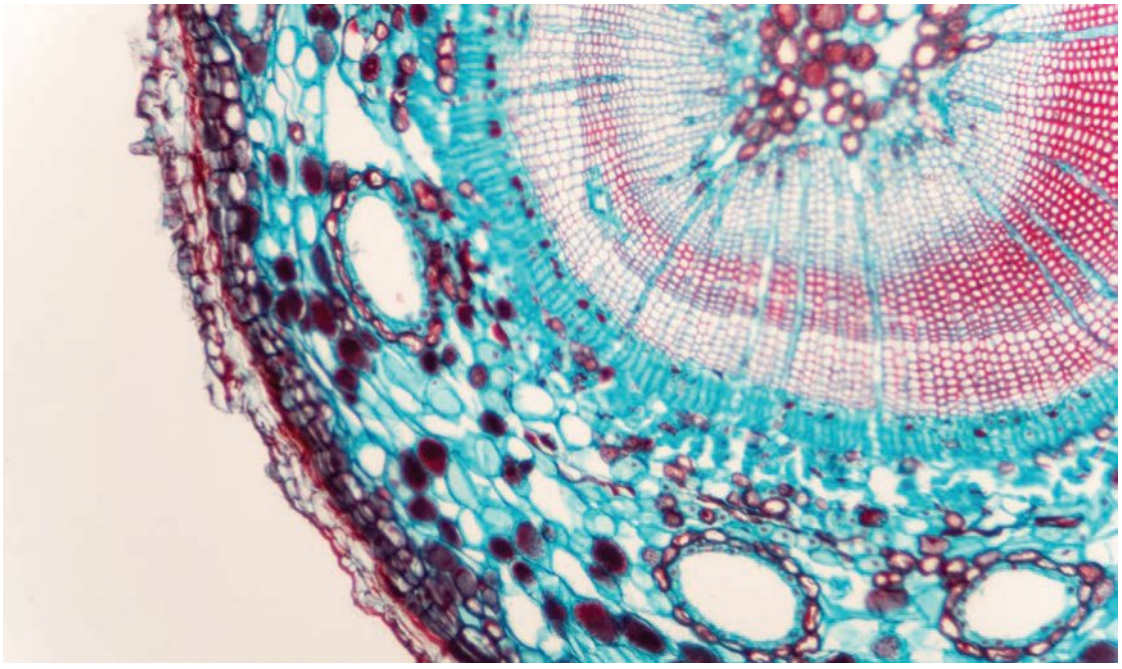


**Figure 1D–3** Thick cell walls are visible in this light microscope view of cells in a plant stem.

ISBN 978-1-108-88711-3

## Comparison of plant and animal cells

Plant cells and animal cells have many organelles in common, but there are some differences (Figure 1D–4).

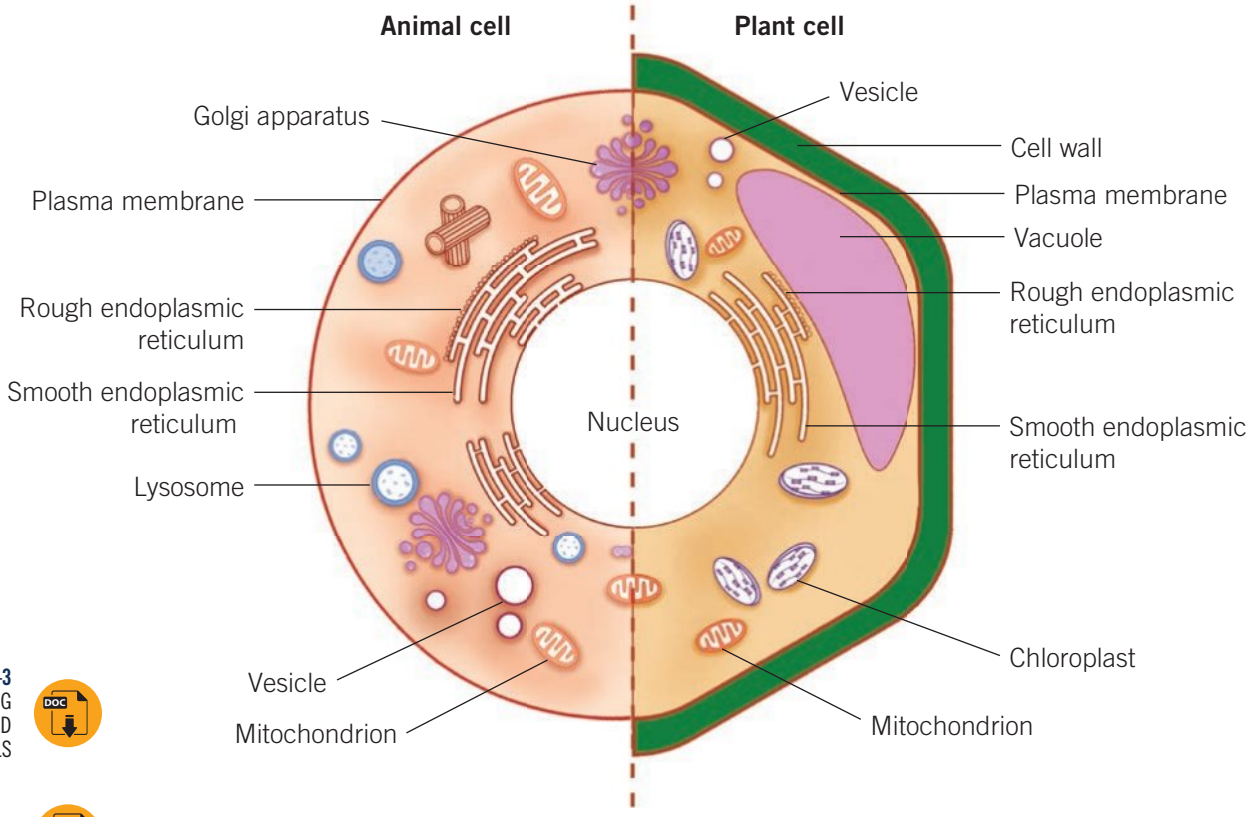
2D ROLE OF CHLOROPLASTS AND MITOCHONDRIA LINK

A misconception is that plant cells only perform photosynthesis and do not respire. In fact, plant cells perform both photosynthesis and aerobic cellular respiration, and so a plant cell has both mitochondria and chloroplasts. Not all the cells in a plant photosynthesise (e.g. root cells do not photosynthesise), but they do all respire. In contrast, animal cells do not have any chloroplasts, and do not photosynthesise.

Two further key differences between plant cells and animal cells:

- *Cell wall* – plant cells have a cell wall to aid with structural support for the whole plant, whereas animal cells do not. Animals have other features, such as an exoskeleton or bones, to provide support.
- *Permanent vacuole* – plant cells have a permanent large vacuole for the storage of water, minerals and ions. The vacuole also assists with the structural support of the cell through turgor pressure (pressure exerted by water). Animal cells do have vacuoles but they are small and are not permanently present, and they do not provide structural support to the cell.

2B OSMOSIS LINK




WORKSHEET 1D–3 COMPARING ANIMAL AND PLANT CELLS

**Figure 1D–4** Similarities and differences between an animal cell and a plant cell

VIDEO 1D–1 ORGANELLES IN PLANT AND ANIMAL CELLS

ISBN 978-1-108-88711-3

## 1D SKILLS

VIDEO 1D–2 SKILLS: UNDERSTANDING PROCESSES THROUGH LINKED STEPS

### Understanding processes through linked steps

A way to remember the function of different organelles is to include them in a series of linked steps that form a process. For example, you can use steps to describe the process of protein synthesis. You will meet this process in detail in Unit 3. Using steps in this way will enable you to deepen your understanding and boost your ability to remember the key organelles and their functions.

LINK UNIT 3

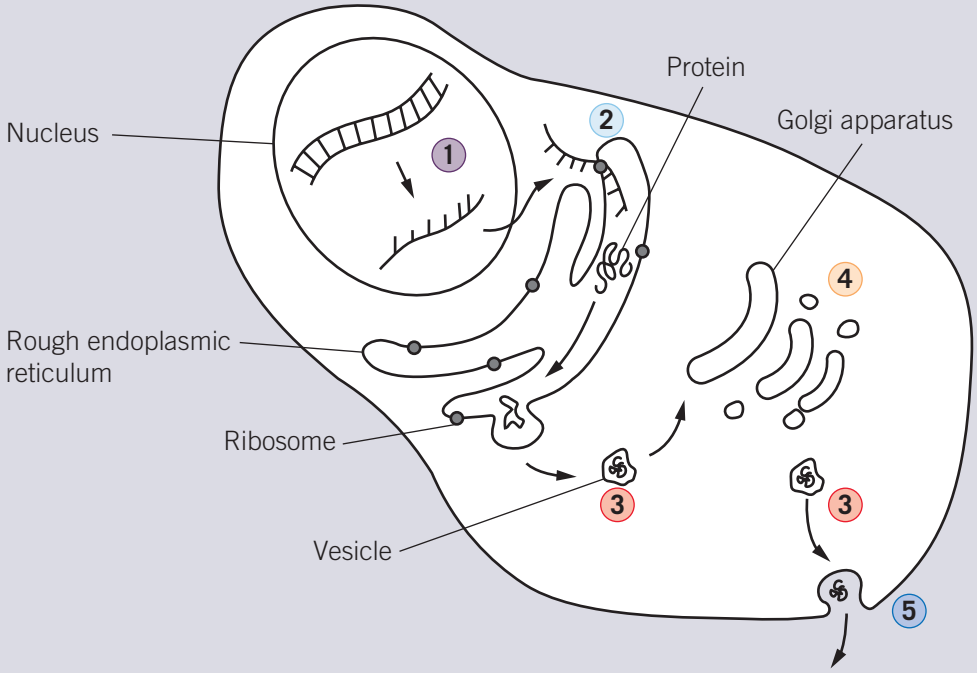



**Figure 1D–5** Outline of protein synthesis

The process of protein synthesis is outlined in diagrammatic form in Figure 1D–5. The steps in this process are as follows:

1 Conversion of DNA to RNA
- Within the nucleus, which contains the genetic material, the DNA is transcribed to build RNA, which leaves the nucleus through a nuclear pore.

2 Conversion of RNA to protein (translation)
- RNA is translated at a ribosome, which synthesises the corresponding protein. If the protein is destined for the outside of the cell or the plasma membrane, the ribosome is attached to the rough endoplasmic reticulum.

3 Transportation of protein
- The rough endoplasmic reticulum transports the protein in a vesicle to the Golgi apparatus.

4 Packaging of protein
- The Golgi apparatus modifies and packages the protein into a vesicle, ready for exporting out of the cell.

5 Secretion of protein (exocytosis)
- The protein is released to the extracellular environment of the cell.

LINK 2A THE NATURE OF SUBSTANCES AND THEIR MODES OF TRANSPORT

### Creating flashcards

A further strategy to help you remember the functions of the organelles is to use the diagrams and definitions from Table 1D–1 to create flip cards (flashcards). The more you use images associated with terms and definitions, the easier it will be for you to correctly recall the organelle functions.

ISBN 978-1-108-88711-3

VIDEO 1D–3 SKILLS: ANSWERING COMPARATIVE QUESTIONS

### Answering comparative questions

Answering comparison-based questions is a vital skill. Here is an example of how to approach a comparative question in relation to animal and plant cells:

> *Question:* What are two differences between the structure of a plant cell and the structure of an animal cell?
>
> *Answer:* A plant cell contains chloroplasts to perform photosynthesis, *whereas* animal cells do not have chloroplasts. Also, a plant cell has a cell wall that surrounds the plasma membrane, while an animal cell only has a plasma membrane as the outermost layer of the cell.

Key points to remember when answering comparative questions:

- Make it clear that there is a comparison, by using terms such as 'whereas', 'although', 'in contrast', and 'unlike'.
- If the question asks for a set number of comparisons, discuss one item in each comparison. For example:
  A plant cell has chloroplasts, whereas an animal cell does not.
  A plant cell has a cell wall, but an animal cell does not.
  - ► Avoid comparing multiple items at the same time, because if one item is wrong, it will make the whole comparison wrong. It can also mean that you run out of items to compare.
- Keep your comparisons succinct and do not repeat the question.
  In the example above, you would *not* begin your answer like this: 'A difference between a plant cell and an animal cell is that …'. If you find that you tend to do this, try starting your answer after 'that' and go from there. You could also use dot points when answering questions.
- Within your comparison, be sure to incorporate the content that you are most confident with, to increase your likelihood of gaining full marks.

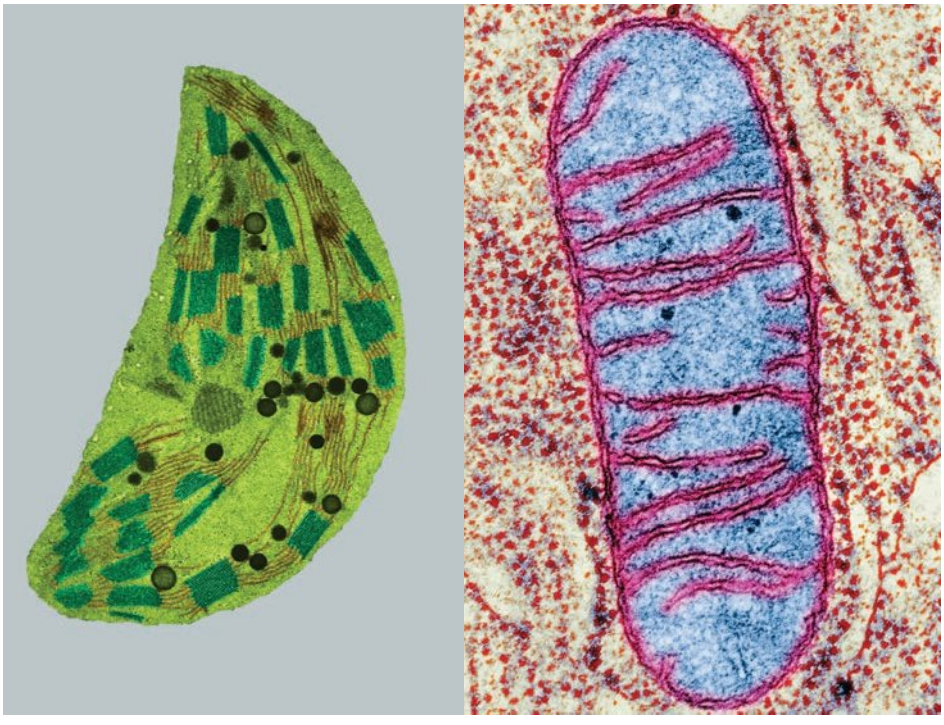
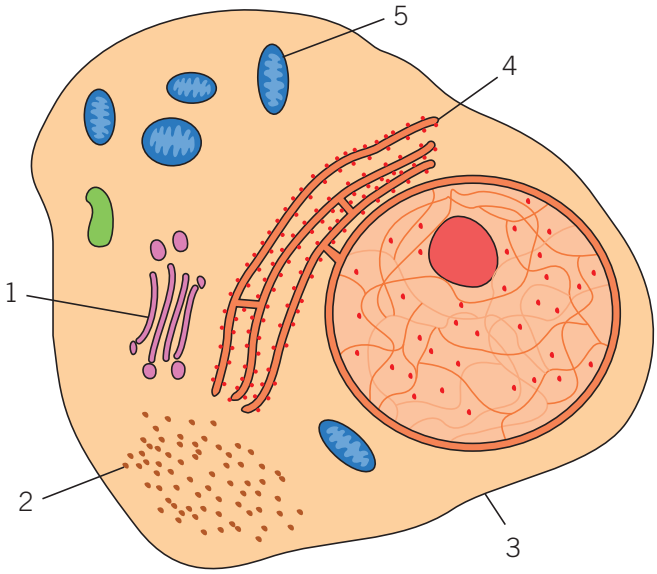


**Figure 1D–6** While both plant and animal cells have mitochondria (right), only plant cells have chloroplasts (left).

ISBN 978-1-108-88711-3

## Section 1D questions

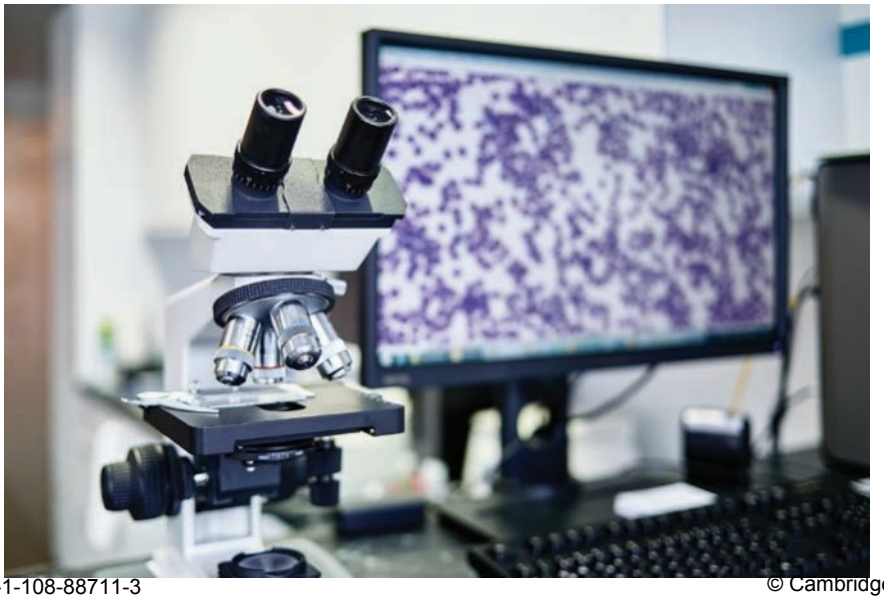
1 Describe the function of the cell wall for a plant.
2 Identify each of the numbered organelles in the diagram.




3 Define the role of:
   a the mitochondria
   b the plasma membrane
   c organelles.
4 Is a bacterial cell a prokaryote or a eukaryote?
5 Identify what you would *not* find in a bacterial cell.
6 Explain why you would not include the label of 'cytoplasm' in a diagram of a bacterial cell.
7 Compare a eukaryotic cell to a prokaryotic cell.
8 Plant cells perform photosynthesis in order to produce glucose. Explain whether it is reasonable to expect chloroplasts to be found in all cells of a plant.

See the Interactive Textbook for Worksheet 1D–4, which discusses how to look at cells using a light microscope and how to represent cells using scientific drawings. Note that this worksheet will help with practical work but is not required by the Study Design.

**WORKSHEET 1D–4**
VIEWING AND DRAWING CELLS



ISBN 978-1-108-88711-3

# Chapter 1 review

## Summary

Create your own set of summary notes for this chapter, on paper or in a digital document. A model summary is provided in the Teacher Resources and can be used to compare with yours.

## Checklist

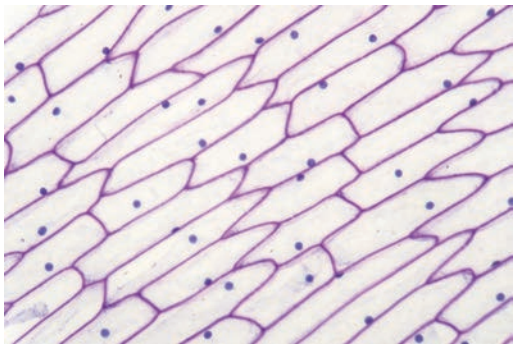
In the Interactive Textbook, the success criteria are linked to the review questions and will be automatically ticked when answers are correct. Alternatively, print or photocopy this page and tick the boxes when you have answered the corresponding questions correctly.

| Success criteria – I am now able to: | | Linked question |
|---|---|---|
| **1A.1** | Recall the four common factors for all organisms | 7☐ |
| **1A.2** | Define the following key terms: abiotic, biotic, multicellular, unicellular | 15a☐ |
| **1A.3** | Outline the functions of the four common factors for an organism | 15b☐, c☐ |
| **1B.1** | Recall and define the following terms: fluid mosaic model, hydrophilic, hydrophobic, plasma membrane, semi-permeable membrane | 10☐ |
| **1B.2** | Recall and define the functions of the different components of the plasma membrane | 10☐ |
| **1B.3** | Identify the different components of a plasma membrane | 4☐ |
| **1B.4** | Draw a plasma membrane, including the identification of the different components | 13b☐ |
| **1B.5** | Use evidence from a diagram to explain the structure of the plasma membrane | 13a☐ |
| **1C.1** | Recall and define the following terms: eukaryote, nucleoid, prokaryote | 5☐, 6☐, 14☐ |
| **1C.2** | Outline the cellular features for a eukaryote and a prokaryote | 5☐, 14☐ |
| **1C.3** | Draw a prokaryote, including the identification of its cellular features | 14☐ |
| **1C.4** | Identify whether a cell is a eukaryote or a prokaryote, based on its cellular features | 1☐, 14☐ |
| **1D.1** | Recall and define the following: cell wall, chloroplast, cilia, flagella, Golgi apparatus, lysosome, mitochondrion, nucleus, organelle, ribosome, rough endoplasmic reticulum, smooth endoplasmic reticulum, symbiosis, vacuole, vesicle | 2☐, 11☐ |
| **1D.2** | Identify the organelles present in a plant and an animal cell | 11☐ |
| **1D.3** | Describe what compartmentalisation is | 11b☐ |
| **1D.4** | Explain the importance of compartmentalisation for cells | 11b☐, c☐ |
| **1D.5** | Draw animal and plant cells, including the identification of organelles | 15c☐ |
| **1D.6** | Compare the structures of plant cells and animal cells | 1☐, 9☐, 12☐ |
| **1D.7** | Explain what organelles would be present in different cell types so that the cell can perform its particular function | 15d☐ |

ISBN 978-1-108-88711-3

## Multiple-choice questions

1 The microscope image shown here is most likely from a
- **A** plant.
- **B** bacterium.
- **C** animal.
- **D** protist.



2 Which of the following is the best description of the function of the rough endoplasmic reticulum?
- **A** It modifies and packages proteins.
- **B** It transports proteins to the Golgi apparatus.
- **C** It contains enzymes to perform cellular respiration.
- **D** It is the site of protein synthesis.

3 The cell theory states that
- **A** all organisms are only made up of protein.
- **B** the cell is the largest single component of an organism.
- **C** a cell lasts for the lifetime of an organism.
- **D** all cells arise from pre-existing cells.

4 A carbohydrate attached to a phospholipid is called a
- **A** carbohydrate.
- **B** carbo-protein.
- **C** glycolipid.
- **D** lipid-hydrate.

5 Which of the following most accurately describes eukaryotic cells?
- **A** They have membrane-bound organelles, and some have flagella and circular DNA.
- **B** They have linear DNA, and some have cell walls and small circular pieces of DNA called plasmids.
- **C** They always have linear DNA and a cell wall.
- **D** They have membrane-bound organelles, and sometimes a cell wall, and sometimes a flagellum.

6 Which of the following is an example of a prokaryotic cell?
- **A** a skin cell
- **B** a bacterium
- **C** an enzyme
- **D** a plasma membrane

7 Which of the following lists features common to all organisms?
- **A** nucleus, plasma membrane, cytosol
- **B** ribosome, cytosol, Golgi apparatus
- **C** cytosol, plasma membrane, ribosome
- **D** Golgi apparatus, plasmid, enzymes

8 An amoeba is a eukaryote because it:
- **A** contains ribosomes, a plasma membrane and cytosol.
- **B** belongs to the Protista kingdom and contains a membrane bound organelle.
- **C** is multicellular and can be as big as 100μm.
- **D** is single celled and does not contain a membrane bound nucleus.

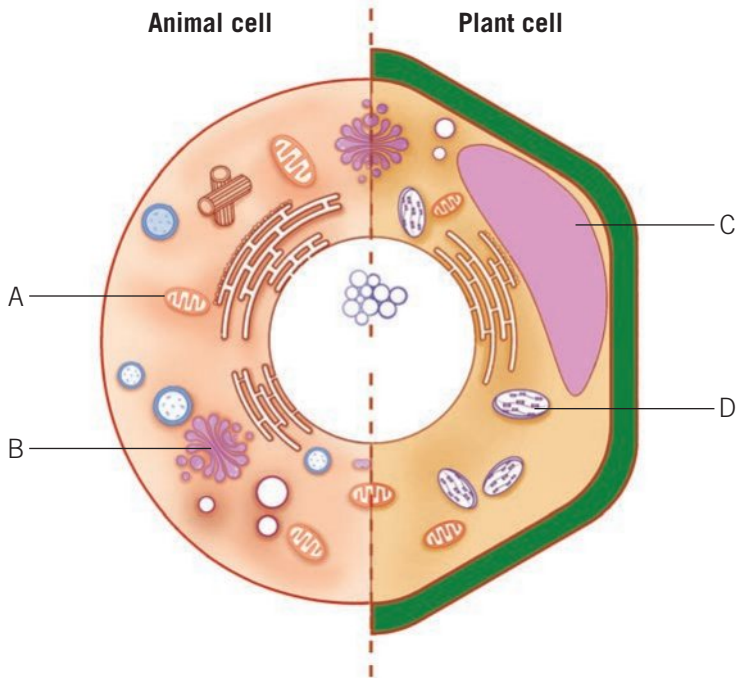
9 Which of the following are found only in plant cells?
- **A** chloroplast, nucleus, vacuole
- **B** vacuole, ribosome, cell wall
- **C** Golgi apparatus, plasma membrane, mitochondria
- **D** chloroplast, cell wall, permanent vacuole

10 Which of the following best describes the structure of a plasma membrane?
- **A** phospholipids with a hydrophilic tail and hydrophobic head
- **B** phospholipids with three fatty acid tails
- **C** glyco-carbohydrates attached to phospholipids
- **D** two layers of phospholipids with proteins embedded between the two layers

ISBN 978-1-108-88711-3

## Short-answer questions

*Use the diagram below to answer Questions 11 and 12.*




**11 a** Identify the components labelled A, B, C and D. (4 × 1 mark)

**b** The components A–D are small compartments known as organelles. Identify one advantage for a cell in having have organelles. (1 mark)

**c** Explain the advantage you identified in part **b**. (2 marks)

**12** Using evidence from the diagram, explain why the right-hand side of the diagram has been labelled 'Plant cell'. (2 marks)

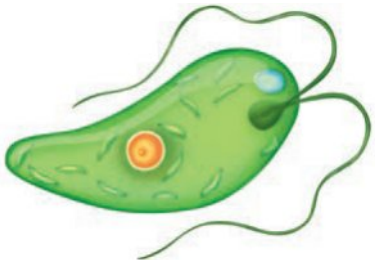
**13** A phospholipid from a plasma membrane is shown below.

**a** One of the fatty acid tails has a bend in it. Outline what is causing the bend. (1 mark)

**b** Draw and fully label a section of a plasma membrane, including all the key components that make up the plasma membrane. (4 marks)

ISBN 978-1-108-88711-3

**14** Safiya and Li disagree about whether the specimen shown here is a eukaryote or a prokaryote. Li argues that it must be a prokaryote because it is unicellular and has flagella. Safiya says it is a eukaryote, because not all eukaryotes are multicellular, and some have flagella.



**a** Provide two characteristics of a prokaryote that have not already been mentioned in this question. (1 mark)

**b** Provide two characteristics of a eukaryote that have not already been mentioned in this question. (1 mark)

**c** Is the specimen in this example a prokaryote or a eukaryote? Provide a justification for your answer. (1 mark)

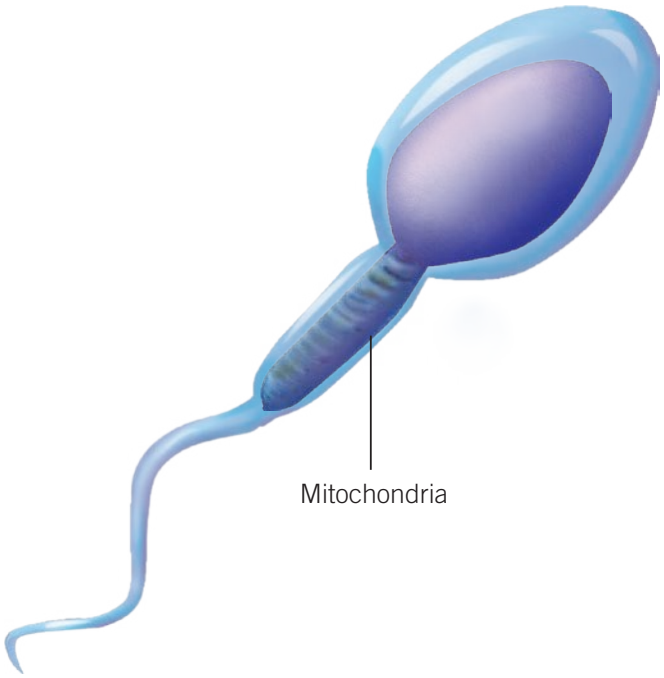
**15** Objects such as the sun or waves are mistakenly considered to be biotic factors. They are actually abiotic.

**a** What is the difference between abiotic and biotic? (2 marks)

**b** What four features do all biotic objects have? (2 marks)

**c** Draw an animal cell and label all four factors you listed for part **b**. (2 marks)

**d** A sperm cell (shown below) is an example of a specialised cell that has a high number of mitochondria. Explain why a sperm cell would require so many mitochondria to perform its function. (1 mark)




ISBN 978-1-108-88711-3

UNIT 1

HOW DO ORGANISMS REGULATE THEIR FUNCTIONS?

CHAPTER 2

# CELLULAR FUNCTIONING

## Introduction

In Biology, we look not only at the functioning of cells but also at how the structure of cells relates to their function. More simply, we want to understand how cells operate and do the things they do, and also how they are able to carry out the processes that allow them to survive and reproduce. This chapter examines the structure and function of the plasma membrane and how it contributes to the functioning of the cell by regulating the movement of substances into and out of the cell. The chapter also explores how the movement of these substances enables cells to carry out essential cellular processes such as photosynthesis and cellular respiration.

## Curriculum

**Area of Study 1 Outcome 1**
**Cellular structure and function**

| Study Design | Learning intentions – at the end of this chapter I will be able to: |
|---|---|
| • The structure and function of the plasma membrane in the passage of water, hydrophilic and hydrophobic substances via osmosis, facilitated diffusion and active transport | **2A The nature of substances and their modes of transport**<br>**2A.1** Draw the plasma membrane, label key structures and state their function<br>**2A.2** Give reasons why substances need to move through the plasma membrane<br>**2A.3** Define semi-permeable, hydrophilic and hydrophobic<br>**2A.4** Summarise the modes of transport used by substances crossing the plasma membrane, including the nature of the substances moving, whether energy is required, and the component of the membrane involved in the transport |
| • The structure and function of the plasma membrane in the passage of water, hydrophilic and hydrophobic substances via osmosis, facilitated diffusion and active transport | **2B Osmosis**<br>**2B.1** Summarise the process of osmosis including the substance moving, whether energy is required, and the component of the membrane involved in the transport<br>**2B.2** Define tonicity, hypertonic, isotonic and hypotonic<br>**2B.3** Distinguish between the movement of substances in hypertonic, isotonic and hypotonic environments |

ISBN 978-1-108-88711-3

| Study Design | Learning intentions – at the end of this chapter I will be able to: |
|---|---|
| • 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 | **2C Surface area to volume ratio**<br>**2C.1** Define surface area to volume ratio (SA:V) and demonstrate how to calculate SA:V ratio<br>**2C.2** Summarise the impact of an increasing or decreasing SA:V ratio on the efficiency of cellular functions<br>**2C.3** Identify the three ways that cells can increase their SA:V ratio<br>**2C.4** Give reasons why cell size is limited |
| • The structure and specialisation of plant and animal cell organelles for distinct functions, including chloroplasts and mitochondria | **2D Role of chloroplasts and mitochondria**<br>**2D.1** Explain the function of chloroplasts and mitochondria<br>**2D.2** Draw the chloroplast and the mitochondrion, label key structures and state the function of these key structures<br>**2D.3** Summarise the inputs, outputs and location of the stages of photosynthesis and cellular respiration (aerobic and anaerobic)<br>**2D.4** State the word equation and balanced chemical equation for photosynthesis and the word equation for cellular respiration (both aerobic and anaerobic)<br>**2D.5** Demonstrate an understanding of the energy shuttle and why cells need ATP to survive |



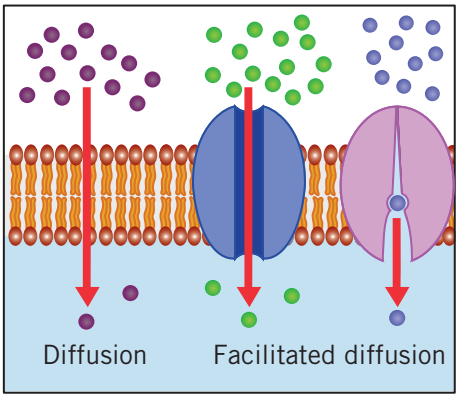
## Glossary

Active transport
ADP (adenosine diphosphate)
Aerobic cellular respiration
Anaerobic cellular respiration
ATP (adenosine triphosphate)
Autotroph
Bulk transport
Carrier protein
Cellular respiration
Channel protein
Chemical energy
Chlorophyll
Concentration gradient
Crenation
Cristae
Endocytosis
Endosymbiosis
Exocytosis
Facilitated diffusion
Fermentation
Flaccid
Glycolysis
Grana
Haemolysis
Heterotroph
Hypertonic
Hypotonic
Hydrophilic
Hydrophobic
Isotonic
Light-dependent stage
Light energy
Light-independent stage
Lipophilic
Lipophobic
Matrix
Osmosis
Passive transport
Phagocytosis
Photosynthesis
Pinocytosis
Plasmolysis
Polar
Protein carrier
Protein-mediated transport
Semi-permeable
Simple diffusion
Sodium–potassium pump
Stroma
Surface area
Surface area to volume ratio (SA:V)
Thylakoid membranes
Tonicity
Turgid
Vesicle-mediated transport
Volume

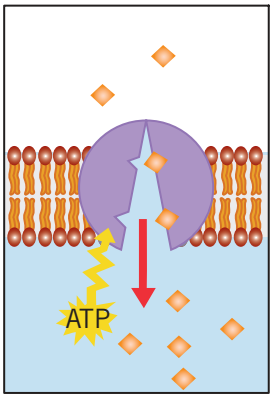
ISBN 978-1-108-88711-3

## Concept map

### 2A The nature of substances and their modes of transport




Passive transport



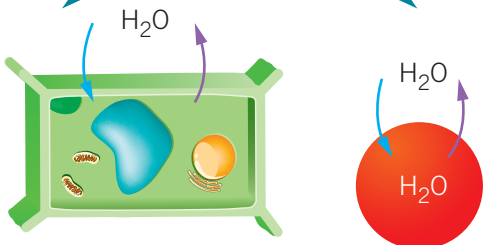

Active transport

*Diffusion of free water is called osmosis*

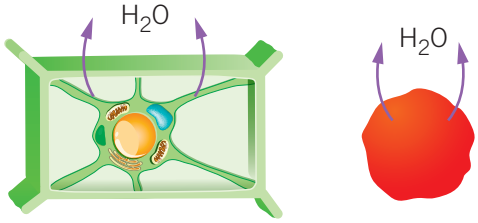
### 2B Osmosis

*Tonicity in plant cells*

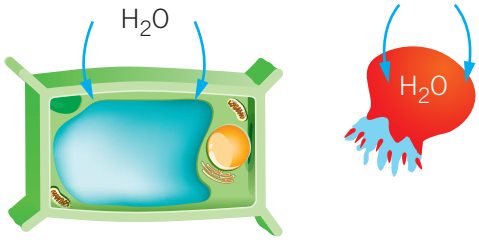
*Tonicity in animal cells*




Isotonic



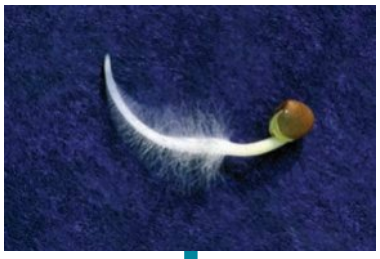

Hypertonic




Hypotonic

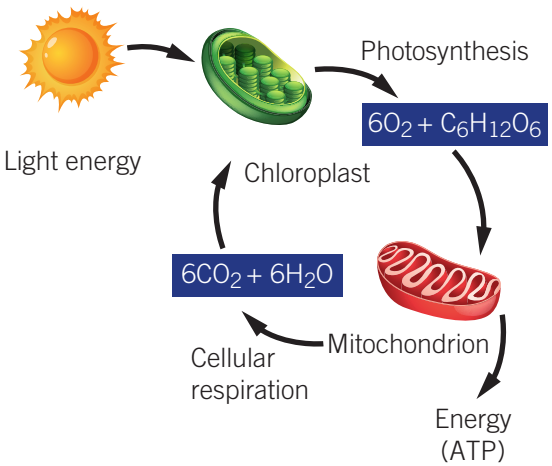
*Efficiency of movement across a membrane is affected by SA:V*

### 2C Surface area to volume ratio



*Processes that occur in the chloroplasts and the mitochondria are dependent on efficient exchange of substances across the membrane*

### 2D Role of chloroplasts and mitochondria




*See the Interactive Textbook for an interactive version of this concept map interlinked with all concept maps for the course, and for a quiz of prior knowledge from Years 9 & 10 science.*

ISBN 978-1-108-88711-3


# The nature of substances and their modes of transport

**Study Design:**
The structure and function of the plasma membrane in the passage of water, hydrophilic and hydrophobic substances via osmosis, facilitated diffusion and active transport

**Glossary:**

| | |
|---|---|
| Active transport | Lipophobic |
| ATP (adenosine triphosphate) | Osmosis |
| Bulk transport | Passive transport |
| Carrier protein | Phagocytosis |
| Channel protein | Pinocytosis |
| Concentration gradient | Polar |
| Endocytosis | Protein carrier |
| Exocytosis | Protein-mediated transport |
| Facilitated diffusion | Semi-permeable |
| Hydrophilic | Simple diffusion |
| Hydrophobic | Sodium–potassium pump |
| Lipophilic | Vesicle-mediated transport |

## ENGAGE

### Transportation across the plasma membrane

In Section 1B you learned that the plasma membrane has a number of functions and that these functions are directly linked to the way it is structured. One of the main roles of the plasma membrane is to control the entry and exit of substances between the internal and external environments of the cell. But what are these substances and why do they need to be transported? What are the different ways in which they move across the plasma membrane? And what could these ideas possibly have to do with eyeballs, neural impulses and disposing of dangerous pathogens?

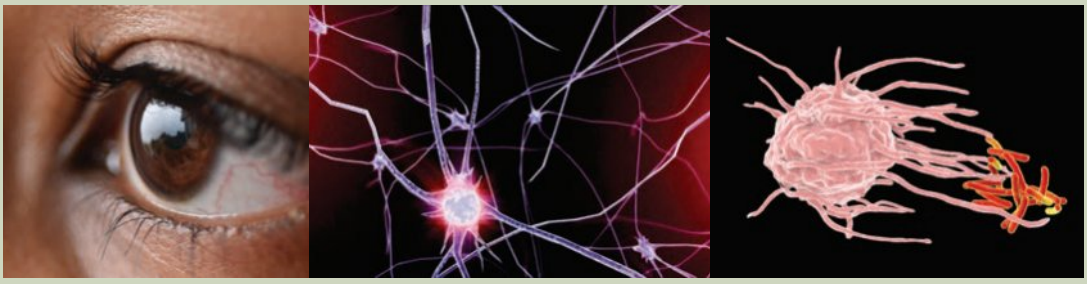


**Figure 2A–1** What do eyeballs, neural impulses and disposing of dangerous pathogens have to do with the movement of substances through membranes?

LINK 1B THE PLASMA MEMBRANE

## EXPLAIN

### The nature of substances and the link to plasma membrane structure

#### Cell survival

The movement of substances into and out of a cell is essential for the cell's survival. Cells need nutrients, so that important cellular processes can occur. For example, they need water, oxygen, amino acids, lipids, sugars and various ions. At the same time, cells need to

LINK 4B THE DIGESTIVE SYSTEM: GETTING THE NUTRIENTS WE NEED

LINK 4E PLANT SYSTEMS

ISBN 978-1-108-88711-3

ensure that unwanted substances or wastes do not accumulate, and so these substances must be disposed of. For example, cells get rid of carbon dioxide, excess water, nitrogenous waste from proteins (such as urea) and particular ions. All these substances move into and out of the cell through the plasma membrane, and in Biology it is imperative that you understand how and why this occurs.

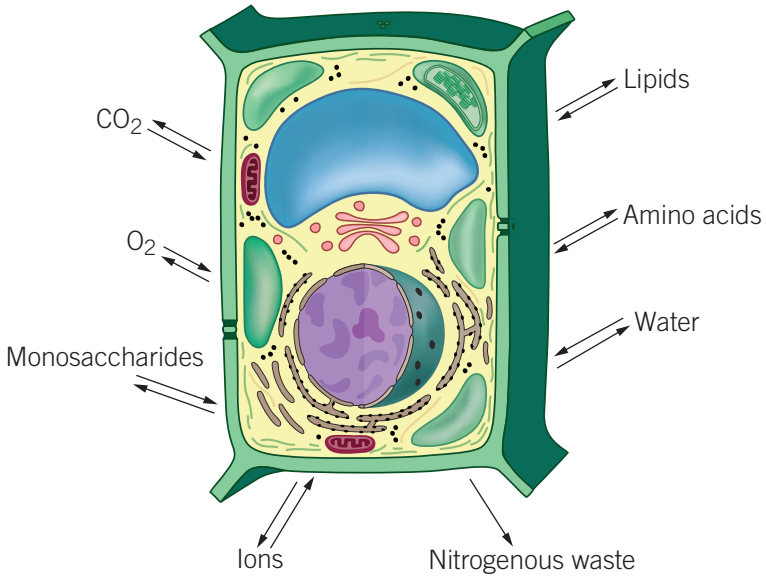



**Figure 2A–2** The movement of different substances across the plasma membrane is essential for the survival of the cell.

**Polar**
describes a molecule that has different charged sides ('poles') and dissolves in water, which is also a polar substance

4E PLANT SYSTEMS LINK

## The nature of substances

What makes understanding the movement of substances challenging is that they do not all have the same characteristics. The molecules of some substances are large, some are small, some are charged and some uncharged, some are **polar** and dissolve in water (**hydrophilic**), while others are non-polar and dissolve in lipids (**lipophilic**).

**Hydrophilic**
dissolves easily in water; also called lipophobic

**Lipophilic**
dissolves easily in lipids; also called hydrophobic

**Lipophobic**
does not dissolve readily in lipids; also called hydrophilic

**Hydrophobic**
does not dissolve readily in water; also called lipophilic

As you progress through this chapter, you will see that several terms can be used interchangeably. For example, substances that dissolve readily in water (and do not dissolve readily in lipids) can be described as *hydrophilic* or **lipophobic**. In the same way, substances that dissolve readily in lipids (and do not dissolve readily in water) can be described as *lipophilic* or **hydrophobic**.

### NOTE

*Hydrophilic* comes from *hydro*, which means water, and *philic*, which means loving. *Lipophobic* comes from *lipo*, which means lipids or fats, and *phobic*, which means hating.

*Hydrophobic* comes from *hydro*, which means water, and *phobic*, which means hating. *Lipophilic* comes from *lipo*, which means lipids or fats, and *philic*, which means loving.

Due to the different characteristics of the substances being transported, there needs to be different ways for the various substances to move across the plasma membrane. It is the different components of the plasma membrane that allow this to happen.

ISBN 978-1-108-88711-3

## Structural elements of the plasma membrane

LINK 1B THE PLASMA MEMBRANE

WORKSHEET 2A–1 MEMBRANES

In Section 1B, the characteristics of the plasma membrane were described. These included the phospholipid bilayer, proteins, carbohydrate chains and cholesterol. Movement through the plasma membrane occurs through two of these structural elements:

- Phospholipid bilayer
  - Lipophilic (hydrophobic) substances move freely through the phospholipid bilayer due to the hydrophobic nature of the fatty acid tails of phospholipids.
  - Water, gases, and other small hydrophobic and polar molecules can diffuse directly across the phospholipid bilayer.
- Protein channels/carriers
  - Polar or hydrophilic substances pass through the channel proteins and carrier proteins.

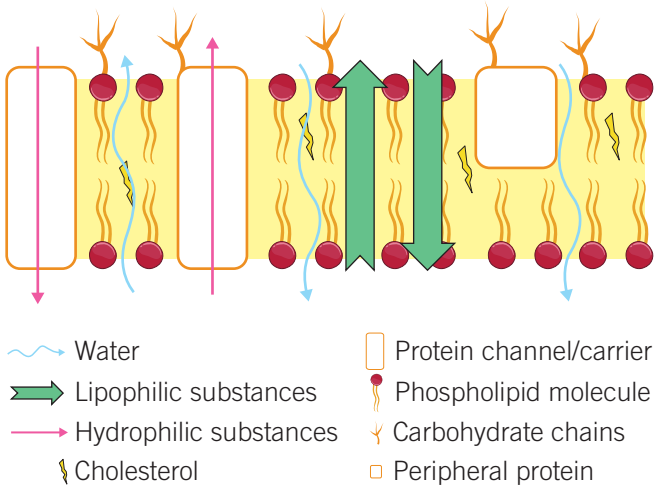



**Figure 2A–3** Depending on their nature, substances move into and out of a cell through the pores (blue arrows), phospholipid bilayer (green arrows) or protein channels/carriers (pink arrows).

It is these structural elements that allow the plasma membrane to be selective about what moves from one side of the plasma membrane to the other. Because of this selectivity, the plasma membrane is referred to as being **semi-permeable** or partially permeable, selectively permeable or differentially permeable. Table 2A–1 summarises the varied nature of substances that a cell needs to move across its plasma membrane in order to survive, and the component of the plasma membrane that these substances move through.

**Semi-permeable** allowing some substances to pass through while preventing the movement of others

**Table 2A–1** The nature of substances (other than water) a cell needs to move, and the component of the plasma membrane they move through

| Nature of substance | Examples | Component of membrane |
|---|---|---|
| Ions | Potassium ($K^+$)<br>Chloride ($Cl^-$)<br>Sodium ($Na^+$) | Protein channel/carrier |
| Non-polar | Oxygen<br>Carbon dioxide | Phospholipid bilayer – pores |
| Hydrophilic and polar | Water | Phospholipid bilayer – pores |
| Lipophilic | Alcohol<br>Lipids, fats, steroids | Phospholipid bilayer |
| Hydrophilic | Sugars (glucose)<br>Amino acids | Protein channel/carrier |
| Large substances | Proteins<br>Complex carbohydrates | Unable to pass through the plasma membrane |

ISBN 978-1-108-88711-3

## Check-in questions – Set 1

1 Give examples of substances that need to move into a cell.
2 Give examples of substances that are moved out of a cell.
3 Define 'semi-permeable'.
4 If a substance is described as 'water soluble', what are some other terms you could use to describe this characteristic?
5 Name the two structural elements involved in movement of substances through the plasma membrane.

**Passive transport** the net movement of a substance from a region of high concentration to a region of low concentration without the need for energy input; can also occur in non-living systems where there is no cell membrane

**Active transport** the net movement of a substance from a region of low concentration to a region of high concentration using a protein carrier and requiring energy input

## The movement of substances

The different modes of transport of substances across the plasma membrane (through the phospholipid bilayer and protein channels/carriers) include simple diffusion, osmosis, facilitated diffusion, active transport and bulk transport.

Biologists classify these forms of transport into two broad categories: **passive transport** and **active transport**. Passive transport does not require any energy to be supplied to the cell (in the form of ATP, which will be explained later). Active transport requires the input of energy. Table 2A–2 shows which of the modes of transport are active and which are passive.

**2D** ROLE OF CHLOROPLASTS AND MITOCHONDRIA LINK

**VIDEO 2A–1** MODES OF TRANSPORT OF SUBSTANCES ACROSS THE PLASMA MEMBRANE

**Table 2A–2** Comparison of passive and active transport

| Type | Energy use | Mode of transport |
|---|---|---|
| Passive | No | Simple diffusion<br>Osmosis<br>Facilitated diffusion |
| Active | Yes | Active transport<br>Bulk transport (endocytosis and exocytosis) |

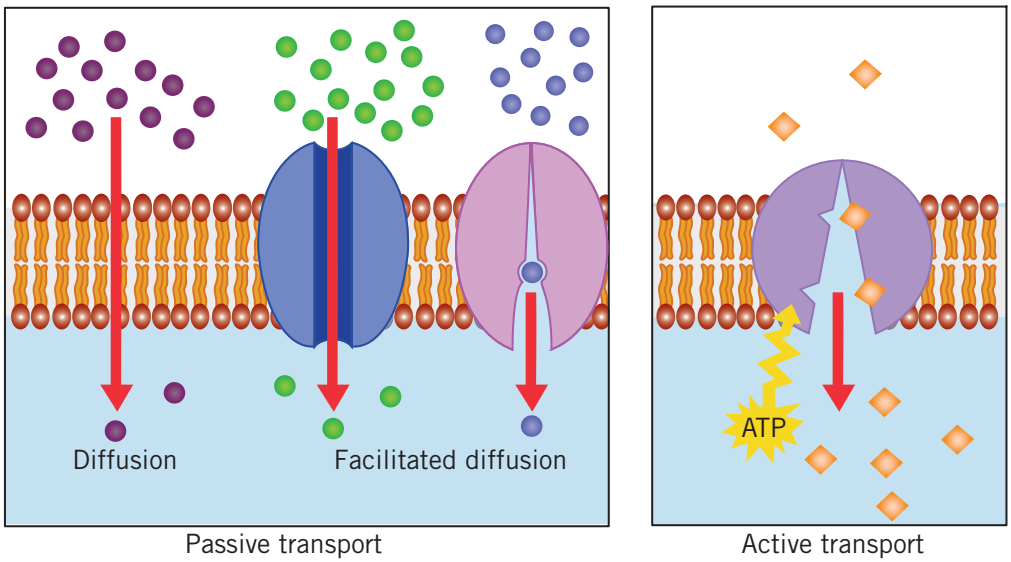



**Figure 2A–4** Comparison of passive and active transport. Can you identify the differences?

ISBN 978-1-108-88711-3

## Passive transport

### Simple diffusion

The most basic way for substances to move is by **simple diffusion** (Figure 2A–5). Diffusion is a type of passive transport, which means it does not require energy. It occurs naturally in both living and non-living systems. In living systems, diffusion can take place across a plasma membrane, as long as the molecule can pass through the hydrophobic fatty acid tails of the phospholipid bilayer. Examples of substances that move by simple diffusion are oxygen, urea, carbon dioxide, alcohol and steroid hormones.

**Simple diffusion** the net passive movement of a substance from a region of high concentration to a region of low concentration until equilibrium is reached; does not require energy

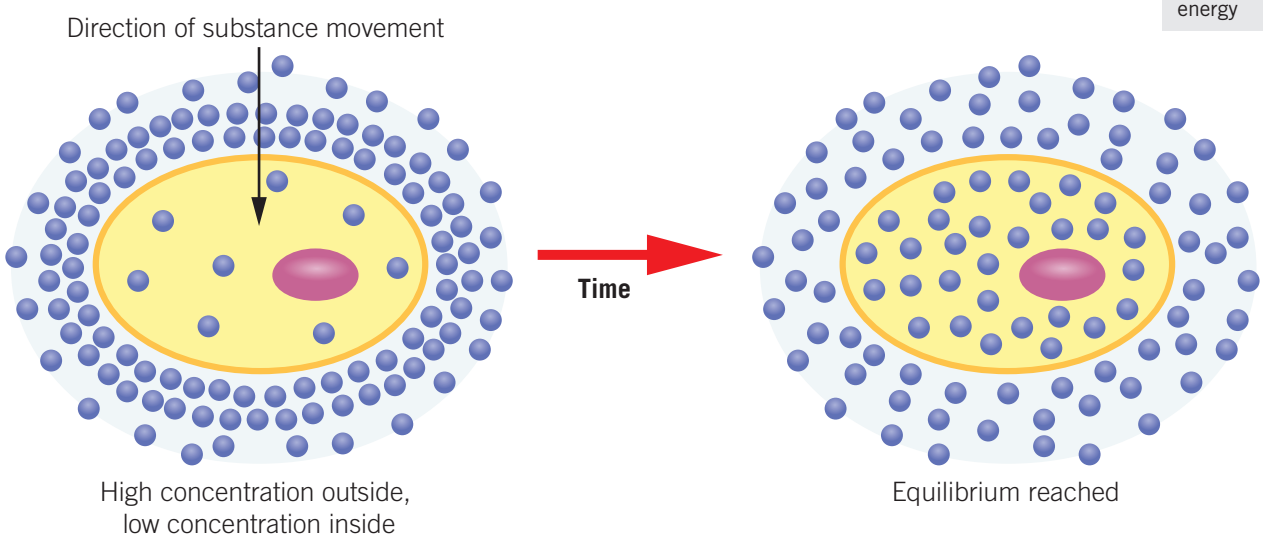



**Figure 2A–5** Diffusion: the net passive movement of a substance from a region of high concentration to a region of low concentration until equilibrium is reached (meaning the concentration is equal on both sides)

As you progress to human body systems in Chapter 4, you will learn more about the role of diffusion in keeping cells alive.

LINK **4B** THE DIGESTIVE SYSTEM: GETTING THE NUTRIENTS WE NEED

### Rate of diffusion

The conditions within a cell can affect the rate or speed at which substances diffuse across the plasma membrane. Because diffusion is necessary for a cell to survive, the cell requires the most optimal conditions so that diffusion is as efficient as possible. Table 2A–3 summarises the main factors that can affect the rate of diffusion.

**Concentration gradient** the difference between the concentrations of a substance in two regions; if there is a large difference, the concentration gradient is steep; diffusion occurs from a region of high concentration to a region of low concentration, along a concentration gradient

**Table 2A–3** Factors that affect the rate of diffusion

| Factor | How diffusion is affected |
|---|---|
| Size | The smaller the molecules of a substance, the higher the rate of diffusion |
| Concentration | The greater the difference in concentration between the two regions (known as a **concentration gradient**), the higher the rate of diffusion |
| Temperature | The higher the temperature, the higher the rate of diffusion. When the temperature increases, the vibrations (kinetic energy) of the molecules also increase, and so it is easier for them to move and also move faster |

ISBN 978-1-108-88711-3

## Check-in questions – Set 2

1 Name two differences between passive and active transport.
2 Give examples of the modes of passive transport.
3 Define 'simple diffusion'.
4 Define 'concentration gradient'.
5 List the factors that can affect the rate of diffusion.

**Osmosis**
the net passive movement of free water from a region of high free water concentration to a region of low free water concentration across a semi-permeable membrane until equilibrium is reached

2B OSMOSIS LINK

1B PLASMA MEMBRANE LINK

### Osmosis

Like diffusion, **osmosis** is a form of passive transport, meaning it requires no input of energy. You will learn more about osmosis in Section 2B, as it is a special case of diffusion, involving the movement of free water molecules. 'Free' in this case means the water molecules are not bound to anything and can move freely.

### Facilitated diffusion

A third type of passive transport is **facilitated diffusion**. As the name implies, this mode of transport is diffusion with assistance from a **carrier protein** or **channel protein**. These are the same protein transport molecules you saw in Section 1B, embedded in the plasma membrane. Keep in mind that this process is diffusion (passive, no energy required, moving from a region of high concentration to a region of low concentration), but it involves moving hydrophilic or polar substances that cannot diffuse through the phospholipid bilayer portion of the plasma membrane. These hydrophilic substances therefore need help to get across the plasma membrane. Facilitated diffusion is also referred to as **protein-mediated transport**.

**Facilitated diffusion**
the net passive movement of a particular substance from a region of high concentration to a region of low concentration with the assistance of carrier proteins or channel proteins; also known as protein-mediated transport

**Carrier protein**
a transmembrane protein that binds to a specific substance (e.g. glucose) and changes shape to move that substance across the plasma membrane, releasing it to the other side

**Channel protein**
a transmembrane protein that allows hydrophilic or polar substances to move across the plasma membrane from a region of high concentration to a region of low concentration

**Protein-mediated transport**
when a transmembrane protein assists in the transport of a substance across a plasma membrane; also known as facilitated diffusion

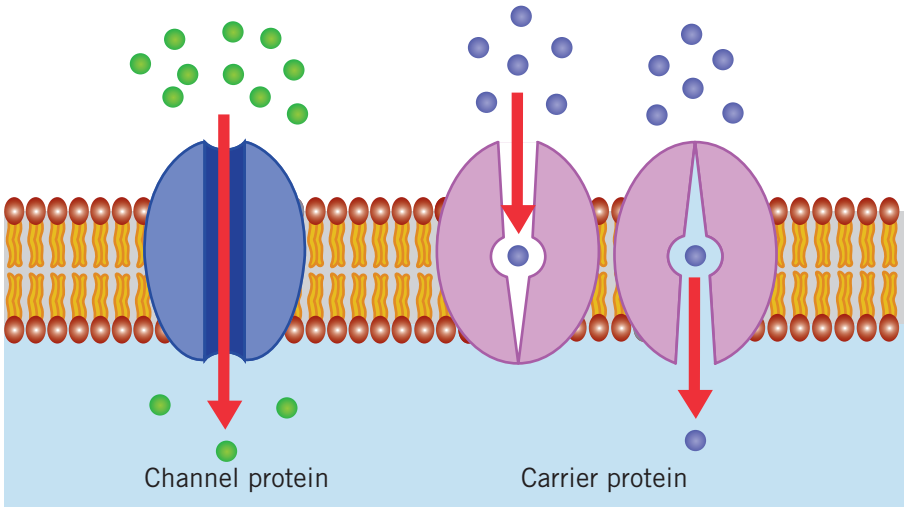



**Figure 2A–6** Facilitated diffusion: the net passive movement of particular hydrophilic or polar substances across the plasma membrane with the assistance of channel proteins (left) or carrier proteins (right)

ISBN 978-1-108-88711-3

The term 'protein-mediated' means that a carrier protein or channel protein is required for this mode of transport to occur.

- *Carrier proteins* are transmembrane proteins that bind to a particular substance and change shape to move the substance across the membrane to the other side. This is the case with hydrophilic substances such as glucose (a monosaccharide) and amino acids (protein monomers). Carrier proteins are specific to the substance they are transporting and are sometimes referred to as being selective, in that some molecules are transported while others are not.
- *Channel proteins* are transmembrane proteins that allow hydrophilic substances to move through the membrane from a region of high concentration to a region of low concentration.

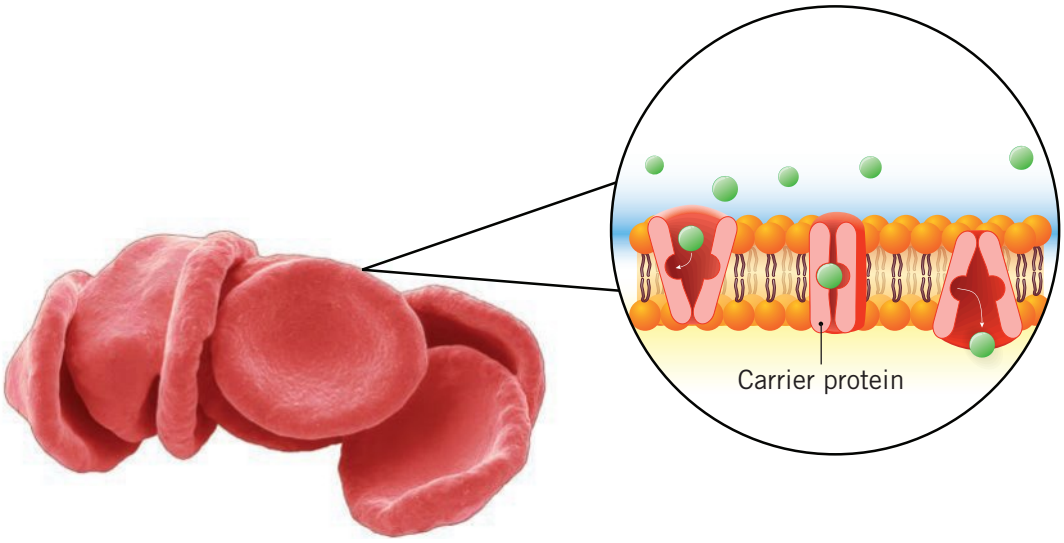



**Figure 2A–7** The transport of glucose by facilitated diffusion across a red blood cell plasma membrane with the assistance of a carrier protein called a uniporter

## Check-in questions – Set 3

1 Define 'facilitated diffusion'.
2 Name the two types of proteins that may be involved in facilitated diffusion.
3 List the similarities between simple diffusion and facilitated diffusion.
4 List the differences between simple diffusion and facilitated diffusion.

### Active transport

Like passive transport, active transport is a selective process for moving substances across a membrane, and it occurs in living cells. However, active transport requires energy, in the form of **ATP (adenosine triphosphate)**, as the substances are moved from a region of low substance concentration to a region of high substance concentration. This is the reverse of the way substances naturally move and become distributed. You will learn more about ATP in Section 2D.

**ATP (adenosine triphosphate)** the main immediate source of chemical energy in a cell, powering most cellular processes; energy is released when a phosphate group is removed, forming ADP (adenosine diphosphate)

LINK **2D** ROLE OF CHLOROPLASTS AND MITOCHONDRIA

ISBN 978-1-108-88711-3

Active transport is a protein-mediated process, just like facilitated diffusion. Every plasma membrane contains special carrier proteins, also called protein pumps, which use ATP as a fuel for the pump. Some carrier proteins transport one substance and some transport two substances simultaneously, but all are specific for certain substances, and in this way they are able to regulate the movement of that substance. This is why active transport is considered to be a selective process. Figure 2A–8 shows the selective nature of the carrier protein and how, during the transport process, the carrier protein undergoes a shape change.

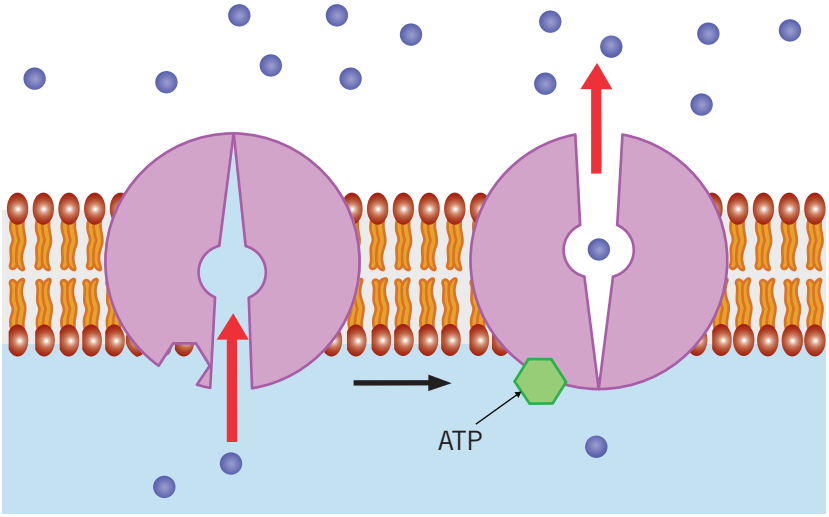



**Figure 2A–8** Active transport is a selective process in which substances are moved from a region of low concentration to a region of high concentration. It requires a carrier protein and ATP.

**Sodium–potassium pump** the exchange of sodium and potassium ions across the plasma membrane of an axon by protein carriers, fuelled by ATP; leads to an action potential

A well-known example of a carrier protein is the **sodium–potassium pump**. The active transport of positive ions into and out of the axon of a neuron, by carrier proteins, is called an *action potential*. This is how the neuron sends electrical messages along its axon.

**4B** THE DIGESTIVE SYSTEM: GETTING THE NUTRIENTS WE NEED LINK

In Chapter 4, you will also explore the human digestive and excretory systems, where active transport allows absorption of glucose in the small intestine and the reabsorption of nutrients in the kidney.

## Check-in questions – Set 4

1 Define the following key terms: ATP, carrier protein, sodium–potassium pump.
2 List the similarities and differences between active and passive transport.
3 List the similarities and differences between active transport and facilitated diffusion.
4 What is the term used to describe carrier proteins that are specific for certain substances and regulate the movement of those substances?

**Bulk transport** the movement of large particles (solid or liquid) across the plasma membrane, requiring the input of energy (ATP)

## Bulk transport

If the molecules of a substance are too large (or if there are too many molecules) for any of the forms of transport discussed so far, **bulk transport** is required. Bulk transport is the movement of large particles (or large volumes of liquids) across the plasma membrane, requiring the input of energy (ATP). As the process needs ATP, it is classified as a form of active transport.

ISBN 978-1-108-88711-3

Bulk transport operates differently from other transport processes. It is **vesicle-mediated transport**, which means it uses membrane-bound structures. This is why cholesterol is such an important component of the plasma membrane – it allows the membrane to be broken and remade as substances enter and leave the cell, avoiding the need for a substance to cross directly through a particular component of the plasma membrane.

The two main types of bulk transport are **endocytosis** and **exocytosis**. In endocytosis:

1. the substance, including fluid, moves closer to the plasma membrane
2. a portion of the plasma membrane is invaginated (turned in on itself)
3. the membrane pinches off, forming a membrane-bound vesicle that contains the substance being transported.

**Vesicle-mediated transport** the movement of substances across the plasma membrane using membrane-bound structures within the cell; vesicles are formed from a section of cell membrane

**Endocytosis** the movement of large particles (or a large quantity of small particles) into the cell without directly crossing the plasma membrane, using vesicles and ATP

**Exocytosis** the movement of large particles (or a large quantity of small particles) out of the cell without directly crossing the plasma membrane, using vesicles and ATP

## NOTE

The term 'endocytosis' comes from *endo* meaning 'internal' and *cyte* meaning 'cell'.

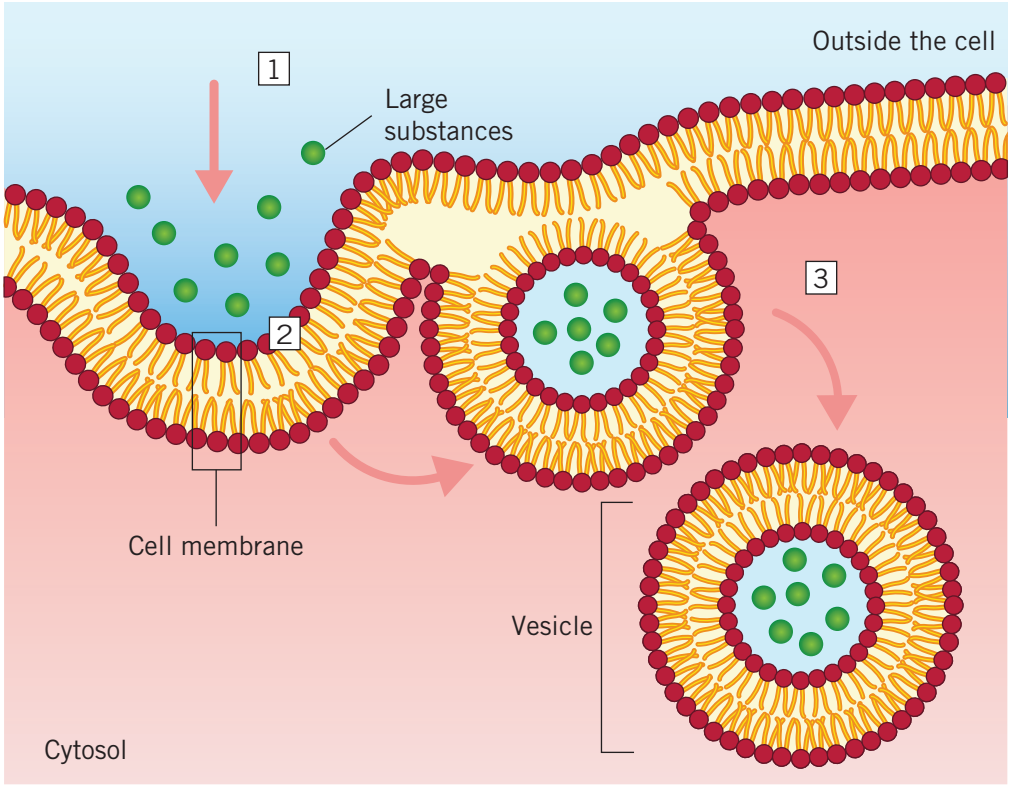



**Figure 2A–9** Endocytosis is a type of active transport where large particles are moved into a cell inside vesicles. Numbers refer to the steps in the text above.

If the substance entering the cell is:

- solid (such as a pathogen or food), the process is called **phagocytosis** (*phago* = eating)
- liquid or dissolved, the process is called **pinocytosis** (*pino* = drinking). Pinocytosis occurs in almost all cells, continuously.

**Phagocytosis** a type of endocytosis in which a solid substance enters a cell by vesicle-mediated transport

**Pinocytosis** a type of endocytosis in which a liquid or dissolved substance enters a cell by vesicle-mediated transport

ISBN 978-1-108-88711-3

WORKSHEET 2A–2 MOVEMENT THROUGH MEMBRANES

Exocytosis is the reverse of endocytosis (*exo* = external). It is the movement of substances out of the cell without crossing the membrane. In exocytosis:

1. the substance to be exported (often protein molecules) is enclosed in a vesicle from the Golgi apparatus
2. the vesicle moves towards and fuses with the plasma membrane
3. the vesicle releases its contents into the extracellular fluid.

1D ORGANELLES LINK

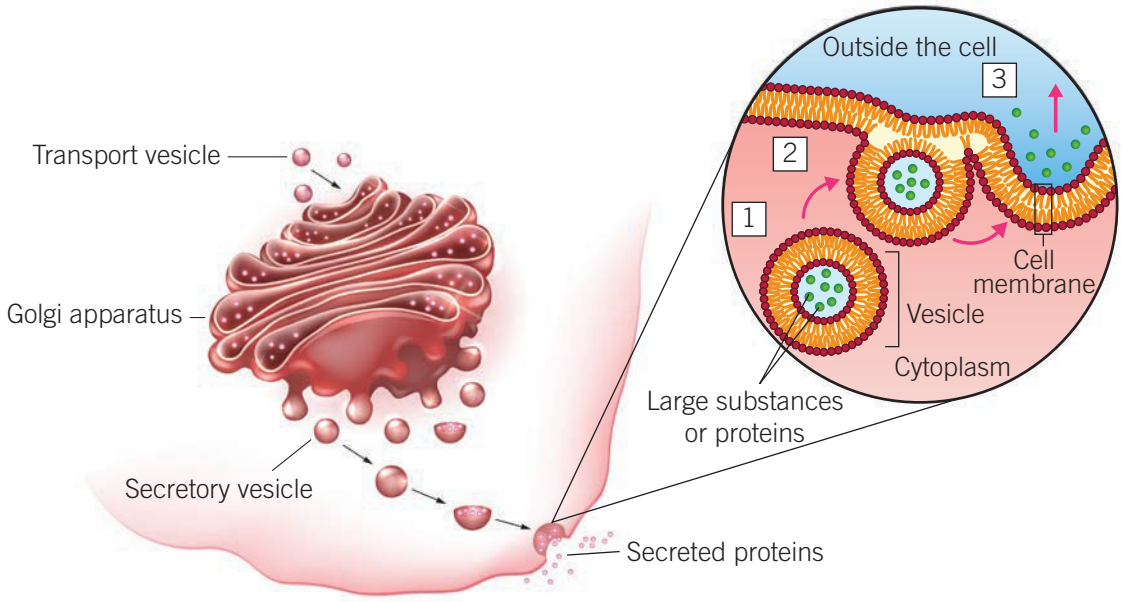


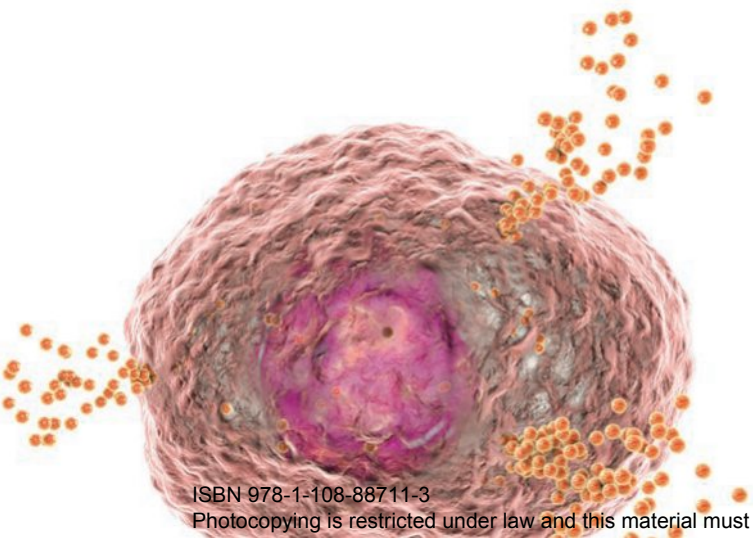

**Figure 2A–10** Exocytosis is a type of active transport in which large substances are moved out of a cell by vesicles. Numbers refer to the steps in the text above.

CHAPTER 4 LINK

The focus of Chapter 4 is your body's physiology, and this includes both endocytosis and exocytosis. For example, enzymes are released from cells in the stomach and small intestine by exocytosis to aid the breakdown of nutrients.

## Check-in questions – Set 5

1. Is bulk transport an active or passive process? Why?
2. What does it mean when we say that bulk transport is vesicle-mediated?
3. Define the following key terms: endocytosis, exocytosis.
4. a What is the term that means 'cell eating'?
   b What is the term that means 'cell drinking'?



ISBN 978-1-108-88711-3

## 2A SKILLS

**VIDEO 2A–2** SKILLS: IDENTIFYING KEY CONTENT WORDS

### Identifying key content words

You may recognise Figure 2A–11 as the phospholipid bilayer of a plasma membrane, with a transmembrane protein going through it. Several structural components are missing from this diagram, but you can still identify it as a plasma membrane.

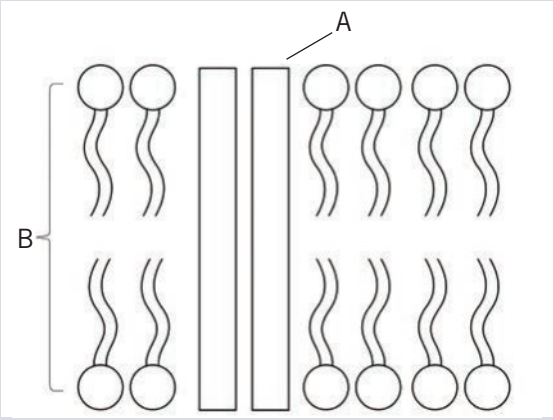



**Figure 2A–11** Sample image of the phospholipid bilayer that you might see in an assessment situation

In Units 1–4 you will need to practise reading questions very carefully so that you answer the question being asked, not the question you want to answer. To do this, you need to identify the key content words. For example, if the question says:

'Name the structures labelled A and B in the figure.'

that is a very different question from:

'What biomacromolecule are structures A and B made of?'

In an examination situation, you may be feeling stressed and busy scanning questions, but it is worth taking the time to read each word, and ensure you understand what is being asked. Highlighting or underlining key words can be a useful way of ensuring that you focus on each key content word in a question.

So: what are the answers to the two questions above?

*Question*: Name the structures labelled A and B in the figure.

*Answer*: A is a channel protein and B is the phosophlipid bilayer.

*Question*: What biomacromolecule are structures A and B made of?

*Answer*: A is made of protein, and B is made of lipid.

To prepare for assessment questions, you can predict the key content words by looking at the glossary terms for each content area and their definitions. Some examples of key content words in this section are: net, passive, osmosis, high concentration, semi-permeable membrane and protein-mediated. It is recommended that you make a comprehensive list of all key content words and their definitions, perhaps using flashcards and/or online tools. Completing practice assessment questions is also very useful, as you will quickly learn to identify the key content words the more questions you do. Therefore, practise writing these definitions meticulously.

ISBN 978-1-108-88711-3

Consider the following example:

*Question*: Draw a diagram showing a semi-permeable membrane with solute molecules on both sides. Include an arrow showing the direction of movement of the solute molecules as they move by active transport.

*Answer*:

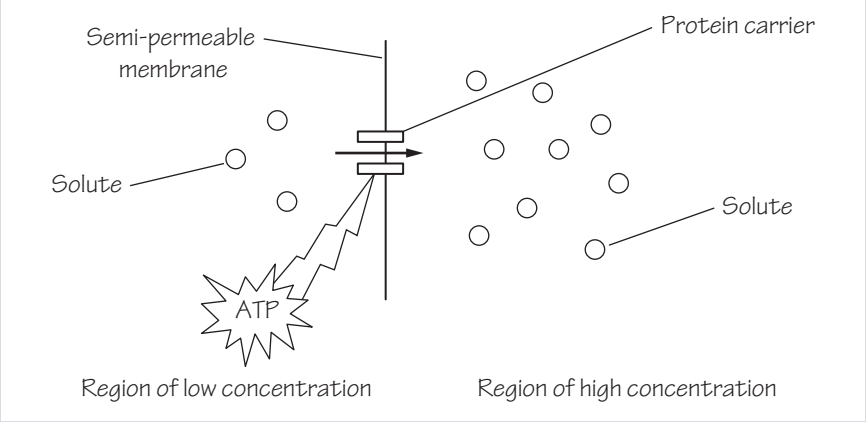



**Figure 2A–12** Sample answer: diagram showing the movement of a solute by active transport

You would answer this question by first highlighting the key content words: semi-permeable membrane, solute and active transport. What do you know about each key word that will help you draw your diagram? A *semi-permeable membrane* allows some substances to pass through and restricts the transport of others; a *solute* is a substance that can dissolve in another substance; *active transport* is the net movement of substances from a region of low substance concentration to a region of high substance concentration using a protein carrier, with energy input. So now you know what you need, as everything is there for you: a semi-permeable membrane, solute in low concentration on one side, arrow to a high concentration of solute on the other side, a protein carrier through the membrane and energy or ATP.

VIDEO 2A–3 SKILLS: COMPARISONS

### Comparisons

In Chapter 1 you read about how to answer comparison-based questions. When preparing for this type of question, consider what content you have covered that could be assessed in this way. Remember, to make a comparison means to give an account of the similarities and differences between two (or more) items, referring to both of them throughout your answer. In this section, the following concepts could be the foundation of comparison-based questions, so you can prepare for these questions by noting down the similarities and differences:

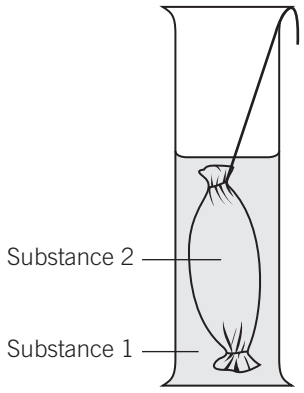
- passive and active transport
- simple diffusion and facilitated diffusion
- facilitated diffusion and active transport
- channel proteins and carrier proteins
- endocytosis and exocytosis.

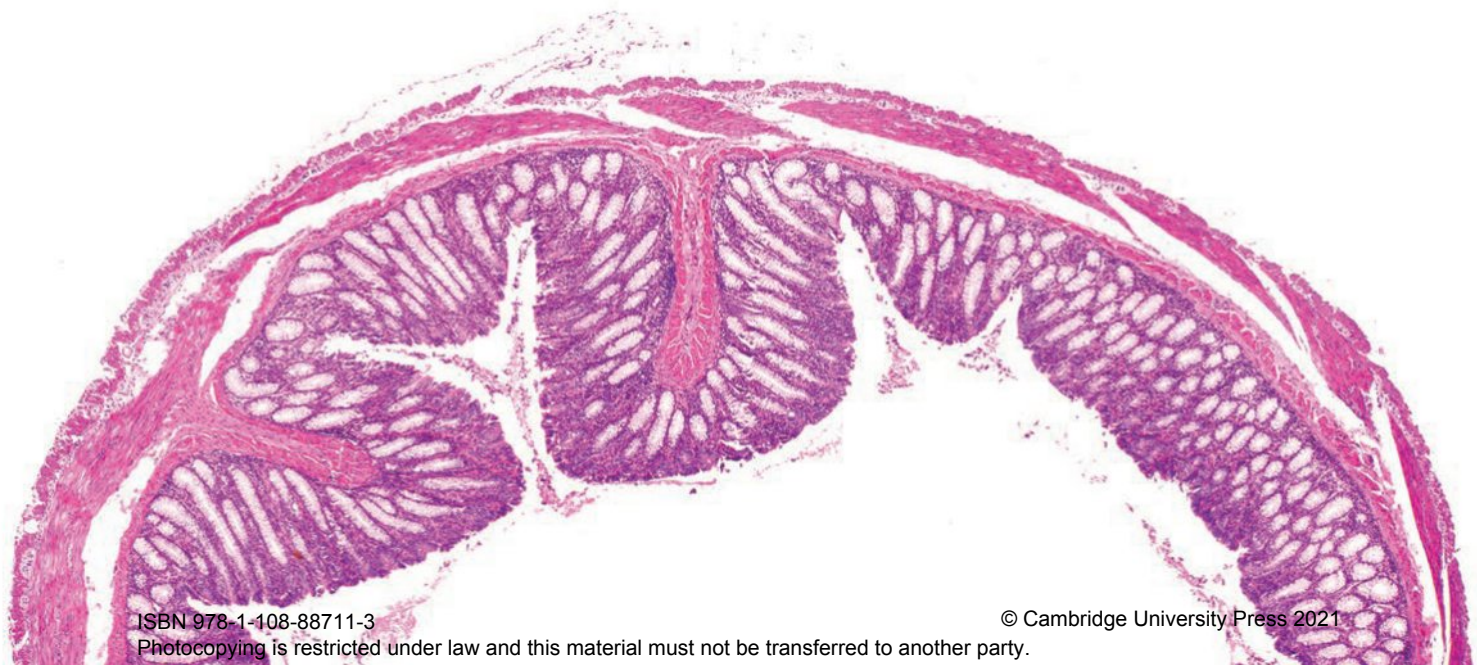
The Check-in questions in this section are designed to help you practise addressing the similarities and differences between many of these concepts, so be sure to attempt these. When you look at the answers, carefully assess how well you met the demands of the question.

ISBN 978-1-108-88711-3

## Section 2A questions

1 State why plasma membranes are crucial to the survival of cells.
2 Why are some membranes called 'selectively permeable'?
3 Give examples of substances that move through:
   a the phospholipid bilayer
   b channel proteins.
4 A tray of cookies was baking in the school Food Technology room. Explain why those closest to the kitchen were first to notice. Include any relevant definitions.
5 Proteins are large molecules that are needed by all cells.
   a Proteins can enter a cell by which process?
   b What source of energy is needed for this process?
   c Is this an example of passive or active transport?
6 Identify three features of facilitated diffusion.
7 Distinguish between channel proteins and carrier proteins.
8 Summarise what is meant by 'concentration gradient', using examples.
9 In murder mystery stories, chloroform is used to daze or knock out people. Chloroform is a hydrophobic molecule that acts extremely quickly. Give reasons why this property allows it to act so rapidly.
10 Sometimes energy is required for the process of transferring nutrients, such as glucose, from the gut to the blood. Determine the conditions in which energy would be required for this transfer of glucose from the gut to the blood, and when it would not be required.
11 Dialysis tubing (see the diagram) is an artificial membrane made of cellulose. Compare dialysis tubing to a natural plasma membrane in terms of its ability to transport substances from one side of the membrane to the other. Consider the different modes of transport and the nature of the substances being moved.
12 Examine how the plasma membrane is involved in endocytosis and exocytosis. Include definitions and diagrams in your answer.



ISBN 978-1-108-88711-3


# Osmosis

**Study Design:**
The structure and function of the plasma membrane in the passage of water, hydrophilic and hydrophobic substances via osmosis, facilitated diffusion and active transport

**Glossary:**
Crenation
Flaccid
Haemolysis
Hypertonic
Hypotonic
Isotonic
Plasmolysis
Tonicity
Turgid

## ENGAGE

### Introducing 'osmosis'

**2A** THE NATURE OF SUBSTANCES AND THEIR MODES OF TRANSPORT LINK

It was noted in Section 2A that osmosis is a mode of transport that warranted some extra attention. But why? It has to do with one of the reasons why kidney dialysis machines work so well to replace normal kidney function. You will learn in Section 4D that the kidneys help to filter wastes (or metabolites) out of the blood and maintain the balance of ions or electrolytes that are dissolved in the blood. If someone has chronic kidney failure, this important process cannot occur successfully. It is the role of kidney dialysis machines to take on this filtering role of the kidney, using a semi-permeable membrane and a liquid called dialysis solution. The membrane allows for the selective exchange of substances between the blood and the dialysis solution and involves the process of osmosis.

**4D** THE EXCRETORY SYSTEM: ELIMINATING WASTE LINK

**Figure 2B–1** A dialysis machine uses osmosis to move toxins out of the blood and replace the filtering function of the kidneys.

## EXPLAIN

### Defining 'osmosis'

As you read in Section 2A, osmosis is a way of transporting water across a plasma membrane. *Osmosis* is a special case of diffusion, so let's first revisit the definition of simple diffusion:

> *Simple diffusion* is the net passive movement of a substance from a region of high concentration to a region of low concentration until equilibrium is reached.

Now the definition of osmosis:

> *Osmosis* is the net passive movement of free water from a region of high free water concentration to a region of low free water concentration across a semi-permeable membrane until equilibrium is reached.

**VIDEO 2B–1** OSMOSIS

As you can see from this comparison, osmosis is about the movement of free water. Just like diffusion (because it is the diffusion of water), osmosis is a passive process that requires no input of energy (ATP) to occur.

ISBN 978-1-108-88711-3

In Figure 2B–2, there are sugar molecules and water molecules on both sides of the semi-permeable membrane, which runs down the centre. In the left image, note where the lowest and highest concentrations of sugar molecules are. Which way will they diffuse across the membrane? Also note where the lowest and highest concentrations of free water molecules are. Which way will they diffuse (by osmosis) across the membrane? Now compare the left image with the right image. What changes have occurred? The free water has moved across the semi-permeable membrane from a region of high free water concentration to low free water concentration until evenly distributed on both sides. This is osmosis. Notice that the sugar molecules have not moved, despite there being a difference in the concentration on each side (concentration gradient). This is because the sugar molecules are too large to move through this membrane, so the free water moved to balance the concentrations of solution on either side of the membrane.

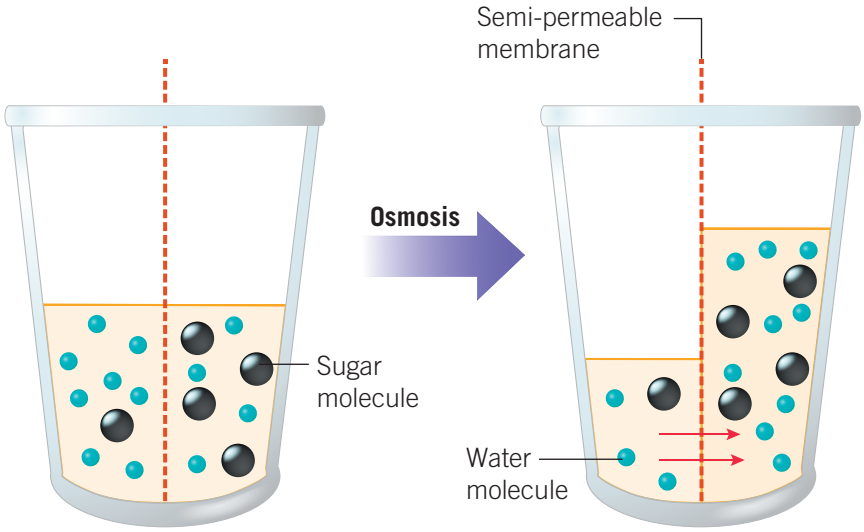



**Figure 2B–2** Osmosis: the net passive movement of free water from a region of high free water concentration to a region of low free water concentration across a semi-permeable membrane until equilibrium is reached

Note that when there is a high concentration of free water molecules in a solution, the solution has a low concentration of solute and is called *dilute*. If there is a low concentration of free water molecules in a solution, there is a comparatively higher concentration of solute and therefore the solution is said to be *concentrated*. In VCE Biology, there are two definitions for osmosis: one refers to free water, as discussed above, and one refers to the solute concentration. In an assessment situation, both definitions are equally acceptable as long as you don't get them confused. So the alternative definition for osmosis is:

> *Osmosis* is the net passive movement of free water from a region of low solute concentration to a region of high solute concentration across a semi-permeable membrane until equilibrium is reached.

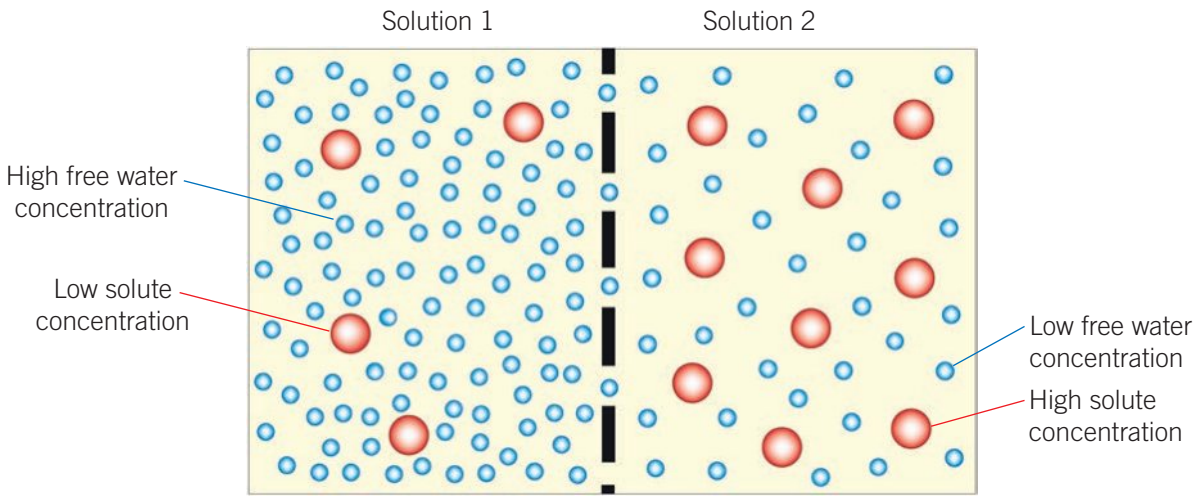



**Figure 2B–3** Solutions can be described in two ways: by their water concentration or by their solute concentration.

ISBN 978-1-108-88711-3

## Check-in questions – Set 1

1 a Define 'osmosis', referring to free water concentration.
  b How could you define 'osmosis' another way?
2 List two similarities and two differences between diffusion and osmosis.

**Tonicity**
how the concentration of solutes dissolved in an extracellular solution determines the direction and rate of osmosis and therefore the volume of a cell

**Hypotonic**
refers to a solution that has a lower solute concentration than the cell's internal environment (*hypo* = lower)

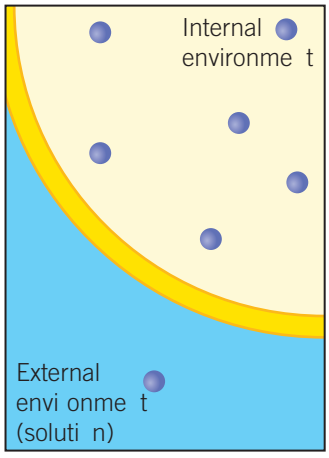
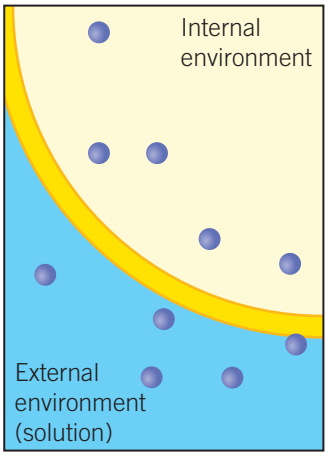
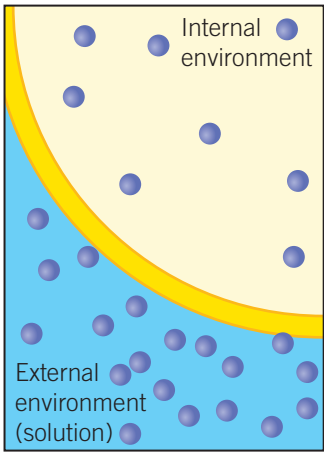
**Isotonic**
refers to a solution that has the same solute concentration as the cell's internal environment (*iso* = same)

**Hypertonic**
refers to a solution that has a higher solute concentration than the cell's internal environment (*hyper* = higher)

## Tonicity

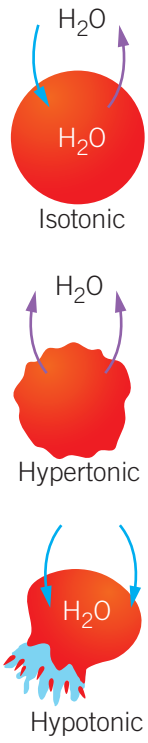
Water is the medium in which many of the chemical processes of cells take place. This is because it is an excellent solvent and can therefore transport a lot of substances (solutes), as water moves easily through the plasma membrane. As a consequence, the water content of the solution outside a cell (the cell's external environment) will affect the conditions inside the cell (the cell's internal environment). This is called **tonicity**. Tonicity means that the concentration of solutes dissolved in an extracellular solution can determine the direction and rate of osmosis, and therefore the volume of a cell. Before investigating tonicity further, you need to understand the terms used to describe the environment in which a cell resides – **hypotonic**, **isotonic** and **hypertonic**.

**Table 2B–1** Describing the solution surrounding cells

| Name | Hypotonic | Isotonic | Hypertonic |
|---|---|---|---|
| Diagram |  |  |  |
| Solute | Solution has a lower solute concentration than inside the cell (*hypo* = less than) | Solution has the same solute concentration as inside the cell (*iso* = same) | Solution has a higher solute concentration than inside the cell (*hyper* = more than) |
| Water | Concentration is higher outside the cell | Concentration is the same inside and outside the cell | Concentration is lower outside the cell |

Let's have a look at how these different environments affect the movement of free water into and out of cells. Assume the solutes in these scenarios are not able to move across the membrane.

ISBN 978-1-108-88711-3




## Tonicity in red blood cells (example of animal cell)

In an *isotonic* environment, the concentration of solutes (and therefore free water) is the same inside and outside the cell. This means there is no concentration gradient, so there is no *net* movement of water or solutes in either direction, because equilibrium already exists. Remember, even though there is no *net* movement, free water is still moving in and out of the cell, just in equal amounts each way.

In a *hypertonic* environment, there is a high concentration of solutes (and therefore low free water) outside the cell. Osmosis is the movement of free water from high free water concentration to low free water concentration, so water tends to move *out* of the cell. When water exits the cell, the cell shrinks and its edge becomes crinkled – this is called **crenation**.

In a *hypotonic* environment, there is a low concentration of solutes (and therefore high free water) outside the cell. Osmosis is the movement of free water from high free water concentration to low free water concentration, and so water tends to move *into* the cell. When water enters the cell, the cell expands and may become so full that it bursts – this is called **haemolysis** (lysis in other types of animal cells).

**Crenation** the shrinkage of a cell that occurs when there is net movement of water out of the cell while it is in a hypertonic solution

**Haemolysis** the rupture or bursting of a red blood cell that occurs when there is net movement of water into the cell while it is in a hypotonic solution

**Figure 2B–4** Tonicity, the concentration of solutes in a cell's external environment, can affect the volume of a red blood cell. Depending on the concentration, crenation (middle – if the cell is in a hypertonic environment) or haemolysis (bottom – if the cell is in a hypotonic environment) may result.

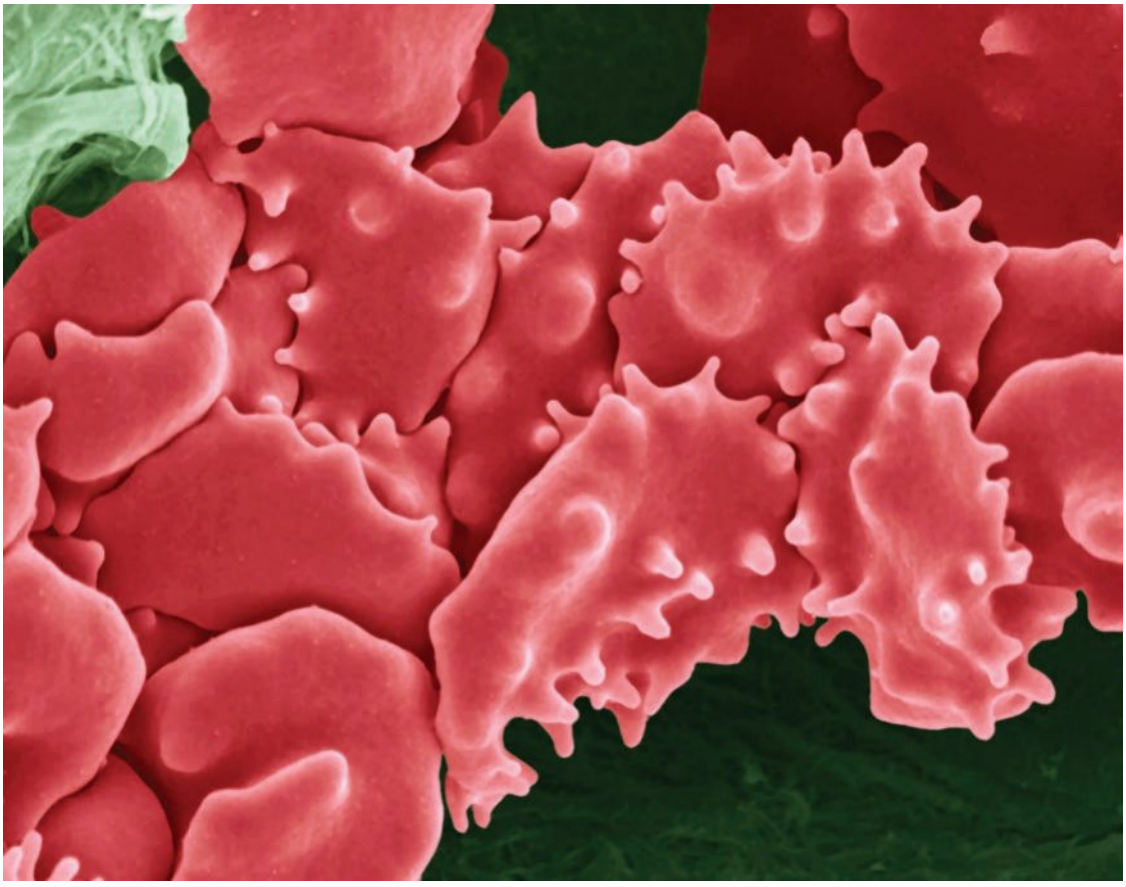


**Figure 2B–5** When a red blood cell is placed in a hypertonic solution, there is net passive movement of free water out of the cell and crenation occurs.

ISBN 978-1-108-88711-3

A great example of diffusion and osmosis working together (although not specifically assessable as part of the Study Design) is the case of kidney dialysis. Here, these processes cause toxins and metabolites (waste products) to move out of the blood and into the dialysis solution, through the semi-permeable membrane. The dialysis solution is continuously replaced to maintain this direction of movement. The membrane also allows electrolytes to pass through so that any excess products can be disposed of in this way too. Blood cells and large proteins that need to stay in the blood vessels are unable to fit through the pores in the membrane.

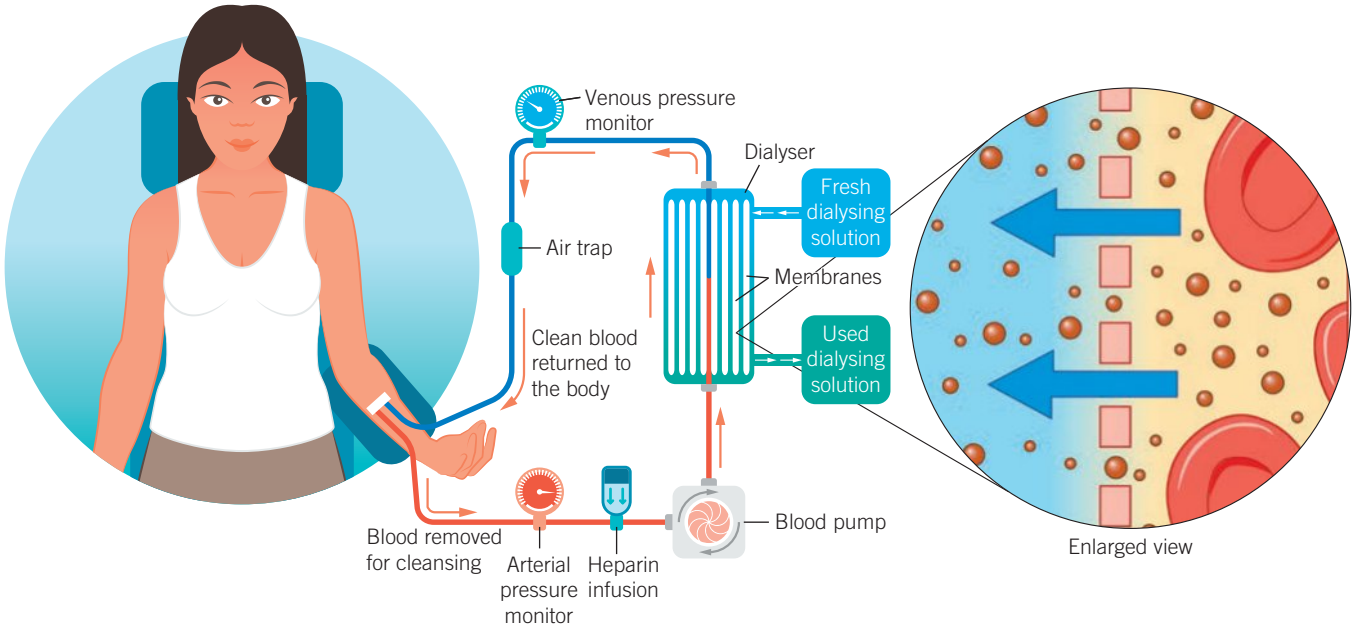



**Figure 2B–6** Kidney dialysis filters the blood of patients whose kidneys are unable to filter their own blood. Toxins, metabolites, excess fluid and excess electrolytes move through the dialysis membrane into the dialysis solution, which is continuously replaced.

**Flaccid** refers to a plant cell that is not turgid or plasmolysed, but is limp due to lack of water and consequently the plant wilts

**Plasmolysis** the contraction of the plasma membrane and cytoplasm of a plant cell away from the cell wall when there is net passive movement of free water out of the cell while it is in a hypertonic solution

**Turgid** refers to a plant cell that has expanded or swollen when there is net passive movement of free water into the cell while it is in a hypotonic solution

## Tonicity in plant cells

A plant cell that is in an *isotonic* environment is in equilibrium, with no *net* movement of free water into or out of the cell (even though water is moving continuously) (Figure 2B–7).

If the plant cell is in a *hypertonic* environment, free water exits the cell, and initially the cells become limp – you would see the plant wilting, or becoming **flaccid** (Figure 2B–9). At a cellular level, the plasma membrane pulls away from the cell wall and contracts, while the vacuole shrinks. This is called **plasmolysis** (Figure 2B–8).

When a plant cell is in a *hypotonic* environment, free water enters the plant cell, the plasma membrane pushes against the cell wall and the vacuole expands – the cell is described as **turgid**. The plant cell will not burst, due to the rigidity of its cell wall.

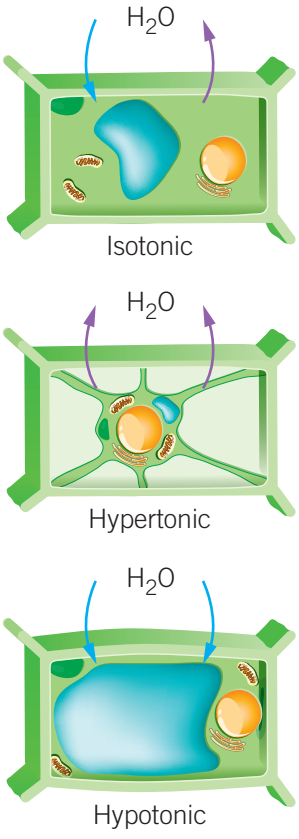



**Figure 2B–7** Tonicity, the concentration of solutes in an external environment, can affect the volume of a plant cell. In a hypertonic environment, plasmolysis (middle) may result. In a hypotonic environement, turgid cells (bottom) may result.

ISBN 978-1-108-88711-3

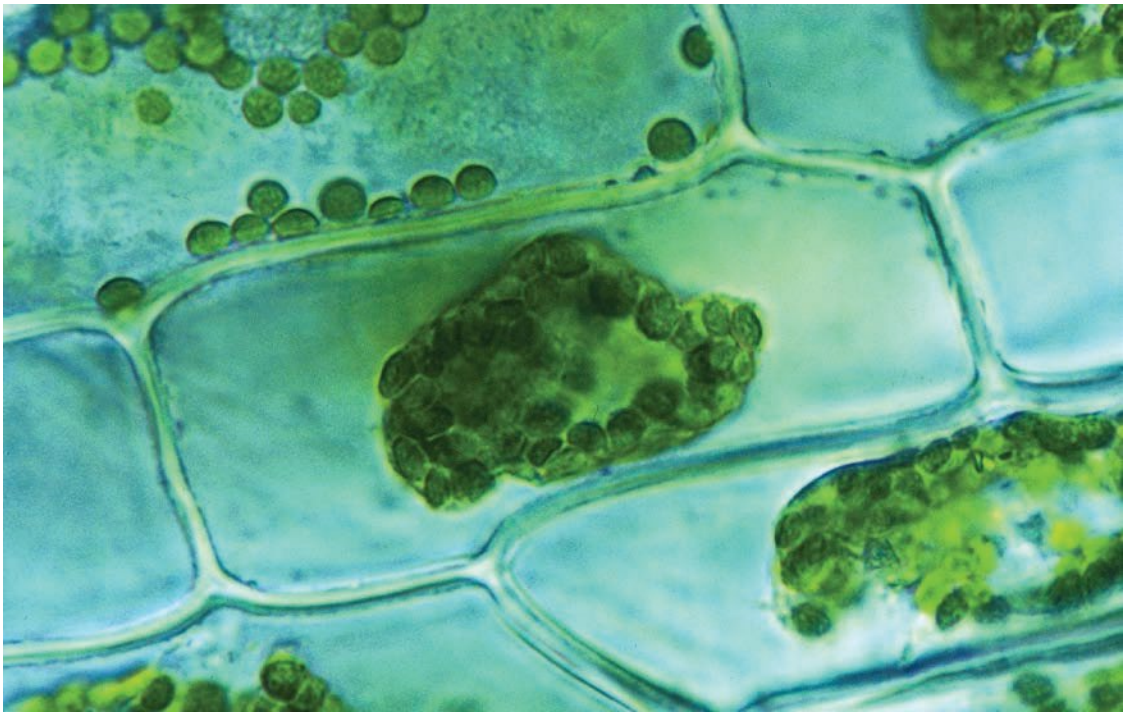


**Figure 2B–8** When plant cells are in a hypertonic environment, there is net movement of water out of the cells (plasmolysis).

You will have seen the effect of tonicity on plant cells if you have ever forgotten to top up the water in a vase of flowers. After a couple days with no water, the flowers end up a droopy mess. By regularly topping up the water, you are providing them with a hypotonic solution and so water can move from the vase through the cut stem and into the plant cells by osmosis and increase the turgor pressure of the plant cells. The flowers will then regain their composure and stand upright.

**Figure 2B–9** As a result of plasmolysis, the plant wilts.

**WORKSHEET 2B–1**
CELLS AND OSMOSIS

## Check-in questions – Set 2

1 Define the following key terms: tonicity, isotonic, hypertonic, hypotonic.
2 Complete the following statement:
If you place a plant cell in a _____ solution, free water will leave the cell by the process of _____. Eventually _____ occurs.
3 Which way does water move when crenation occurs in a red blood cell?
4 Complete the following statement:
The opposite of a flaccid plant cell is a _____.

ISBN 978-1-108-88711-3

## 2B SKILLS

### Knowing your definitions

The definitions that you learn should be precise, and so there are things you can do to prepare for this kind of question:

- Make flashcards or use online tools, for all key terms you learn in class.
- For any definitions you are unsure of, check with your textbook and your teacher.
- Read through the Year 12 examiners' reports from old exam papers. In these reports, the chief examiner will note acceptable definitions. Some definitions have several key components, and if you miss any component you will not achieve full marks.

VIDEO 2B–2 SKILLS: HOW TO EXPLAIN

### How to explain

*Command terms* are important when you are answering questions, as they indicate what you need to do to attain full marks. *Explain* is an example of a command term used regularly in assessment situations. To explain means to give a detailed account of causes, reasons or mechanisms or to essentially say why something happened. Consider the following question:

> *Question*: Identical pieces of potato (all of the same mass) were placed in each of four beakers containing a solution. They were left for 30 minutes. Explain which piece of potato would have the largest loss of mass after 30 minutes. (2 marks)

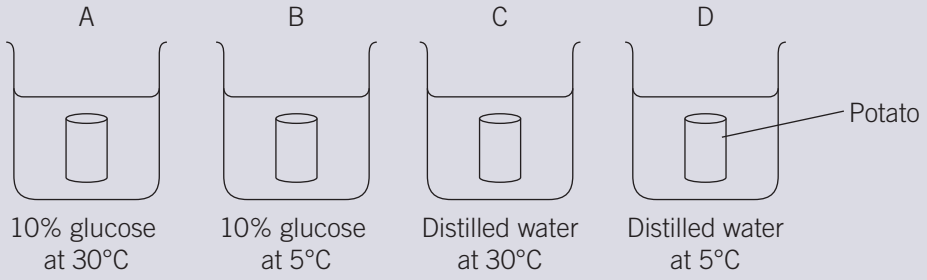



**Figure 2B–10** Set-up of a student experiment investigating the loss of mass from potato

*Answer*:

- Water moves by osmosis from high free water concentration to low free water concentration across a semi-permeable membrane.
- Therefore, for there to be a loss of mass, water must be moving out of the potato, so high free water must be inside the cell and low free water outside the cell (beaker A or B).
- Osmosis occurs faster at a higher temperature as the molecules have more kinetic energy.
- Therefore, beaker A will show the greatest loss of mass in the 30 minutes.

Notice that this answer is set out in four dot points. The question is worth 2 marks and this often equates to four points being required for full marks. Examiners don't mark you down in Biology for using dot points in your answer, so if dot points help, use them.

An acronym you might find useful when answering questions is DER, which stands for:

- *Define* – include key and relevant definitions in your answer, for key content words.
- *Explain* – give a detailed account of causes, reasons or mechanisms relevant to the question.
- *Relate* back to the question – relate your explanation to the information provided in the question, so the assessor can clearly see the link.

ISBN 978-1-108-88711-3

Here is an example of what this looks like:

*Question*: A student was carrying out an experiment using an artificial semi-permeable membrane. The holes in this membrane allow water to pass through, but not larger molecules like the sugar sucrose. The student added the same amount of water on each side of the membrane. Then, at time = 0 minutes, they added sucrose to one side, as shown in the figure. Explain what results you would expect at time = 30 minutes.

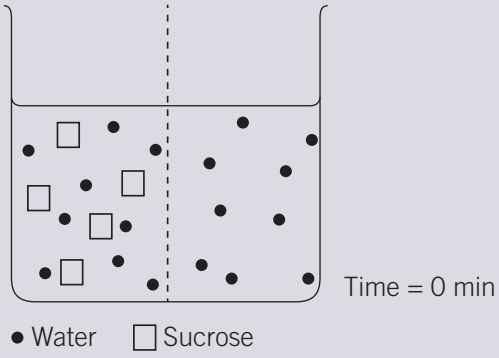



**Figure 2B–11** Set-up of student experiment investigating the movement of molecules

*Answer*:

- Define – osmosis is the net passive movement of free water from a region of high free water concentration to a region of low free water concentration across a semi-permeable membrane until equilibrium is reached.
- Explain – therefore, because sucrose has a high concentration on the left, it will tend to move to the right by diffusion, but it is too large to fit through the holes in the membrane, so it cannot move. However, water can fit through the holes and so it moves by osmosis from the right (high free water/low solute concentration) to the left, where the solute concentration is high.
- Relate back to the question – due to water moving to the left where the sucrose is and cannot move, the water level on the left will have increased by time 30 minutes.

**VIDEO 2B–3** SKILLS: DETERMINING THE ISOTONIC POINT

### Determining the isotonic point

In this chapter, the term 'isotonic point' has not specifically been mentioned. However, with your knowledge of tonicity you will be able to determine what it means. In assessments, you will come across scenarios, situations and even terms, that you are not familiar with. Keep in mind that the assessments are not trying to trick you. Their role is to assess your knowledge and understanding by challenging you to apply what you have learned. You know that an isotonic solution is one that has the same solute concentration as the cell's internal environment; therefore, the isotonic point is the point at which the concentration of the solution is the same as the concentration of the cell.

Consider this example:

*Question*: A student is investigating the change in mass of apple pieces when placed in a range of salt solutions. The average mass change of the apple pieces after several hours is shown in the figure. Using the data presented, determine the isotonic point and give reasons for your decision.

*Note:* A positive mass change is a gain in mass. A negative mass change is a mass loss.

ISBN 978-1-108-88711-3

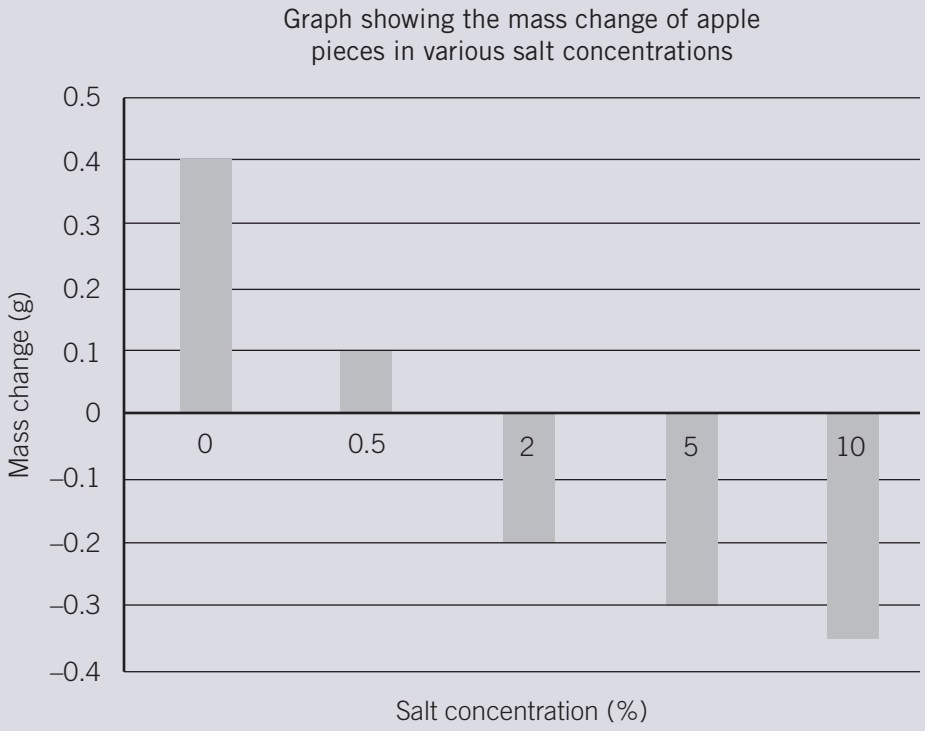



**Figure 2B–12** Student results showing the average mass change of the apple pieces after several hours

*Answer*: An isotonic solution (and therefore the isotonic point) is one that has the same solute concentration as the cell's internal environment. Therefore, the isotonic point is the point at which the concentration of the solution is the same as the concentration of the cell. There will be no net mass loss or net mass gain when the apple is in an isotonic solution, as there is no net movement of water by osmosis. Therefore, reading from the graph, the isotonic point must be between 0.5% salt concentration (where there was mass gain) and 2% salt concentration (where there was mass loss). The isotonic point is approximately 1% salt solution.

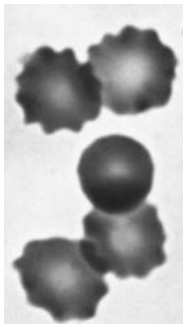
## Section 2B questions

1 Diffusion is one way that substances can move across the plasma membrane.
   - **a** What term means 'net passive movement of a substance from a region of high concentration to a region of low concentration until equilibrium is reached'?
   - **b** List the differences between osmosis and diffusion.
   - **c** Are osmosis and simple diffusion passive or active forms of transport?

2 If a solution is described as being isotonic compared to the cell, what does it mean?

3 List two circumstances that might lead to a plant cell becoming plasmolysed.

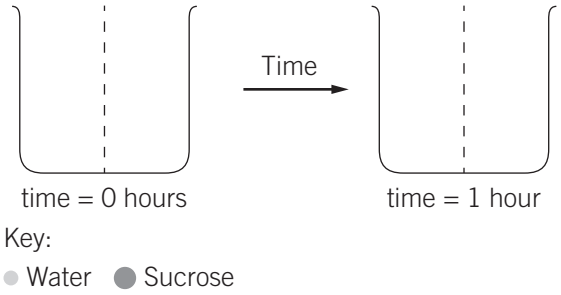
4 The photo on the left shows what happens to the shape of red blood cells that have been placed in a salt solution.
   - **a** Explain why a red blood cell takes on this shrunken appearance. Be sure to include the name of the process.
   - **b** Explain the change that would occur if a red blood cell were placed in distilled water.
   - **c** What terms could be used to describe the solution in part **a** and the solution in part **b**?



ISBN 978-1-108-88711-3

5 Using what you have learned in this chapter, summarise why drinking sea water is not a good idea if you have been stranded at sea in a rowboat for days.

6 As part of a project, a student was asked to demonstrate osmosis to their peer, who was absent from class on the previous day. The student had a beaker, cellulose membrane (semi-permeable), sucrose (sugar) solution and distilled water. The student put the membrane in the centre of the beaker to separate it into two halves. They half-filled one side of the beaker with sucrose solution, and half-filled the other side with distilled water. Complete the following blank diagram by showing the position of the sucrose and water at time = 0 hours (left) and time = 1 hour (right).




7 If you have kidney disease, extra fluid and salts may accumulate in your blood, because the kidneys are not able to remove them. This may lead to a condition known as oedema, which is swelling of the body caused by accumulation of fluid in the tissues. It is common for patients at risk of oedema to be given a saline drip.
In such cases, would the saline be hypotonic, isotonic or hypertonic? Give reasons for your answer and include any relevant definitions.

8 The cells in plant roots use active transport to move mineral ions from the soil into the cytosol of the cell.
   a Define 'active transport'.
   b Justify how this would allow the cells to also take up water.

9 Once a week at the school canteen, potatoes are cut into chips several hours before they are cooked. Due to the early preparation time, something needs to be done to prevent the chips drying out. In order to keep the water content of the chips constant, they are stored in a salt solution. The canteen manager has asked you to investigate what concentration of salt solution would be best to use. You weighed five chips, placing them in different concentrations of salt solution, then reweighing them an hour later. The results are shown in the table.

| | Concentration of salt solution (M) | | | | |
|---|---|---|---|---|---|
| | 0 | 0.5 | 1 | 2 | 3 |
| Mass of chip (g) at time = 0 hours | 2.7 | 2.6 | 2.7 | 2.6 | 2.6 |
| Mass of chip (g) at time = 1 hour | 2.8 | 2.6 | 2.6 | 2.4 | 2.1 |

Determine which concentration of salt solution the chips should be kept in, and give reasons for your answer by describing all your observed results.

ISBN 978-1-108-88711-3


# Surface area to volume ratio

**Study Design:**
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

**Glossary:**
Surface area
Surface area to volume ratio (SA:V)
Volume

## ENGAGE

### The lion's mane jellyfish

Jellyfish are among the most beautiful creatures to observe moving, as their bodies undulate in the ocean's currents. The lion's mane jellyfish has a bell up to 2.5 metres in diameter and tentacles that have been recorded to be 37 metres long! Interestingly, the gelatinous body of this, and most other jellyfish, is made up of about 98% water and is entirely supported by the processes of diffusion and osmosis. But surely diffusion and osmosis are not efficient enough to supply this massive organism with all the substances crucial to its survival?

**Figure 2C–1** The lion's mane jellyfish is found worldwide, including in Australian marine environments.

## EXPLAIN

### The survival of different-sized organisms and their cells

1B PLASMA MEMBRANE LINK

Section 1B explored how organisms need to exchange materials with their environment. It is the plasma membrane that allows this to occur by acting as a semi-permeable barrier between the external and internal environments of a cell. The cells of organisms need:

- oxygen and nutrients to move in from their surroundings so that cellular processes such as growth, repair and reproduction can occur
- to remove waste products from their internal environment to prevent a build-up of dangerous substances such as carbon dioxide and urea
- to maintain the conditions in their internal environment, such as pH and temperature, within a narrow range.

**Surface area**
the area on the outside of an object that is exposed to the external environment; in the case of a cell, this is the plasma membrane's surface

2A THE NATURE OF SUBSTANCES AND THEIR MODES OF TRANSPORT
2B OSMOSIS LINK

In sections 2A and 2B you learned about the ways in which substances move across the plasma membrane. But organisms and cells come in different shapes and sizes, so how does this variation affect the rate of transport of substances across the plasma membrane? For example, how does a gigantic organism like the lion's mane jellyfish move substances just as efficiently as a small organism? And why don't single-celled organisms grow larger? To answer these questions, we must begin by looking at the relationship between the **surface area** of the plasma membrane and the **volume** of the cell that the membrane surrounds.

**Volume**
the amount of space inside an object; in the case of a cell, this is the cytoplasm

ISBN 978-1-108-88711-3

VIDEO 2C–1 SURFACE AREA AND VOLUME

LINK 2A THE NATURE OF SUBSTANCES AND THEIR MODES OF TRANSPORT

## Relationship between surface area and volume

A cell's continual exchange of material between the internal and external environments needs to be efficient enough to ensure the survival of the cell. The more surface area that is available per unit of volume, the more exchange that can occur, which increases the cell's chance of survival. The efficiency of exchange is affected by the:

- area of the plasma membrane's surface that is exposed to the external environment – the larger the surface area, the more substances that can be exchanged
- volume of the cell's cytoplasm – the larger the volume, the more nutrients that are required for essential cell functions.

To learn about the relationship between surface area and volume, let's look at some cubes (hypothetical cells) of different sizes. Consider the cube in Figure 2C–2. The surface area of the cube is calculated by adding the areas of the exposed sides. The cube (shown at left) has six exposed surfaces, which you can see when the cube is 'unfolded' to form the net (shown on the right). Each of the six surfaces measures 1 unit by 1 unit, so $6 \times 1^2$ gives the total surface area of the cube. This can be simplified to:

Surface area (SA) = $6l^2$ where $l$ is the length of the side.

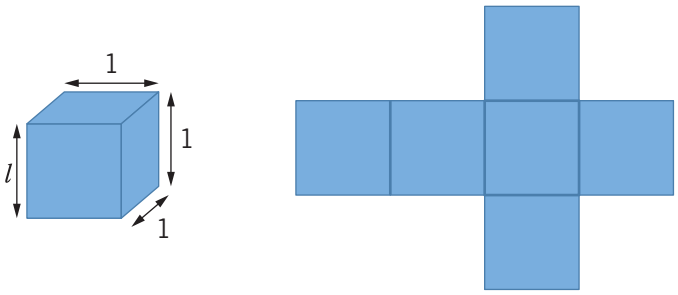



**Figure 2C–2** Calculating surface area of a cell (represented at left by a cube) involves thinking about the area of the cell that is exposed to the external environment. The net on the right represents the surface area of the cell.

Volume is calculated by multiplying length by height by width. For a cube, the rule can be simplified, because all sides are the same length:

Volume (V) = $l^3$ where $l$ is the length of the side.

Now consider the three cubes, or hypothetical cells, in Figure 2C–3.

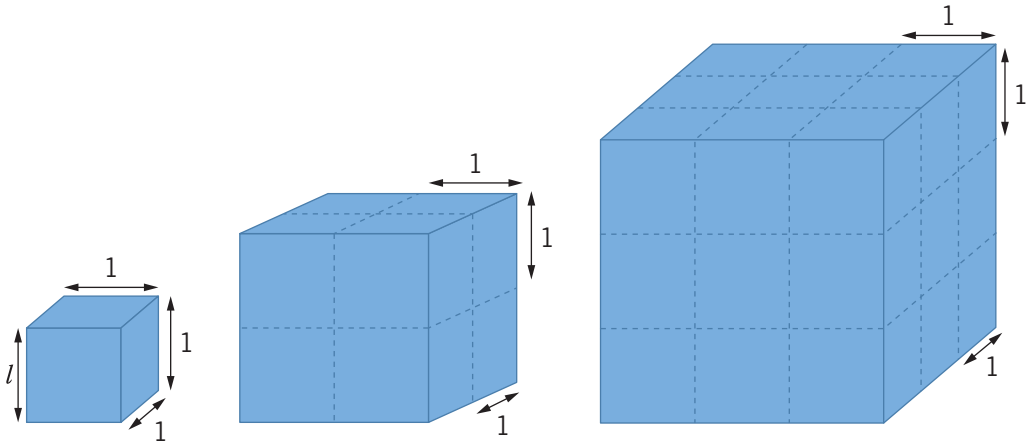



**Figure 2C–3** Three cubes of different sizes can be used to demonstrate the relationship between surface area and volume of different-sized cells.

ISBN 978-1-108-88711-3

**Surface area to volume ratio (SA:V)** the relationship between the amount of plasma membrane that is exposed to the external environment (surface area) and the volume of the cytoplasm of the cell (volume)

The relationship between surface area and volume can be written as a ratio, known as the **surface area to volume ratio**, and represented as **SA:V**. Table 2C–1 summarises the surface area, volume and SA:V ratio for the three 'cells'.

**Table 2C–1** Relationship between surface area and volume of three different-sized cubes

| | Side length | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| **Surface** | $6 \times 1^2 = 6$ | $6 \times 2^2 = 24$ | $6 \times 3^2 = 54$ |
| **Volume** | $1^3 = 1$ | $2^3 = 8$ | $3^3 = 27$ |
| **SA:V ratio** | 6:1 | 24:8 = 3:1 | 54:27 = 2:1 |

From the table you can see that the smallest cell has the highest SA:V ratio. This means there is more surface available for exchanging materials per unit of volume. If there is more surface area available, then the exchange of materials across the membrane can be faster or more efficient. As the 'cell' grows, its surface area and the volume increase, but not at the same speed. The volume increases faster than the surface area, so as the cell grows, the SA:V ratio decreases. Therefore, the efficiency of substances being exchanged decreases as a cell grows in size.

WORKSHEET 2C–1 BUILDING NETS

## Check-in questions – Set 1

1 Define the following terms: surface area, volume, SA:V ratio.
2 How do you calculate:
   a surface area? b volume?
3 What part of the cell are we talking about when we refer to the:
   a surface area of a cell? b volume of a cell?
4 As a cell grows in size, what happens to the size of the:
   a surface area? b volume? c SA:V?

## The impact of size on cells

The size of a cell is very important to the exchange of material across the plasma membrane. As cells grow larger, they have less surface area available (per unit volume) for the transport of substances into and out of the cell. Large cells need more oxygen and nutrients, and they have a lot of wastes they need to get rid of compared to smaller cells. So eventually, a growing cell reaches a point where exchange isn't fast enough to support the volume of the cell and keep its internal conditions within the safe range. In this situation, the cell will eventually die. Therefore, growing cells tend to divide to form two smaller cells when they reach a certain size. This maintains the smaller cell size and the high SA:V ratio that is crucial for their survival.

3B THE CELL CYCLE LINK

However, some cells are big. A motor neuron in your leg can be up to a metre long.

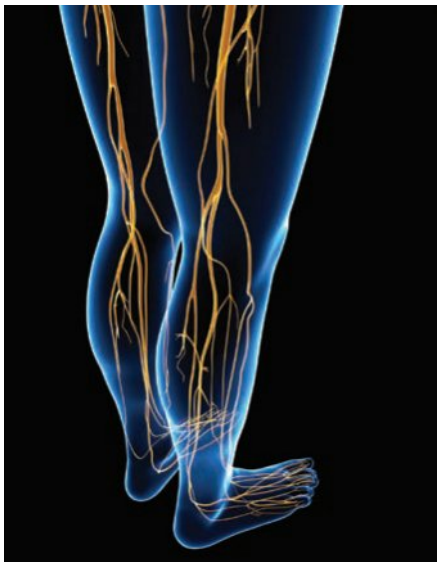


**Figure 2C–4** Motor neurons in the legs have a cell body around 100 µm (micrometres) in diameter and a length of up to about a metre.

ISBN 978-1-108-88711-3

So how can a cell increase its surface area without increasing its volume? Cells have evolved to be more efficient by having:

- a flattened shape
- compartments
- folds.

Before we investigate these three features, keep in mind that not all cells exist on their own. A cell may be part of a multicellular organism. In Chapter 4 you will see how multicellular organisms have specialised organs and transport systems, for this reason. Your lungs and kidneys, your circulatory and digestive systems, are just some examples of where cells have developed high SA:V ratios to enable efficient exchange.

LINK 4B THE DIGESTIVE SYSTEM: GETTING THE NUTRIENTS WE NEED

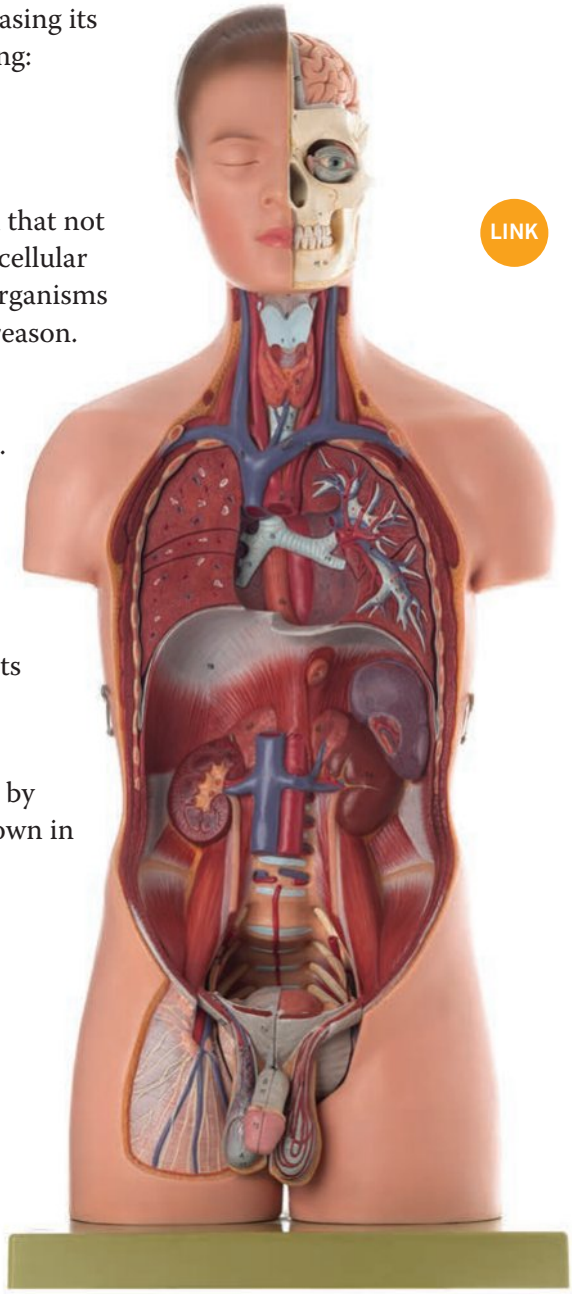


**Figure 2C–5** The human body consists of many specialised systems made of cells that have high SA:V ratios.

## Flattened shape

The shape of a cell can affect its SA:V ratio. Thin, flat cells have a greater SA:V ratio than cubic or spherical cells of the same volume. Most cells are relatively flat because of this greater efficiency in exchange of nutrients and wastes.

Consider the three shapes A, B and C in Figure 2C–6. Each shape consists of eight cubes of side lengths 1 unit by 1 unit, so the volume of all three shapes is the same (shown in Table 2C–2).

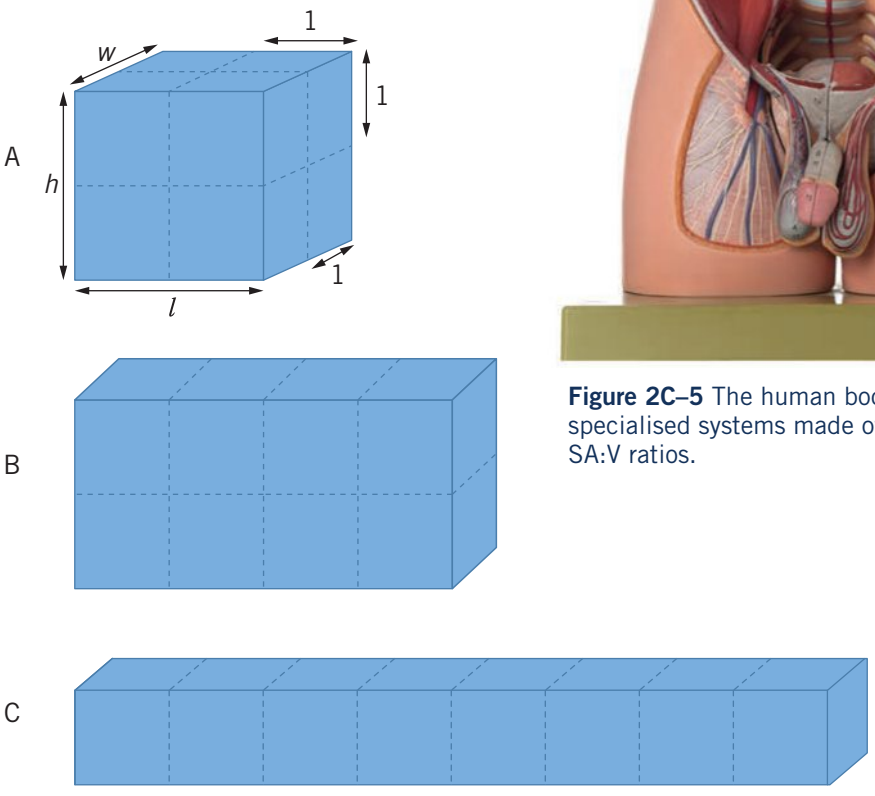



**Figure 2C–6** The three shapes all have the same volume, but the longer, flatter shape has the highest surface area.

ISBN 978-1-108-88711-3

Table 2C–2 demonstrates that a flatter, thinner shape (cell) has a greater SA:V ratio than a shape (cell) of the same volume with a less flat shape.

**Table 2C–2** The relationship between surface area and volume of the three shapes ('cells') in Figure 2C–6

| | A | B | C |
|---|---|---|---|
| **Description ($l \times h \times w$)** | $2 \times 2 \times 2$ | $4 \times 2 \times 1$ | $8 \times 1 \times 1$ |
| **Surface area** | 24 | 28 | 34 |
| **Volume** | 8 | 8 | 8 |
| **SA:V ratio** | 24:8 = 3:1 | 28:8 = 3.5:1 | 34:8 = 4.25:1 |

For example, the lion's mane jellyfish has a body, or jelly material (mesoglea), that consists of only two layers, the top layer (epidermis) and the inner layer (gastrodermis). These layers are made of very flat cells that are thin enough to be semi-permeable, which allows the efficient diffusion of oxygen and nutrients from the water into the cells of the jelly.

## Compartments

1D ORGANELLES LINK

In Section 1D you read about how compartmentalisation, or having organelles, allows eukaryotic cells to be extremely well organised. Each membrane-bound organelle is a self-contained unit with all the right conditions and requirements for a specialised process, which is considerably more efficient than having all the cell's processes occurring randomly throughout the cell. The more internal membranes there are, the more surface area there is for carrying out these cellular processes.

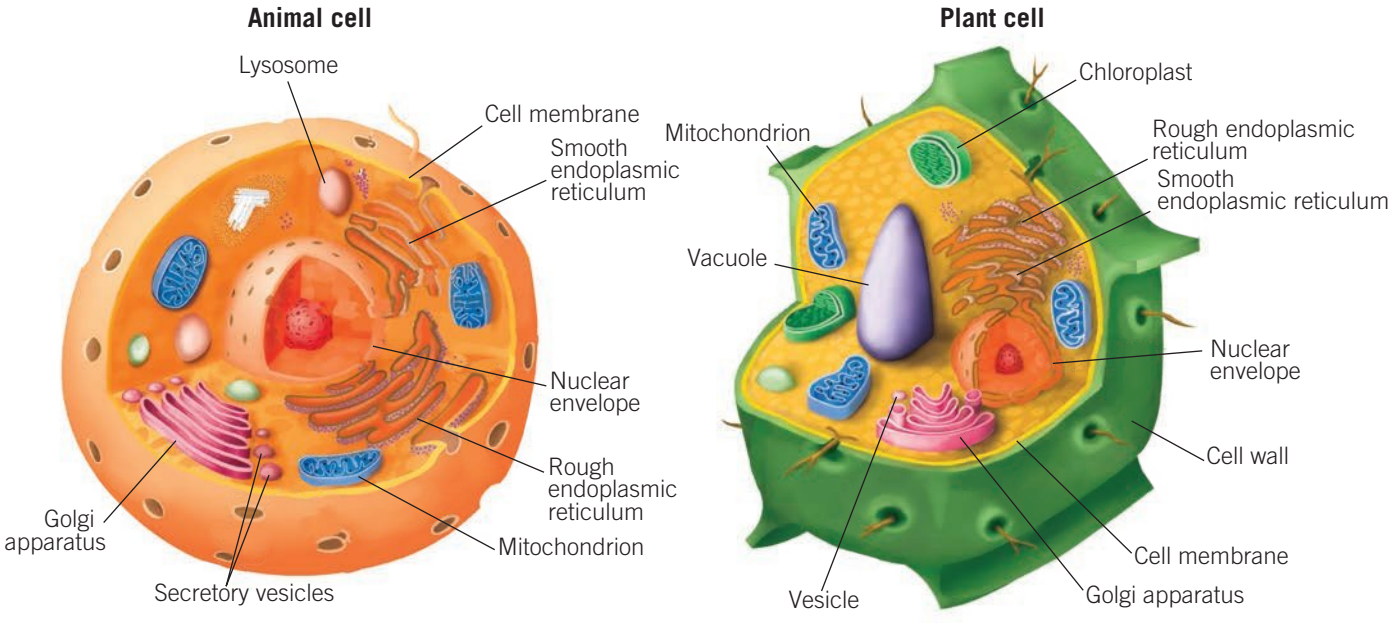



**Figure 2C–7** Eukaryotic cells are relatively large and contain many membrane-bound organelles, as shown in this copy of Figure 1D-2. The more internal membranes there are, the higher the surface area available for carrying out cellular processes.

ISBN 978-1-108-88711-3

## Folds

Instead of having compartments or a flattened shape, some cells increase their SA:V ratio by having folded plasma membranes. In cells with an absorptive function, this feature increases the efficiency of exchange. This can be demonstrated by looking at an A4 piece of paper (Figure 2C–8). When flat, the length of one side of paper is just under 300 mm. If the paper is folded several times, the overall length of the same side is now about 50 mm. So the same surface area of the paper has been condensed into a smaller space. This means another five pieces of folded A4 paper could be added along the ruler in order to fit into the 300 mm.

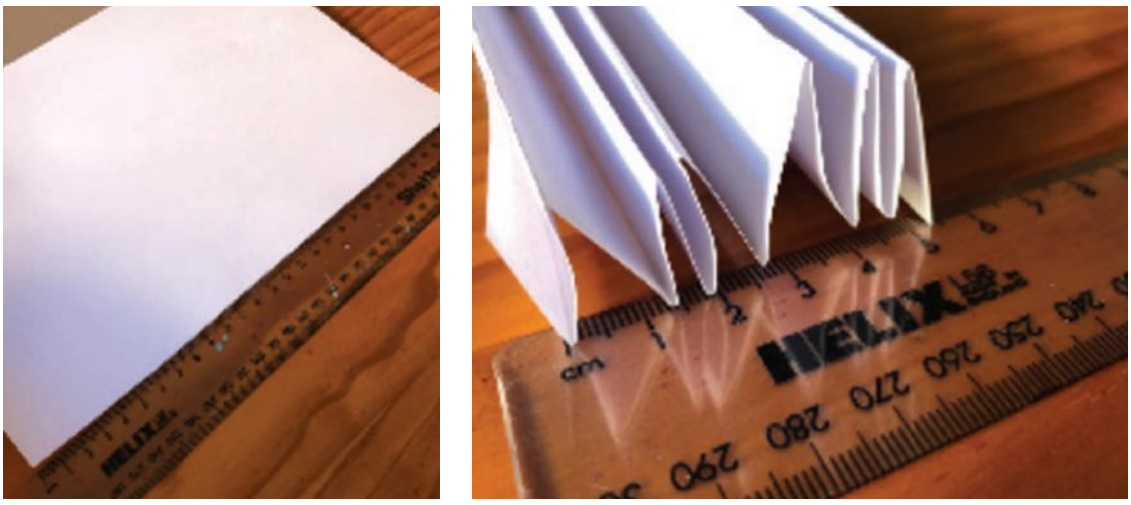



**Figure 2C–8** Modelling how folds can increase the surface area available in a given space

Now consider the roots of plants, whose function is to absorb water and mineral ions from the soil. They are covered in tiny folds (extensions) called root hairs (see Figure 2C–9), each increasing the surface area of the root.

In the same way, the cells of your small intestine have little folds or projections, called *villi*, and each villus increases the absorption of the products of digestion around 30-fold. (This is explained further in Section 4B.) In fact, there are even extensions on the villi, called *microvilli*, which are believed to increase the absorptive surface area of the small intestine 600-fold. This equates to a surface area about the size of a tennis court!

LINK **4B** THE DIGESTIVE SYSTEM: GETTING THE NUTRIENTS WE NEED

**Figure 2C–9** Root hairs are small extensions on plant roots that massively increase the absorptive surface area of the root.

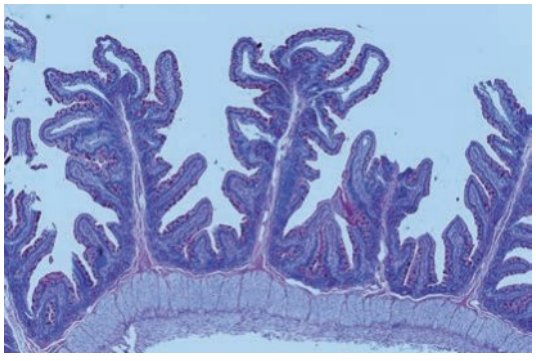


**Figure 2C–10** In order to maximise the absorption of nutrients from the gut, the small intestines have tiny folds, called villi and microvilli, which increase the SA:V ratio.

ISBN 978-1-108-88711-3

WORKSHEET 2C–2
SURFACE AREA : VOLUME

## Check-in questions – Set 2

1 List the three ways a cell can increase its surface area without increasing its volume.
2 What shape of cells has a higher SA:V ratio?
3 Outline how compartments within a cell increase SA:V ratio.
4 Outline how folds increase SA:V ratio.
5 Give examples of where folds can increase the surface area available for absorption from the external environment.

## 2C SKILLS

VIDEO 2C–2
SKILLS: IDENTIFYING TRENDS

### Identifying trends

In Biology it is very important that you can both collect data and represent it graphically, as well as interpret and analyse graphs to determine any trends. Your Units 1–4 assessments will definitely include data and associated graphical representations, and, therefore, it is valuable to practise.

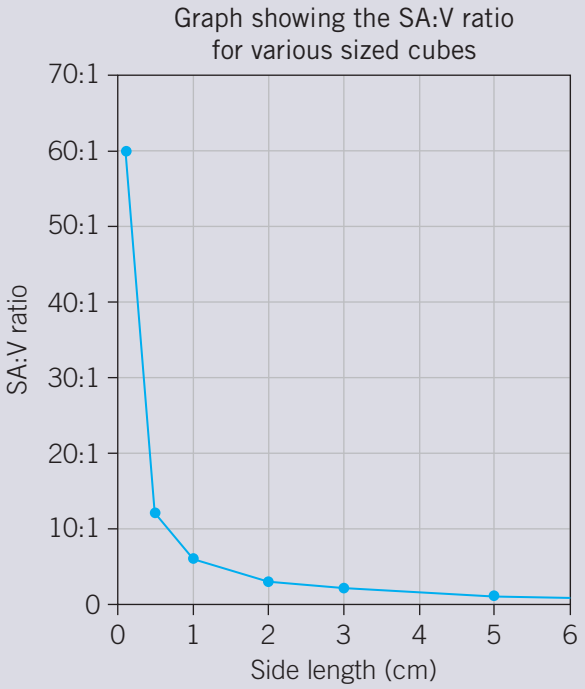



**Figure 2C–11** Student results when investigating SA:V for various-sized cubes

Consider the graph in Figure 2C–11. If you are not comfortable with interpreting graphs, choose one point on the curve and determine what that point is 'saying' by referring to the axes. For example, the first point (reading from left to right on the graph) says that when a cell has a side length of 0.1 cm, its SA:V ratio is 60:1. The second point from the left says that a cell with side length of 0.5 cm has a SA:V ratio of 12:1 ... and so on. Now look for a trend. A *trend* is the general direction in which something is going. In this graph, the trend is that, as the side length increases, the SA:V ratio gets smaller.

Here is an example to help you with these types of questions.

> *Question*: Using the data provided in the graph, what size cell would be the most efficient at gas exchange? Give reasons for your answer. (2 marks)
>
> *Answer*:
> - The graph shows that cells with smallest side length (cm) have the largest SA:V ratio.
> - For example, a cell with a side length of 0.1 cm has a ratio of 60:1, while a cell with a side length of 5 cm has a SA:V ratio of 1.2:1.
> - A higher SA:V ratio means more surface area per unit volume is available for gas exchange.
> - Therefore, the smallest cells have the most efficient exchange, as they have the largest SA:V ratio.

ISBN 978-1-108-88711-3

Key points to remember when answering questions about trends:

- Ensure you mention what the trend (or the relationship between two things) is. For example, 'as $x$ gets larger, $y$ gets smaller'.
- If a question asks you to explain your answer, you will need to include reasons for your statement/conclusion. For example, explain how a large SA:V ratio means more efficient exchange.
- When a question asks you to use data to answer it, you must refer to the data specifically to demonstrate the trend in your answer.
- When you refer to data, be sure to include any units.

**Linking ideas sequentially**

**VIDEO 2C–3**
SKILLS:
LINKING IDEAS
SEQUENTIALLY

When answering a question, you should do so in a sequential way – this means in a logical order. But it is not always easy to do so. It can require you to change the way you think about what is happening. When you answer questions in this way, it helps the assessor to see what you are thinking, and enables them to identify that you know your content and are able to link ideas together.

Let's look at an example of how to approach a question of this nature.

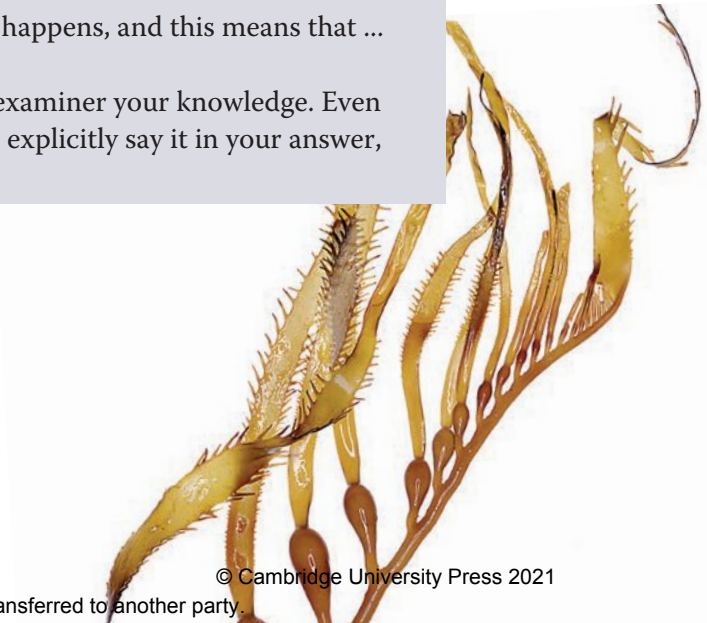
*Question*: Explain why it isn't always better to be bigger in the cell world. (2 marks)

*Answer*:

- To survive, a cell needs to exchange materials with its external environment – for example, nutrients and oxygen in and wastes out. This exchange occurs across a plasma membrane.
- A large surface area (area of the plasma membrane that is exposed to the external environment) to volume (space within the cell) ratio is better for increasing the rate of movement of molecules across the cell membrane into/out of a cell, as there is more surface through which to exchange materials.
- As a cell gets larger, its surface area and its volume increase, but the volume increases more, so there is less surface area (SA) available per unit volume (V) for exchange.
- This means a larger cell is not as efficient at exchanging materials as a small cell, as the SA:V ratio decreases as cell size increases.

Key points to remember when answering this kind of question:

- Within your answer, incorporate relevant definitions to show your knowledge of the content.
- Talk it through step by step: 'This happens, so this happens, and this means that ... so this occurs'.
- Remember, you want to show your teacher or the examiner your knowledge. Even though they will know what you mean, if you don't explicitly say it in your answer, you will not gain full marks.

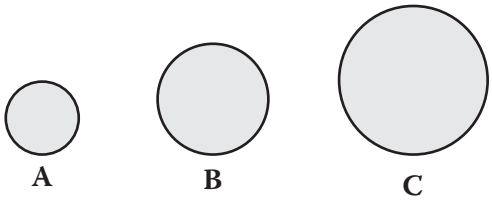


ISBN 978-1-108-88711-3

## Section 2C questions

**1** **a** List the functions of the plasma membrane.
**b** What are the different substances that need to be exchanged across a cell's plasma membrane?
**c** How can these substances move passively across the plasma membrane? Include definitions.

**2** Calculate the surface area to volume ratio (SA:V) of the hypothetical cells in the table below. (Numbers have been rounded off for convenience.)

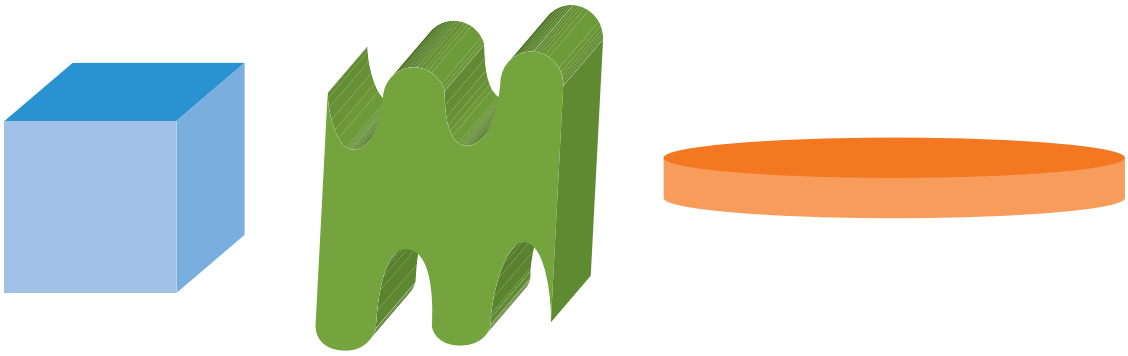



| | A | B | C |
|---|---|---|---|
| **Diameter** | 1 | 2 | 3 |
| **Surface area** | 3 | 12 | 28 |
| **Volume** | 0.5 | 4 | 14 |
| **SA:V** | | | |

**3** Answer the following questions based on your findings from Question 2.
**a** Which cell would be most efficient at moving substances across the plasma membrane?
**b** Which cell would be least efficient?
**c** What is the relationship between cell size and SA:V ratio?
**d** If cells B and C were placed in the same conditions, which would take up nutrients and oxygen at a greater rate? Explain why.

**4** Outline the advantages of having a folded plasma membrane.

**5** Compare the different-shaped cells below and explain how each shape affects its SA:V ratio and therefore the efficiency of exchange. *Note:* All shapes have the same volume.



ISBN 978-1-108-88711-3


# Role of chloroplasts and mitochondria

**Study Design:**
The structure and specialisation of plant and animal cell organelles for distinct functions, including chloroplasts and mitochondria

**Glossary:**
ADP (adenosine triphosphate)
Aerobic cellular respiration
Anaerobic cellular respiration
Autotroph
Cellular respiration
Chemical energy
Chlorophyll
Cristae
Endosymbiosis
Fermentation
Glycolysis
Grana
Heterotroph
Light-dependent stage
Light energy
Light-independent stage
Matrix
Photosynthesis
Stroma
Thylakoid membranes

## ENGAGE

### What is energy?

*Energy* can be defined as the capacity to do work, and *transformation* means to change form. But how do these terms relate to Biology, the study of living things? One way to apply these terms to our living world is to understand that living things are constantly active, even if you can't see this activity. It is energy that fuels the work that sustains these activities.

Energy exists in different forms, but the forms of energy that are most important to life on Earth are light (or radiant) energy, the chemical energy stored in food, and heat. In our living world, cells and organisms carry out reactions to transform these forms of energy into forms they can use. It doesn't matter whether the organism is a bacterium living on the rocks of hydrothermal vents in the depths of the ocean, a frog that freezes solid over winter and thaws months later when spring comes, or a microscopic tardigrade that can survive up to 30 years without food or water. All living things need energy and must have ways of capturing it, transforming it and storing it.

**Figure 2D–1** The wood frog of Alaska spends nearly 7 months a year frozen, turning two-thirds of its body water into ice to survive the winter.

ISBN 978-1-108-88711-3

EXPLAIN

## The link between life and energy

For organisms to survive, they require energy. This energy originates from the Sun in the form of light energy. This light energy is then transformed into other forms of energy that organisms can use. For example, plants transform light energy into chemical energy in the form of glucose; animals eat the plants to obtain the chemical energy stored in the glucose, which the animals can then convert into energy in the form of ATP for growing, moving, repairing, reproducing and so on.

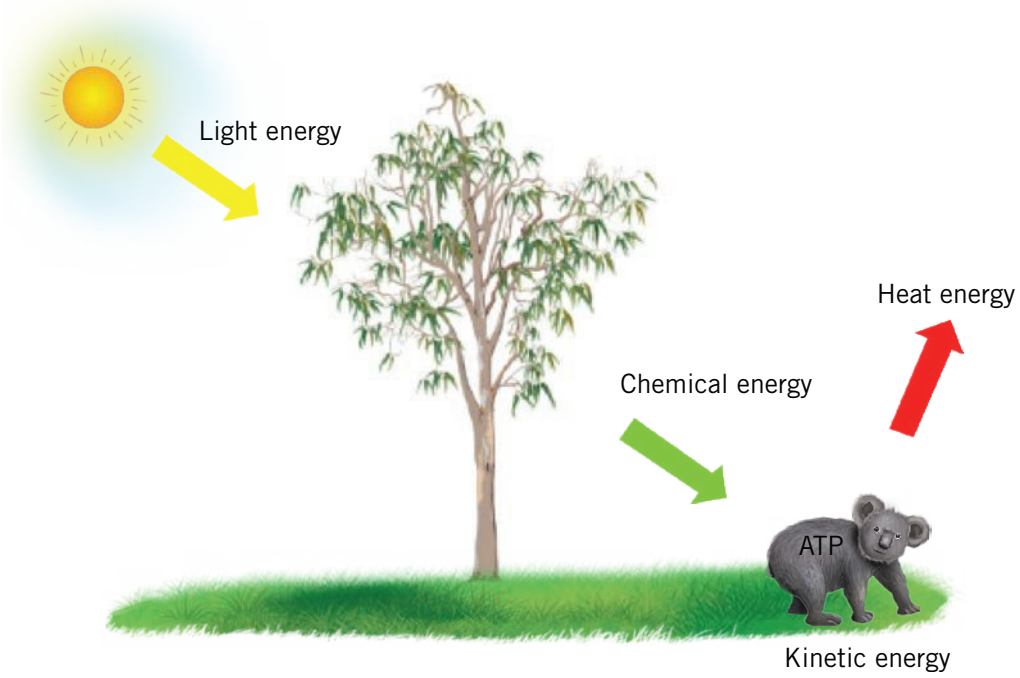



**Figure 2D–2** How a koala uses energy transformations to run between gum trees

**Table 2D–1** For organisms to survive, they need to take in, convert and store energy.

| External source of energy | Which organisms use it | Energy conversion | What excess energy is stored as |
|---|---|---|---|
| **Light energy** | Plants and algae | Light energy is converted into chemical energy (glucose) by photosynthesis | ATP<br>Starch |
| **Chemical energy** | Animals, plants and fungi | Chemical energy is released by breaking down organic molecules (e.g. glucose) into smaller subunits by cellular respiration | ATP<br>Glycogen<br>Fats (lipids) |

**Light energy** energy from the Sun

**Chemical energy** energy from organic molecules in food

ISBN 978-1-108-88711-3

## Autotrophs and heterotrophs

Organisms can be categorised by the way they gain energy and obtain the organic compounds that are crucial to their survival.

- **Autotrophs** are 'self-feeders' in that they make their own organic materials (or food) by taking in energy from the environment. For example, autotrophs such as green plants take in light energy from the Sun and use this energy to convert inorganic compounds (such as water and carbon dioxide) into organic ones (such as glucose). This process is called **photosynthesis**. Autotrophs can then use the glucose they make for their own energy needs (for growing, reproducing and so on).
- **Heterotrophs** cannot make their own food, so they obtain their organic materials by feeding on autotrophs or on other organisms and their products. They then use the organic materials to make energy available, in the form of ATP. This process is called **cellular respiration**.

**Autotroph**
an organism that synthesises its own organic materials (food), by taking in energy from its physical environment, to meet its energy needs (*auto* = self, *troph* = food)

**Photosynthesis**
a chemical reaction in which the Sun's light energy is used to convert the inorganic compounds carbon dioxide ($CO_2$) and water ($H_2O$) into the organic compound glucose; occurs in the chloroplast (*photo* = light, *synthesis* = build, put together)

**Heterotroph**
an organism that ingests organic materials by feeding on autotrophs or on other organisms and their products, in order to make energy available in the form of ATP (*heteros* = other, *troph* = food)

**Cellular respiration**
a chemical reaction in which the organic compound glucose is broken down, commonly in the presence of oxygen, to form the inorganic compounds carbon dioxide ($CO_2$) and water ($H_2O$), and energy in the form of ATP; occurs in the cytosol and mitochondria

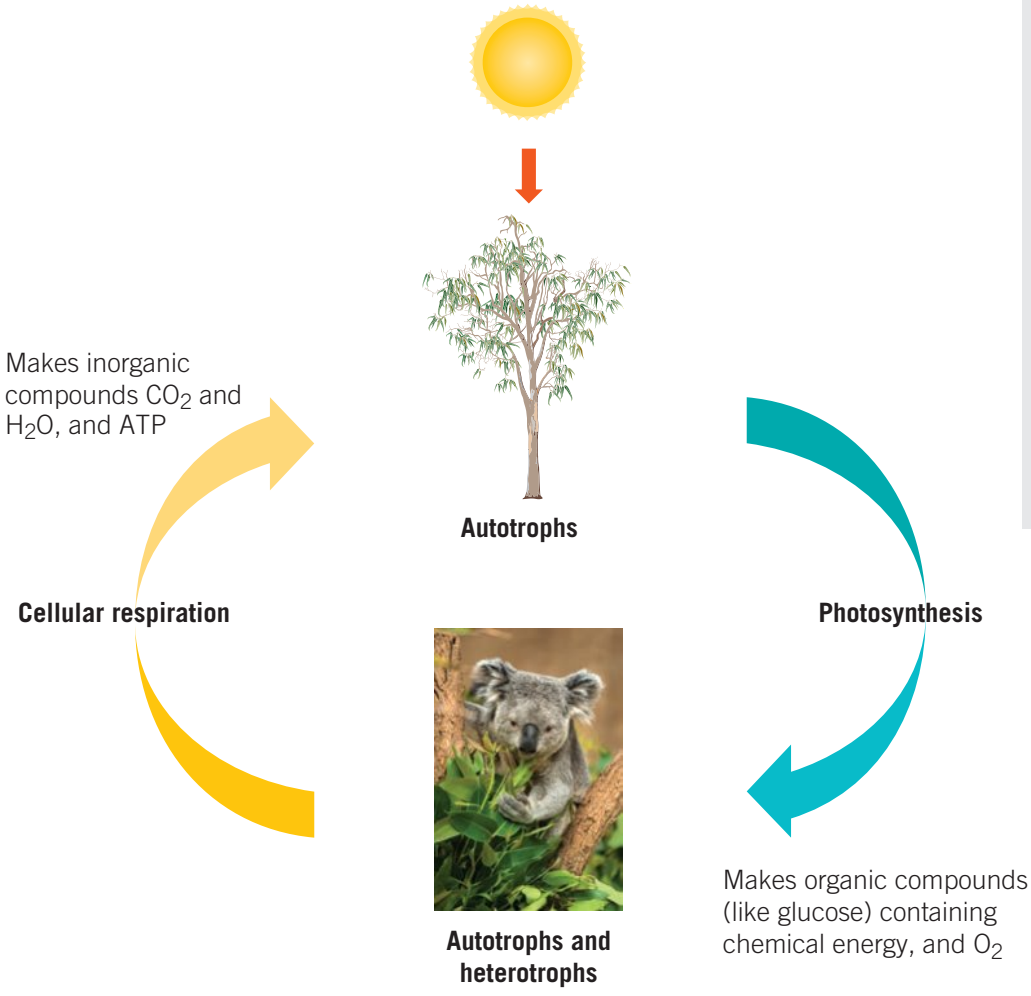



**Figure 2D–3** The relationship between autotrophs and heterotrophs in terms of how they each gain energy and obtain the organic compounds needed for survival

## Check-in questions – Set 1

1 Why do organisms need energy to survive?
2 What type of energy is the original source of energy for most living things on Earth?
3 Draw up a table that includes a definition for the key terms 'autotroph' and 'heterotroph', an example of organisms for each, and the name of the process they use to convert energy into a useable form.

ISBN 978-1-108-88711-3

VIDEO 2D–1 PHOTOSYNTHESIS

## Chloroplasts: photosynthesis

UNIT 3 LINK

Most autotrophs are photosynthetic. This means they capture the Sun's light energy in their chloroplasts to convert the inorganic compounds carbon dioxide ($CO_2$) and water ($H_2O$) into chemical energy, which is stored in the bonds of the organic compound glucose. Photosynthesis consists of a series of steps (biochemical pathway), and each step is controlled by a different enzyme.

The overall process of photosynthesis can be written as a word equation:

$$\text{carbon dioxide + water} \xrightarrow[\text{chlorophyll}]{\text{light energy}} \text{oxygen + glucose}$$

or as a balanced chemical equation:

$$6CO_2 + 12H_2O \xrightarrow[\text{chlorophyll}]{\text{light energy}} 6H_2O + 6O_2 + C_6H_{12}O_6$$

**Chlorophyll** the green pigment on the thylakoid membranes of the chloroplasts of green plants; absorbs light energy for photosynthesis

or the simplified version:

$$6CO_2 + 6H_2O \xrightarrow[\text{chlorophyll}]{\text{light energy}} 6O_2 + C_6H_{12}O_6$$

Notice the words *light energy* and **chlorophyll** above and below the arrow – this means that both are needed for the reaction to occur. Photosynthesis needs the Sun's energy (light energy) to convert the reactants into the products. Chlorophyll is also essential because it absorbs the Sun's energy.

2A THE NATURE OF SUBSTANCES AND THEIR MODES OF TRANSPORT LINK

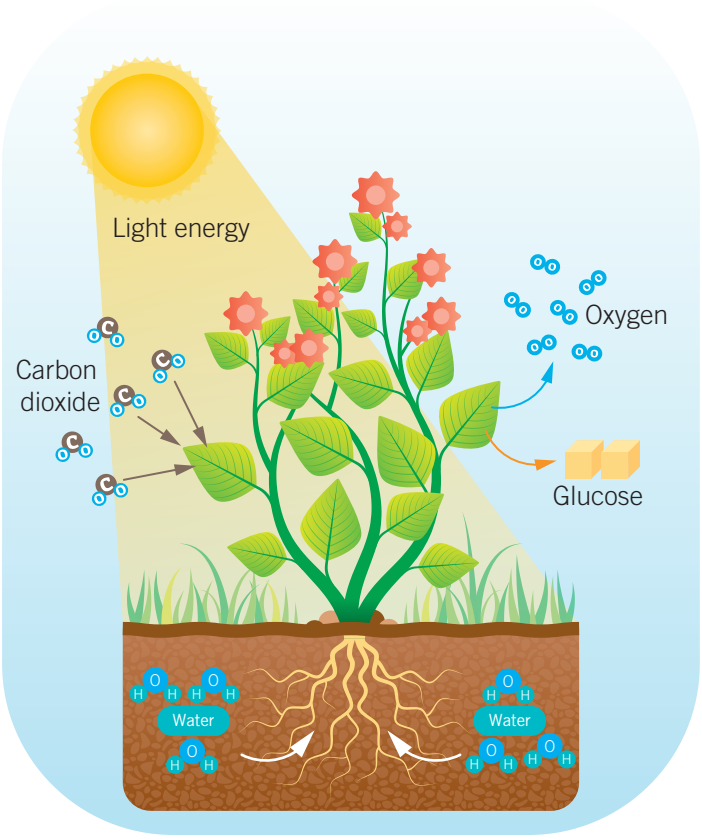



**Figure 2D–4** Plants need the Sun's light energy, mineral nutrients and water to survive. We depend on them because we consume them for their organic materials, and because they are the 'lungs' of the planet – they convert carbon dioxide to oxygen.

ISBN 978-1-108-88711-3

## Inside the chloroplasts

The structure and shape of the leaves of plants and their cells help them carry out photosynthesis. In Section 1C you learned that plant cells are eukaryotic and therefore contain membrane-bound organelles. One such organelle is the chloroplast, whose primary function is photosynthesis.

LINK 1C CELL TYPES

Figure 2D–6 shows the structure of a chloroplast. It has a double membrane, and inside the inner membrane are stacks of what look like pancakes – these are the **grana** (singular: granum), which are made of **thylakoid membranes**. Chlorophyll (the green pigment in plants) sits on the surface of each thylakoid and captures light energy from the Sun. The more thylakoid membranes there are, the more surface area is available for capturing light energy and for exchange of the other materials and waste products of photosynthesis. The grana is where the first stage of photosynthesis, called the *light-dependent stage*, occurs. The remaining space in the chloroplast is a gel-like fluid called the **stroma**, and this contains a large number of ribosomes, due to the large number of enzymes that are needed for the second stage of photosynthesis, called the *light-independent stage*.

LINK 2C SURFACE AREA TO VOLUME RATIO

**Figure 2D–5** Chloroplasts in a pea plant. Note the stacks of thylakoid membranes that form the grana, and the space between them, which is the stroma. The black spots are starch granules.

**Grana** stacks of thylakoid membranes inside the chloroplasts of plant and algal cells, where the light-dependent stage of photosynthesis occurs

**Thylakoid membranes** interconnected and folded membranes inside a chloroplast that make up the grana and are the location of the pigment chlorophyll

**Stroma** gel-like fluid inside a chloroplast that surrounds the grana and is the site of the light-independent stage of photosynthesis

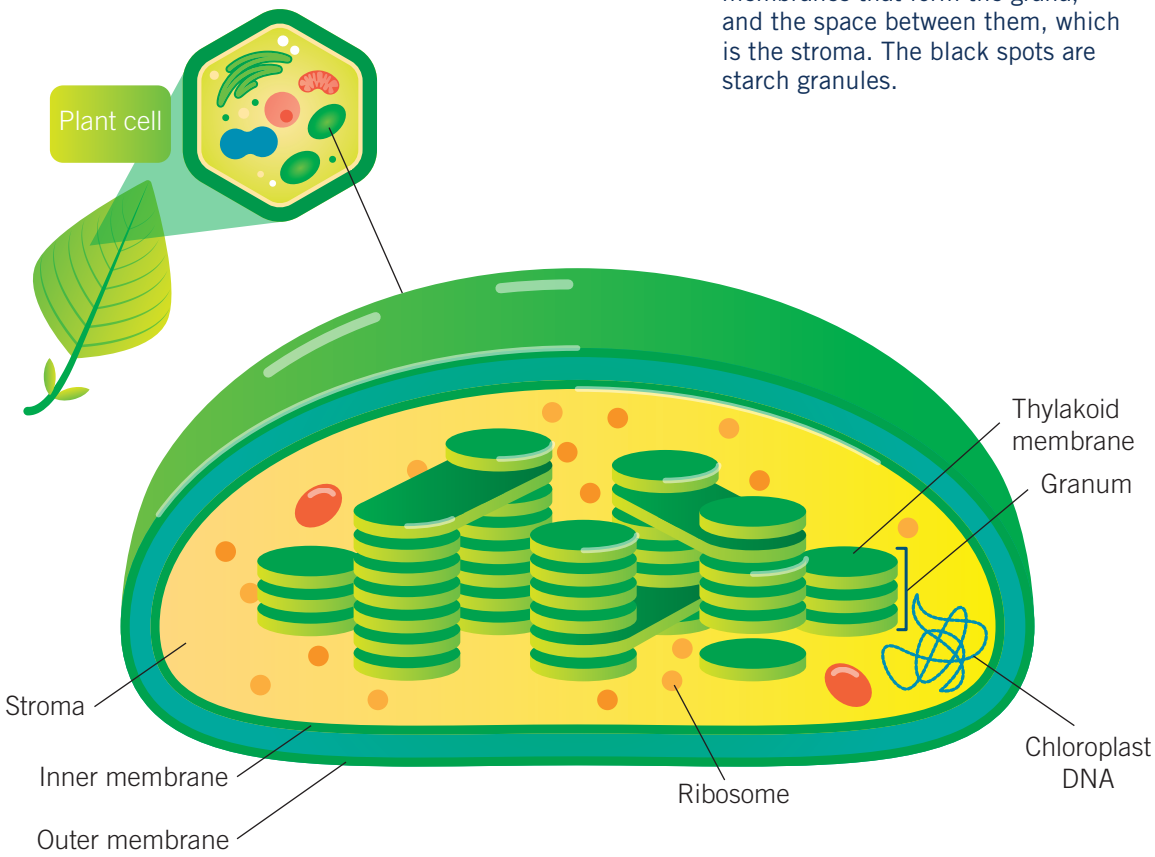



**Figure 2D–6** Chloroplasts are the organelles in plant cells that carry out the process of photosynthesis. The grana and stroma of a chloroplast are the sites of the different stages of photosynthesis.

ISBN 978-1-108-88711-3

## The first chloroplast

**Endosymbiosis** a beneficial relationship between two organisms where one lives inside the other

Chloroplasts have a double membrane, ribosomes and their own DNA. Scientists think that these features are evidence that chloroplasts arose via **endosymbiosis**, where originally a chloroplast was an independent prokaryotic cell that was then engulfed by a larger prokaryotic cell, by phagocytosis. The engulfed chloroplast remained undigested, as it provided a new function for the engulfing cell – in this case, photosynthesis. Over time, the engulfed prokaryotic cell became an organelle of the engulfing cell, which became a eukaryotic cell.

## Check-in questions – Set 2

1 Write the word equation for photosynthesis.
2 Write a balanced chemical equation for photosynthesis.
3 Draw a chloroplast and label a granum, thylakoid membrane, stroma, inner membrane, outer membrane, ribosomes and DNA.
4 Where in the chloroplast is the green pigment chlorophyll located?

UNIT 3 LINK

## The role of chlorophyll

Chlorophyll can absorb most wavelengths of the Sun's light energy, but the red and blue wavelengths of light are absorbed the most and are therefore used for photosynthesis. Chlorophyll is assisted by accessory pigments that help absorb different wavelengths of light energy, as you can see in Figure 2D–7. Accessory pigments include carotenoids (orange/red) and xanthophylls (yellow).

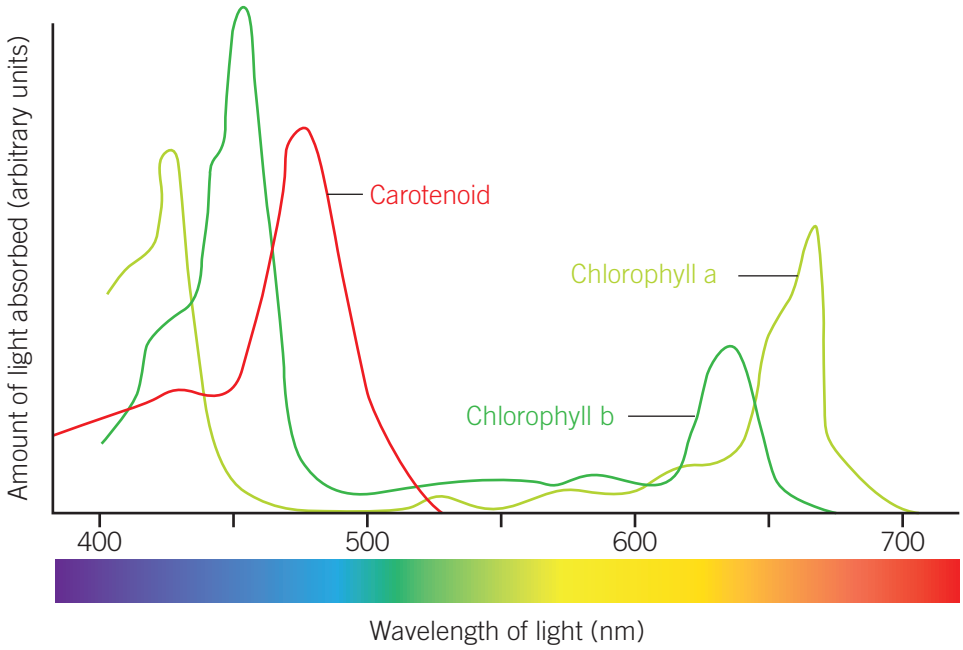



**Figure 2D–7** Amount of light absorbed at the different wavelengths by the pigments in leaves: chlorophyll (a and b) and the accessory pigment carotenoid

ISBN 978-1-108-88711-3

## Check-in questions – Set 3

1 Light energy is converted into what form of energy during photosynthesis?
2 What part of the plant does the water come from in photosynthesis?
3 Name a red, orange or yellow plant pigment that helps chlorophyll harness light energy.

WORKSHEET 2D–1 PHOTOSYNTHESIS

## Mitochondria: cellular respiration

As you know, animals and fungi are heterotrophs: they cannot make their own food (organic material). They consume the organic compound glucose produced by autotrophs. Although autotrophs (green plants and algae) make their own organic material by photosynthesis, they also carry out cellular respiration in order to access the energy stored in glucose.

VIDEO 2D–2 CELLULAR RESPIRATION

In cellular respiration, the chemical energy stored in the bonds of glucose molecules is used to make ATP (adenosine triphosphate), which is the primary energy source for the activities of all cells.

### The energy shuttle

The glucose produced in photosynthesis is used as a raw fuel by the mitochondria in organisms to make energy in the form of ATP. The energy stored in ATP is needed for many biochemical processes in cells, including cell growth and repair, muscle movement, transmission of nerve impulses, moving molecules by active transport, and synthesising molecules such as proteins.

LINK 2A THE NATURE OF SUBSTANCES AND THEIR MODES OF TRANSPORT

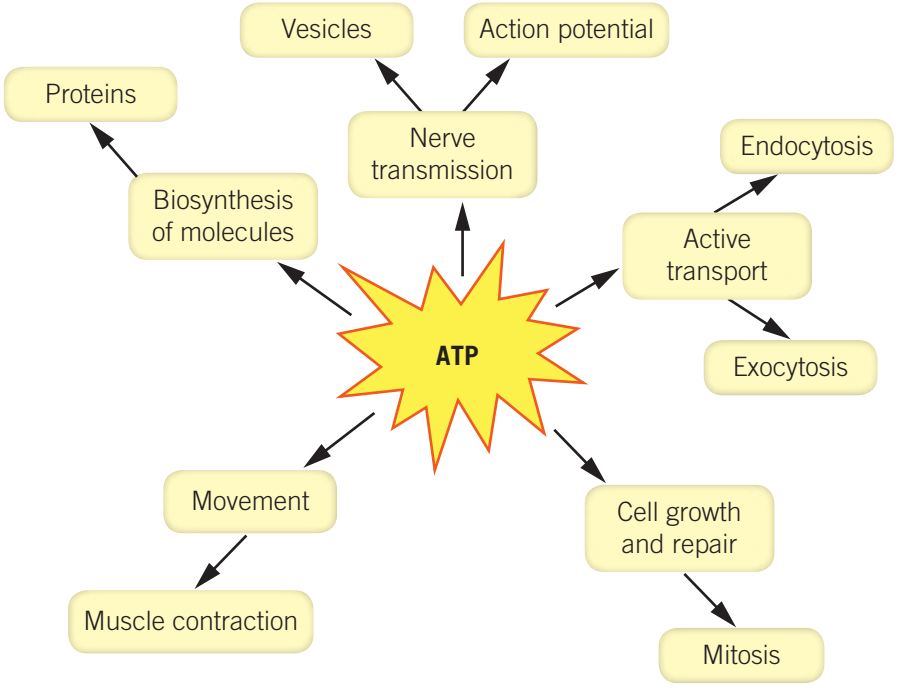



**Figure 2D–8** ATP is the energy currency of the cell, as the energy it stores can be used for many biochemical processes, such as those shown here.

ISBN 978-1-108-88711-3

**ADP (adenosine diphosphate)** a compound composed of adenosine and two phosphate groups that can store energy when another phosphate group is added, forming ATP

As chemical reactions occur in different places within the cell, energy needs to be transferred between reactions. ATP acts as an 'energy shuttle', delivering energy to the various locations where it is needed. The ATP molecule consists of adenosine (an adenine molecule attached to a ribose sugar) and three phosphate groups.

When a cell needs energy, the high-energy bond in ATP is broken, removing a phosphate, and the energy stored in the bond is released (Figure 2D–9). This energy can then be used for cellular processes. The remaining molecule now only has two phosphates and so is named adenosine diphosphate, or **ADP (adenosine diphosphate)**.

When a cell needs to store excess energy, it adds an inorganic phosphate ($P_i$) back onto ADP and stores the energy in the bond, re-forming ATP.

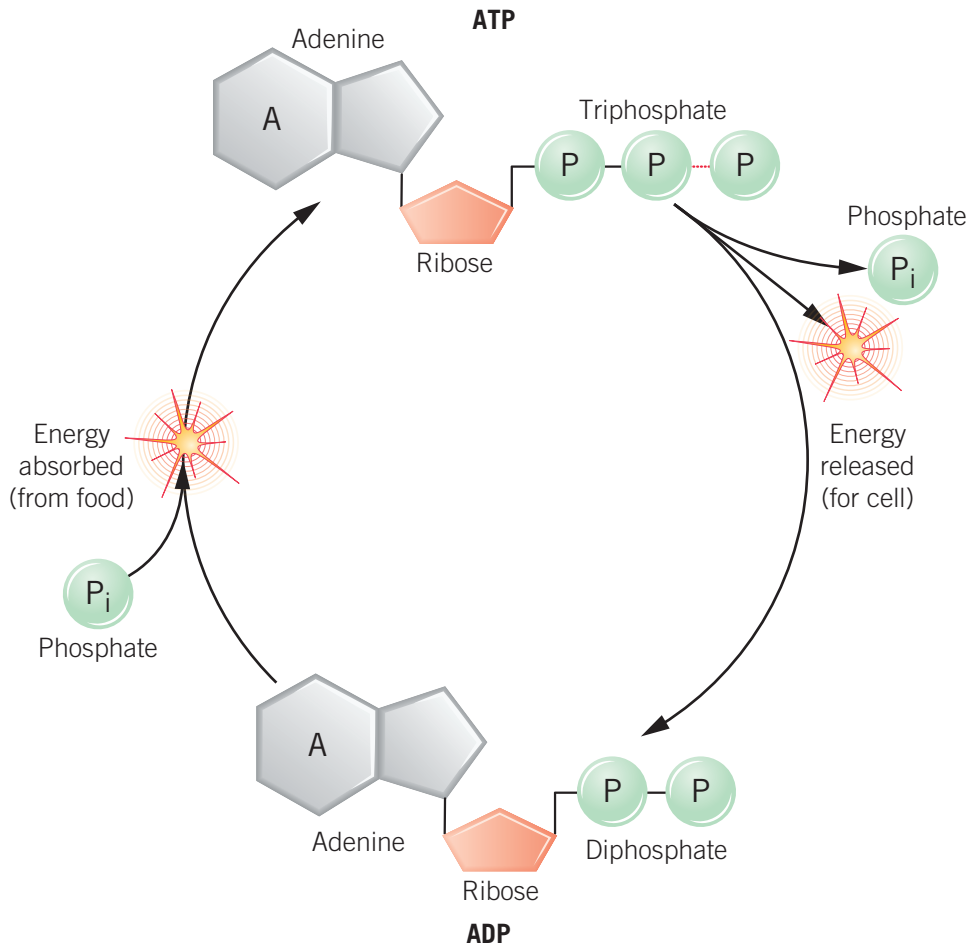



**Figure 2D–9** The energy shuttle, or ATP–ADP cycle. ATP is able to shuttle energy to the location of cellular processes requiring energy, and then release it by breaking the bond between the second and third phosphates, forming ADP. Excess energy is then able to be stored by adding an inorganic phosphate ($P_i$) to ADP, to form ATP.

## Check-in questions – Set 4

1 Draw the structures of ATP and ADP.
2 Outline the relationship between ATP and ADP.

ISBN 978-1-108-88711-3

## The stages of cellular respiration

Like photosynthesis, cellular respiration occurs as a series of steps (biochemical pathway), with each step controlled by a different enzyme. These steps are investigated in more detail in Unit 3. Cellular respiration begins with the process of **glycolysis**, which occurs in the cytosol of cells and does not require oxygen. What happens after glycolysis depends on whether oxygen is present (Figure 2D–10):

LINK UNIT 3

- In **aerobic cellular respiration**, glucose is broken down in the presence of oxygen to produce carbon dioxide, water and ATP.
- In **anaerobic cellular respiration**, glucose is broken down in the absence of oxygen to produce ethanol (in plants and yeast) or lactic acid (in animals).

**Glycolysis**
the first stage of cellular respiration, in which one molecule of glucose is broken down into two pyruvate molecules in the cytosol, producing two ATP molecules; does not require oxygen

**Aerobic cellular respiration**
cellular respiration that occurs in the presence of oxygen and involves the transformation of the chemical energy in glucose into ATP

**Anaerobic cellular respiration**
cellular respiration that occurs in the absence of oxygen and involves the transformation of the chemical energy in glucose into ATP; also known as fermentation

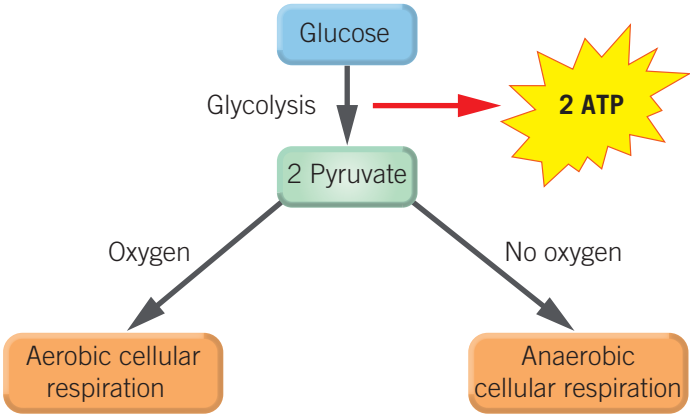



**Figure 2D–10** Cellular respiration begins with glycolysis. What happens after that depends on whether oxygen is present.

### Glycolysis

Glycolysis is the first stage of cellular respiration. It takes place in the cytosol of the cell, and involves the breakdown of glucose into two molecules of pyruvate. (*Glyco-* refers to the carbohydrate glucose and *-lysis* refers to something being broken down.) Glycolysis actually consists of ten different reactions, with each step being catalysed by a specific enzyme. Overall, two molecules of ATP are produced during glycolysis.

### Aerobic cellular respiration

In aerobic cellular respiration, the second and third stages occur in the mitochondria, which are known as the powerhouse of cells. In Unit 3 you will explore each of these reactions in greater detail, but for now you need to know where they occur and how they contribute to the production of ATP in a cell.

LINK UNIT 3

- The *Krebs cycle* (or citric acid cycle) occurs in the fluid **matrix** of the mitochondria and produces two ATP molecules.
- The *electron transport chain* occurs on the inner membrane of the mitochondria, the **cristae**. Most of the ATP is produced in this stage.

**Matrix**
the fluid component of the mitochondria and site of the second stage of aerobic cellular respiration, the Krebs cycle

**Cristae**
the highly folded inner membrane of the mitochondria and site of the third stage of aerobic cellular respiration, the electron transport chain

The overall process of aerobic cellular respiration can be written as a word equation:

$$\text{glucose + oxygen} \longrightarrow \text{carbon dioxide + water + energy}$$

or as a balanced chemical equation:

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_6 + 6H_2O + 36 \text{ or } 38 \text{ ATP}$$

ISBN 978-1-108-88711-3

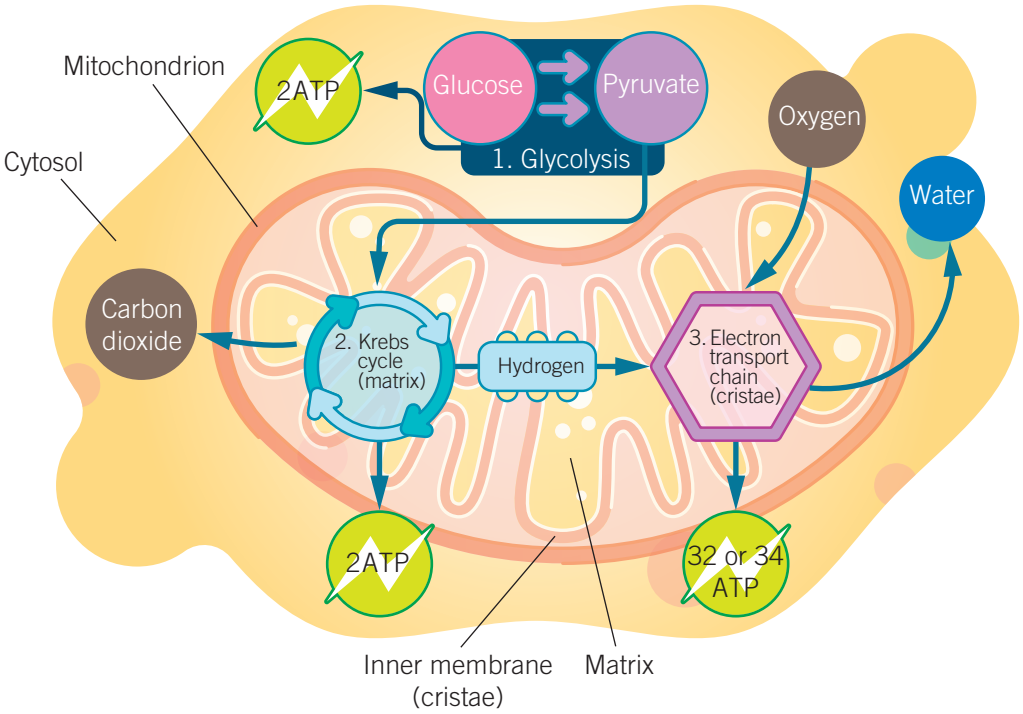



**Figure 2D–11** An overview of aerobic cellular respiration: glycolysis, the Krebs cycle and the electron transport chain

## Inside the mitochondrion

When you observe the structure of a mitochondrion, as shown in Figure 2D–12, you will see that mitochondria share features with chloroplasts that are believed to be evidence of endosymbiosis: a double membrane, ribosomes and DNA. The inner membrane of the mitochondrion is folded over and over, forming a layered structure called the cristae. The more cristae, the more surface area is available for carrying out the important reactions of the electron transport chain. The remaining space in the mitochondrion is a fluid called the matrix, and this contains many ribosomes due to the large number of enzymes (made of protein) that are needed for the reactions that occur during the Krebs cycle and the electron transport chain.

1D ORGANELLES LINK
2C SURFACE AREA TO VOLUME RATIO LINK

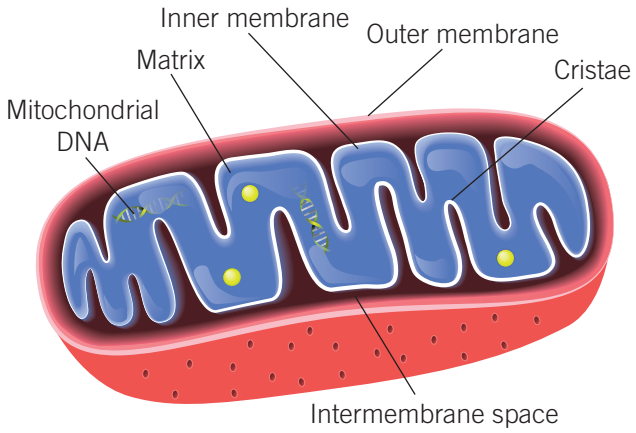



**Figure 2D–12** The mitochondrion is an organelle found in eukaryotic cells, and is where aerobic cellular respiration takes place, with different stages occurring in the matrix (Krebs cycle) and the cristae (electron transport chain).

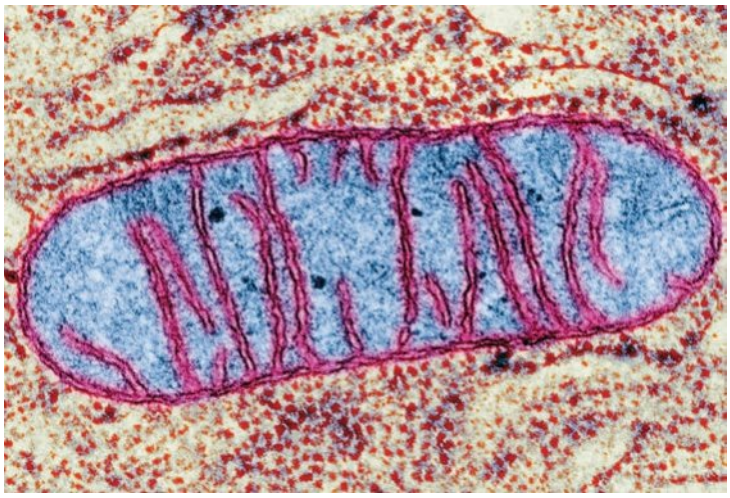


**Figure 2D–13** Transmission electron microscope image of a mitochondrion

ISBN 978-1-108-88711-3

## Check-in questions – Set 5

1 Glycolysis is the first stage of cellular respiration.
   a Briefly state what happens during glycolysis.
   b In which part of a cell does glycolysis occur?
   c Does glycolysis require oxygen?
   d During glycolysis, how many ATP molecules are produced from one glucose molecule?

2 Consider the reactants and products in the balanced chemical equation for aerobic cellular respiration:

$$\text{glucose} + \text{oxygen} \longrightarrow \text{carbon dioxide} + \text{water} + \text{energy}$$

Using Figure 2D–11 to help you, identify the stage of aerobic cellular respiration at which each of the following occurs.
   a Glucose enters.
   b Oxygen enters.
   c Carbon dioxide is produced.
   d Water is produced.
   e The most ATP is produced.

3 Draw up a table that summarises the three stages of aerobic cellular respiration and where in the cell each stage occurs.

### Anaerobic cellular respiration

All organisms can metabolise glucose without oxygen. However, for a cell, the anaerobic process is far less efficient than with oxygen (aerobic cellular respiration), as it produces only two ATP molecules for every glucose molecule that is broken down. Anaerobic cellular respiration, or **fermentation**, begins with the breakdown of glucose to pyruvate (during glycolysis). The next stage continues in the cytosol, and depends on the type of organism.

**Fermentation** the process by which one molecule of glucose is broken down in the absence of oxygen to produce two molecules of ATP; also called anaerobic cellular respiration

In plants and yeast, *alcoholic fermentation* occurs:

$$\text{glucose} \longrightarrow \text{ethanol} + \text{carbon dioxide} + \text{energy (ATP)}$$

In animals, *lactic acid fermentation* occurs:

$$\text{glucose} \longrightarrow \text{lactic acid} + \text{energy (ATP)}$$

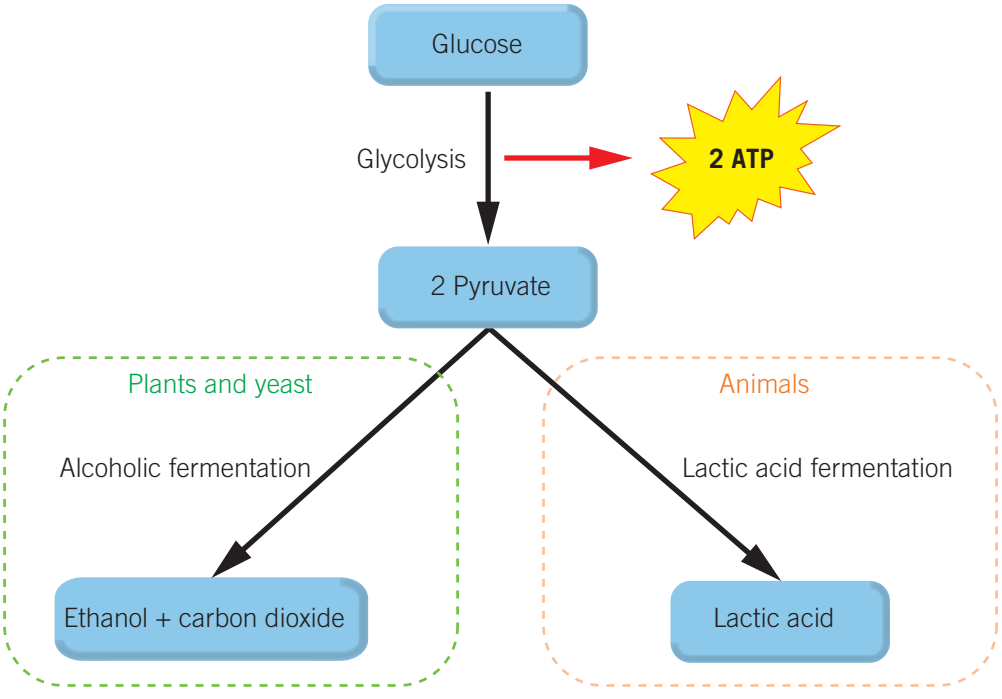



**Figure 2D–14** Anaerobic cellular respiration occurs in the cytosol in the absence of oxygen. It begins with glycolysis, but what happens after glycolysis depends on which type of organism the process occurs in.

ISBN 978-1-108-88711-3

### Comparing aerobic and anaerobic cellular respiration

Aerobic and anaerobic cellular respiration both include glycolysis as the first stage, but they differ in what happens after glycolysis, including where it occurs, the products that result and how much ATP is produced. Table 2D–2 compares the two processes.

**Table 2D–2** Comparison of aerobic and anaerobic cellular respiration

| | Aerobic cellular respiration | Anaerobic cellular respiration |
|---|---|---|
| **Location** | Cytosol and mitochondria | Cytosol |
| **Oxygen required** | Yes | No |
| **ATP yield** | 36 or 38 ATP | 2 ATP |
| **Energy production speed** | Slow ATP production | Rapid ATP production |
| **Reactants** | Glucose + oxygen | Glucose |
| **Products** | Carbon dioxide + water + energy (ATP) | Plants and yeast:<br>Ethanol + carbon dioxide + energy (ATP)<br>Animals:<br>Lactic acid + energy (ATP) |
| **Stages** | Glycolysis<br>Krebs cycle<br>Electron transport chain | Glycolysis<br>Fermentation |

WORKSHEET 2D–2 CELLULAR RESPIRATION

## Check-in questions – Set 6

1 The following questions are about anaerobic cellular respiration.
   a What is another name for this process?
   b In what part of the cell does it occur?
   c How many ATP molecules does it produce from one molecule of glucose?
   d What is the first stage?
2 Write the word equations for anaerobic cellular respiration in plants and animals.

## The link between photosynthesis and cellular respiration

At the start of this section, Figure 2D–3 summarised the link between autotrophs, heterotrophs, photosynthesis and respiration. Figure 2D–15 also summarises the complementary nature of photosynthesis and cellular respiration.

- Photosynthesis occurs in chloroplasts, organelles found only in the cells of green plants and algae.
- Photosynthesis requires light energy and so it can only occur during daylight hours.
- The products of photosynthesis (oxygen and glucose) are used as reactants in the process of aerobic cellular respiration.
- Cellular respiration can occur 24 hours a day in both plant and animal cells.
- Aerobic cellular respiration occurs mostly in mitochondria, organelles found in eukaryotic cells.
- Aerobic cellular respiration uses the products of photosynthesis to produce ATP, an energy storage molecule, which can then release energy to meet the cell's requirements.
- In plants, the products of aerobic cellular respiration (water and carbon dioxide) are used as reactants in the process of photosynthesis.

ISBN 978-1-108-88711-3

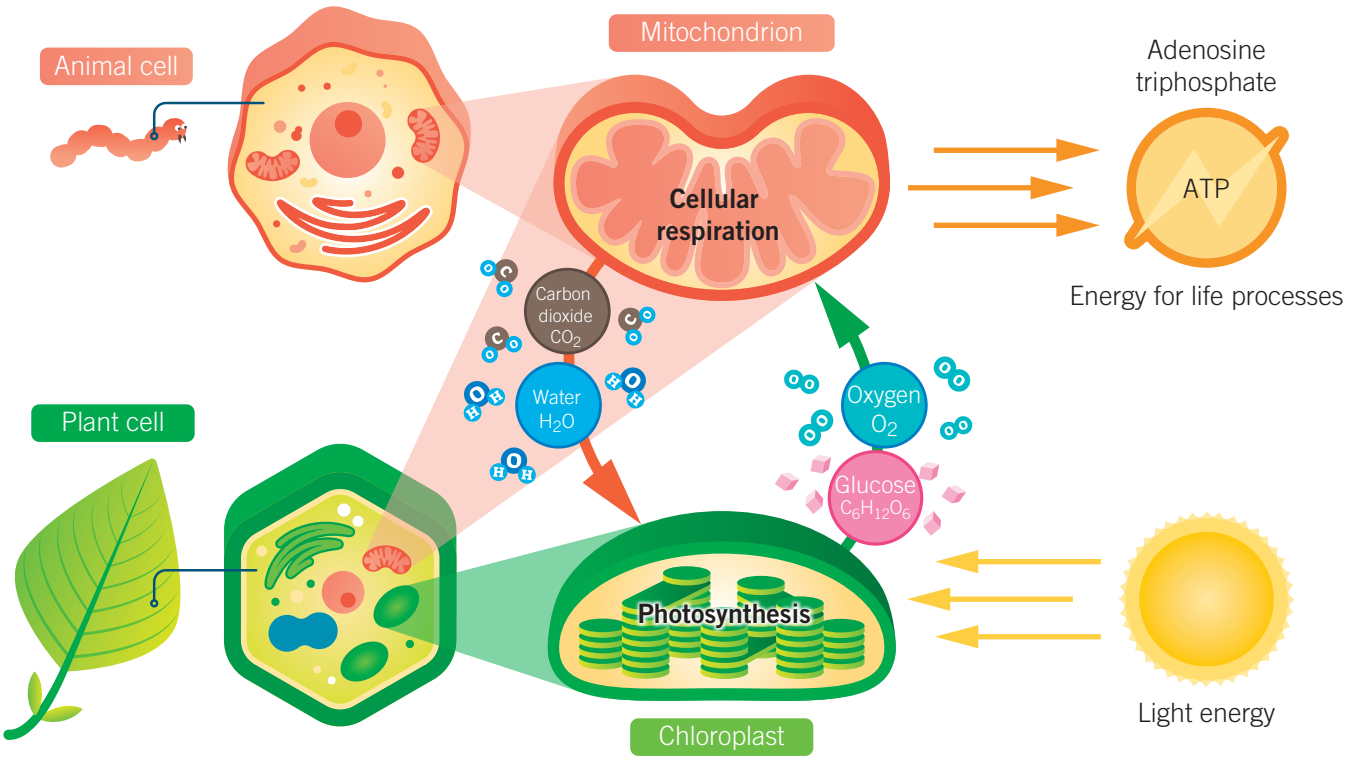



**Figure 2D–15** The complementary nature of the photosynthesis and cellular respiration reactions means that carbon, hydrogen and oxygen cycle continually through organisms and their environments.

## 2D SKILLS

VIDEO 2D–3 SKILLS: WRITING DEFINITIONS

### Writing definitions

As mentioned previously, defining key terms correctly in an assessment is essential in Biology. So, what should you keep in mind from this section?

- The equation for photosynthesis (word and balanced chemical equations) *must* include light energy and chlorophyll on the reaction arrow.
- 'Light' is not an acceptable term, so practise using 'light energy' in your notes.
- You need to understand inputs, outputs and locations of the different stages of photosynthesis and aerobic cellular respiration.
- You should be able to compare fermentation pathways (lactic acid and alcoholic) in terms of their locations, inputs, outputs and ATP yield.
- In assessments, you may use suitable abbreviations such as ATP, and chemical formulas such as $H_2O$, $CO_2$ and $O_2$.

Also keep in mind that what you have learned in Unit 1 about energy transformations, ATP, photosynthesis and cellular respiration will all be of use to you in Units 3 and 4. Making glossaries and flashcards will set you up well for the coming year. In the same way, if you are a visual learner, making posters, concept maps, mind maps and annotated diagrams can help. Even if you are not a visual learner, these ways of revising can force you to organise your thoughts and determine what you do and do not understand, which is a necessary part of reflecting and learning.

ISBN 978-1-108-88711-3

**VIDEO 2D–4** SKILLS: UNDERSTANDING WORD AND BALANCED CHEMICAL EQUATIONS

**Understanding word and balanced chemical equations**

In a chemical reaction, the substances that you start with are called *reactants*, and the substances you finish with are called *products*. We can represent these chemical reactions in different ways, such as a word equation or a balanced chemical equation.

Let's look at aerobic cellular respiration.

Word equation:

$$\text{glucose + oxygen} \longrightarrow \text{carbon dioxide + water + energy}$$

Balanced chemical equation:

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_6 + 6H_2O + 36 \text{ or } 38 \text{ ATP}$$

The *reactants* are on the left of the arrow: glucose and oxygen. Note that the formula for glucose is $C_6H_{12}O_6$, six atoms of carbon joined to 12 atoms of hydrogen and six atoms of oxygen. The *products* are on the right of the arrow: carbon dioxide, water and energy in the form of ATP.

You may have noticed that in front of the oxygen on the left, there is the number 6, and there is also a number 6 in front of the $CO_2$ and $H_2O$ on the right. These extra numbers are not part of the formula for the molecule but are part of the process of balancing chemical equations. You covered this as part of your Year 9/10 Science course. Atoms can't be destroyed or created; they just move around during chemical reactions. This means the number of atoms in the reactants must be the same as in the products.

## Section 2D questions

1 **a** How many membranes surround a chloroplast and a mitochondrion? Explain the theory and evidence behind your answer.
   **b** Why do the membranes in these two organelles have such large surface areas?
   **c** Sketch a chloroplast, label the key structures involved in photosynthesis, and identify what stage occurs at each location labelled.
   **d** Sketch a mitochondrion, label the key structures involved in aerobic cellular respiration, and identify what stage occurs at each location labelled.

2 ATP is a molecule that contains a lot of energy.
   **a** Provide examples of what the energy stored in ATP is needed for.
   **b** Explain how this energy is released from ATP and can be stored at a later time.

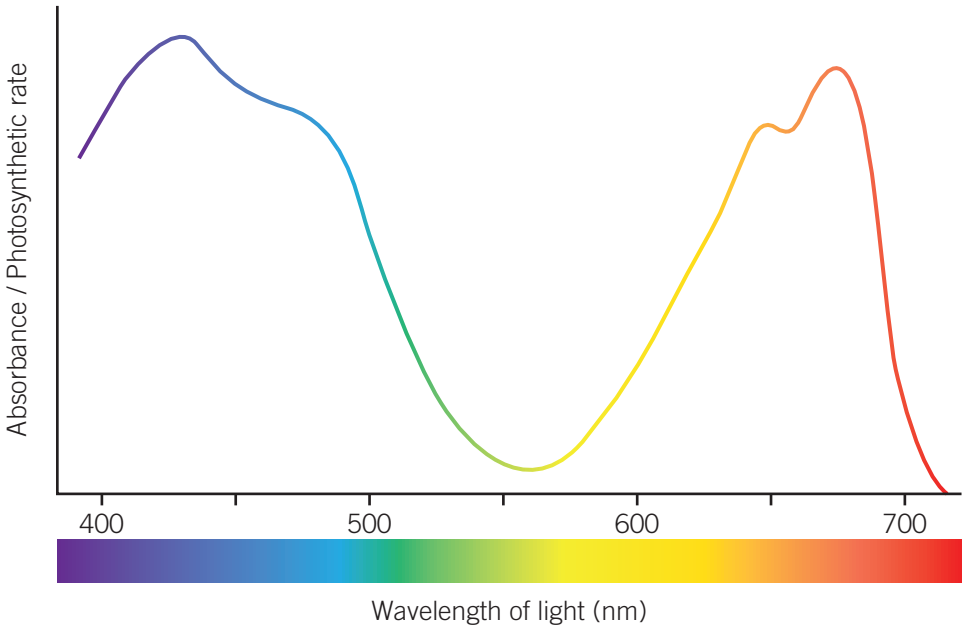
3 Both lactic acid fermentation and alcoholic fermentation begin with the organic compound glucose.
   **a** What is the name of the process by which the glucose molecule was made?
   **b** What type of organism can carry out the process you named in part **a**?
   **c** The first stage of fermentation is glycolysis. How many ATP molecules are produced from one molecule of glucose during this stage?
   **d** Write the word equation for alcoholic fermentation.

4 Cells cannot directly use the chemical energy stored in glucose. Summarise how the energy stored in glucose is transformed, in the presence of oxygen, into a high-energy compound.

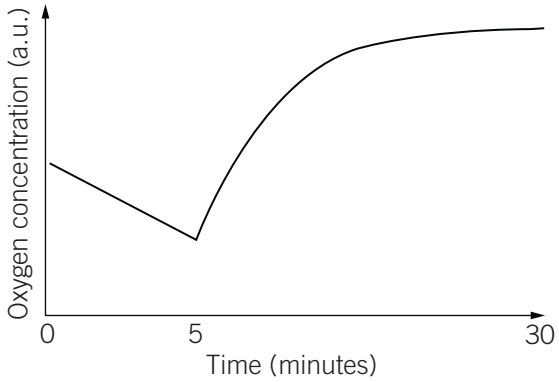
ISBN 978-1-108-88711-3

**5** Compare and contrast aerobic and anaerobic cellular respiration.

**6** Consider the graph below. What is the relationship between the absorbance of the different wavelengths of light energy by the pigments in leaves, and the rate of photosynthesis when the leaves are exposed to different wavelengths of light? Justify your answer, showing your understanding of the link between absorbance of light energy and photosynthesis.




**7** A group of students were investigating the effect of light energy on photosynthesis. They placed plants in a clear plastic box with a data logger that measured the $O_2$ concentration in the air surrounding the plant leaves. For the first 5 minutes the plants were placed in a dark cupboard and then they were exposed to light energy for 25 minutes. The graph below summarises the students' results. Give reasons why the $O_2$ concentration decreased in the first 5 minutes and then increased over the remaining 25 minutes.




ISBN 978-1-108-88711-3

# Chapter 2 review

## Summary

Create your own set of summary notes for this chapter on paper or in a digital document. A model summary is provided in the Teacher Resources, which can be used to compare with yours.

## Checklist

In the Interactive Textbook, the success criteria are linked from the review questions and will be automatically ticked when answers are correct. Alternatively, print or photocopy this page and tick the boxes when you have answered the corresponding questions correctly.

| Success criteria – I am now able to: | | Linked question |
|---|---|---|
| **2A.1** | Draw the plasma membrane, label key structures and state their function | 3☐, 11☐ |
| **2A.2** | Give reasons why substances need to move through the plasma membrane | 12☐ |
| **2A.3** | Define semi-permeable, hydrophilic and hydrophobic | 9☐, 12☐ |
| **2A.4** | Summarise the modes of transport used by substances crossing the plasma membrane, including the nature of the substances moving, whether energy is required, and the component of the membrane involved in the transport | 4☐, 5☐, 12☐, 13☐ |
| **2B.1** | Summarise the process of osmosis including the substance moving, whether energy is required, and the component of the membrane involved in the transport | 5☐, 8☐, 16☐, 18☐ |
| **2B.2** | Define tonicity, hypertonic, isotonic and hypotonic | 9☐, 15☐, 18☐ |
| **2B.3** | Distinguish between the movement of substances in hypertonic, isotonic and hypotonic environments | 9☐, 15☐, 18☐ |
| **2C.1** | Define surface area to volume ratio (SA:V) and demonstrate how to calculate SA:V ratio | 14☐ |
| **2C.2** | Summarise the impact of an increasing or decreasing SA:V ratio on the efficiency of cellular functions | 6☐, 13☐, 14☐ |
| **2C.3** | Identify the three ways that cells can increase their SA:V ratio | 14☐ |
| **2C.4** | Give reasons why cell size is limited | 19☐ |
| **2D.1** | Explain the function of chloroplasts and mitochondria | 7☐ |
| **2D.2** | Draw the chloroplast and the mitochondrion, label key structures and state the function of these key structures | 7☐, 13☐ |
| **2D.3** | Summarise the inputs, outputs and location of the stages of photosynthesis and cellular respiration (aerobic and anaerobic) | 1☐, 2☐, 10☐, 13☐, 17☐ |
| **2D.4** | State the word equation and balanced chemical equation for photosynthesis and the word equation for cellular respiration (both aerobic and anaerobic) | 13☐ |
| **2D.5** | Demonstrate an understanding of the energy shuttle and why cells need ATP to survive | 4☐, 13☐ |

ISBN 978-1-108-88711-3

## Multiple-choice questions

1 The correct order of stages in aerobic cellular respiration is
- **A** glycolysis → Calvin–Benson cycle → electron transport chain.
- **B** light-dependent stage → glycolysis → Krebs cycle.
- **C** glycolysis → Krebs cycle → electron transport chain.
- **D** electron transport chain → Krebs cycle → glycolysis.

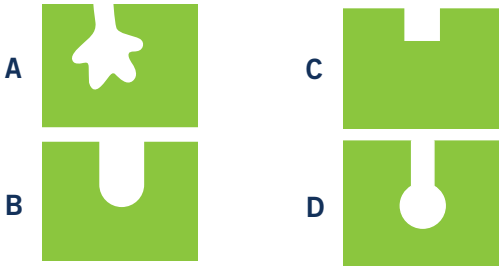
2 Which of the statements below is true?
- **A** Photosynthesis occurs in the first half of the day.
- **B** Photosynthesis occurs during daylight hours, while cellular respiration occurs all the time.
- **C** ATP is produced in the light-independent stage of photosynthesis.
- **D** ATP provides energy for cellular respiration.

3 Which statement best describes the structure of the plasma membrane?
- **A** phospholipid bilayer with proteins and carbohydrates
- **B** phospholipid bilayer with carbohydrates
- **C** protein bilayer with phospholipids
- **D** phospholipid bilayer with lipids

4 ATP is a high-energy molecule. Which of the following pairs of processes both require an input of energy?
- **A** cell movement, diffusion
- **B** active transport, cell growth
- **C** osmosis, cell reproduction
- **D** cell repair, facilitated diffusion

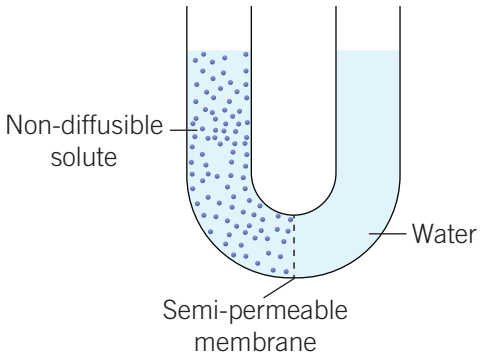
5 Which of the following is *incorrect*?
- **A** Cells are unable to directly control the movement of water through the plasma membrane.
- **B** One role of the plasma membrane is to regulate the movement of substances into and out of cells.
- **C** Water molecules move from low to high free water concentration by osmosis.
- **D** Osmosis is the movement of water from low to high solute concentration through the plasma membrane.

6 Identify which of the following shapes would allow the most efficient exchange across the plasma membrane.




7 Which of the following statements is correct?
- **A** Mitochondria are found only in eukaryotic animal cells, while chloroplasts are found only in eukaryotic plant cells.
- **B** Chloroplasts contain stacks of thylakoid membranes called grana and a gel-like substance called the matrix.
- **C** Mitochondria are the site of anaerobic cellular respiration.
- **D** Mitochondria and chloroplasts both contain a double membrane and many ribosomes.

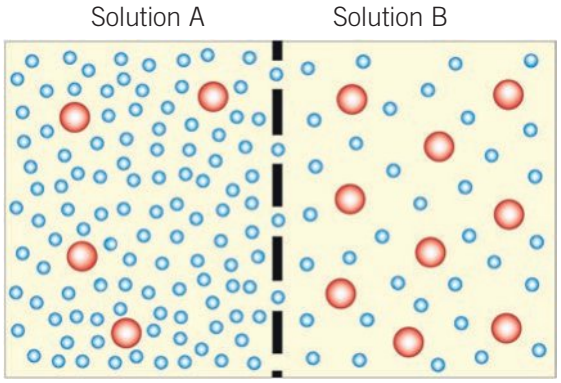
8 The U-shaped tube in the figure below is divided by a semi-permeable membrane that selectively allows water to pass through but not large solutes, such as starch. Which of the following will occur?




- **A** Water will move from right to left by osmosis.
- **B** Water will move from left to right by osmosis.
- **C** Starch will move from right to left by osmosis.
- **D** Starch will move from left to right by osmosis.

ISBN 978-1-108-88711-3

**9** Two solutions were separated by a semi-permeable membrane, as shown in the figure. Both solutions contain water (blue) and glucose (red), and both molecules can move through the pores of the membrane.




Using the information provided, you could say that

**A** solution A is hypertonic compared to solution B.
**B** glucose will need ATP to move from solution B to solution A.
**C** solution B is hypertonic compared to solution A.
**D** solution A and B are isotonic.

**10** Which of the following lists contains the products created when a yeast cell undergoes fermentation?

**A** ethanol and water
**B** lactic acid and water
**C** ethanol and carbon dioxide
**D** lactic acid and carbon dioxide

## Short-answer questions

**11** Draw a plasma membrane, labelling the following parts:
phospholipid bilayer, cholesterol, glycoprotein, glycolipid. (2 marks)

**12** The cell controls the entry and exit of substances through the plasma membrane.

**a** Give reasons why cells need to move substances through the plasma membrane. (2 marks)

**b** Not all substances can enter and leave a cell through the plasma membrane. Name and define the term that describes this characteristic. (1 mark)

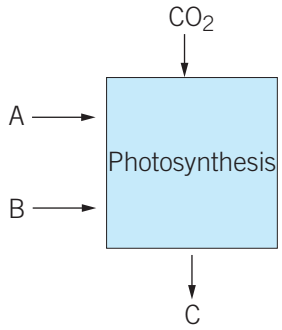
**c** Copy and complete the table below by filling in the gaps. (3 marks)

| Nature of substance | Example | Mode of transport | Passive or active |
|---|---|---|---|
| Small uncharged | | | |
| | Protein | | |

**d** Explain the process of endocytosis. (2 marks)

**e** Name two processes that could not be carried out by cells if their plasma membrane lacked carrier proteins. (1 mark)

**13** The diagram shows a basic summary of photosynthesis.




**a** What are the names of inputs A and B? (1 mark)

**b** What is the name of the six-carbon output labelled C and how does it move through a plasma membrane without the expenditure of energy? (2 marks)

**c** Where does photosynthesis occur? (1 mark)

**d** What is the name of the output that is missing from the diagram and how does it move through the plasma membrane? (2 marks)

ISBN 978-1-108-88711-3

**e** Two processes can then use output C to produce energy in the form of ATP. Name these two processes and explain the advantage of one of these processes over the other. (2 marks)

**f** Write the balanced word equation for the process named in part **e** that requires oxygen to occur. (1 mark)

**g** As the mitochondria break down output C, carbon dioxide is produced as a waste. Would the carbon dioxide molecules move out of the cell faster if the cell had a small volume or a large volume? Explain your answer. (1 mark)

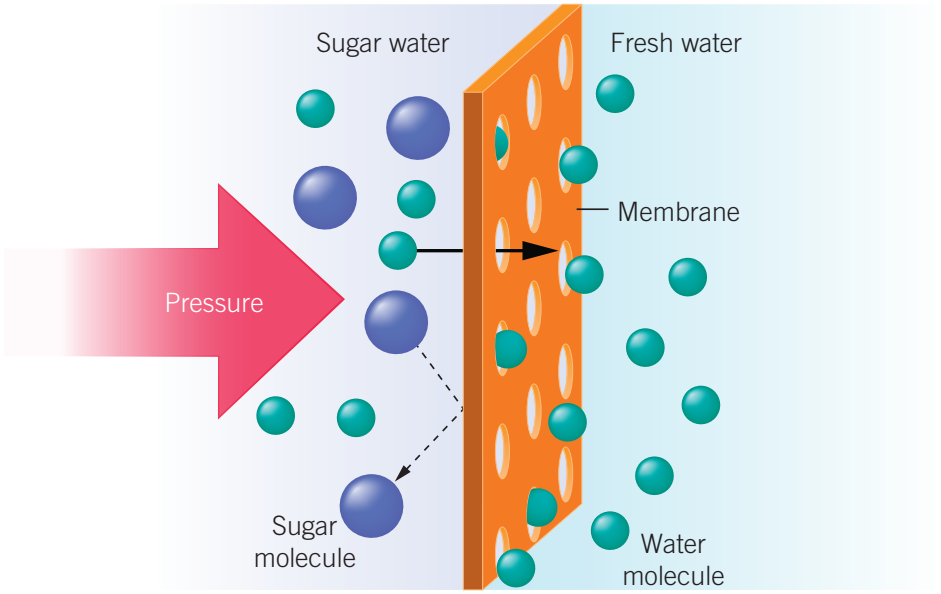
**14 a** Explain the meaning of the term 'surface area to volume ratio', referring to the relevant cell structures in your answer. (1 mark)

**b** Explain what value increasing the surface area has to the cell. (2 marks)

**c** Identify ways in which cells can increase their surface area without increasing their volume. (1 mark)

**15** Lysis occurs in animal cells, not plant cells. Summarise the circumstances that lead to lysis. (3 marks)

**16** Reverse osmosis is often used in desalination plants as a means of separating sugar from water. Using the following figure and your understanding of movement through membranes, distinguish between osmosis and reverse osmosis. (2 marks)




**17** Measurements of a leaf show it is giving out oxygen and taking in carbon dioxide. Does this prove that aerobic cellular respiration is not occurring in this leaf? Justify your answer. (3 marks)

ISBN 978-1-108-88711-3

**18** It is possible to dissolve and hence remove the outer hard shell of a hen's egg using vinegar.

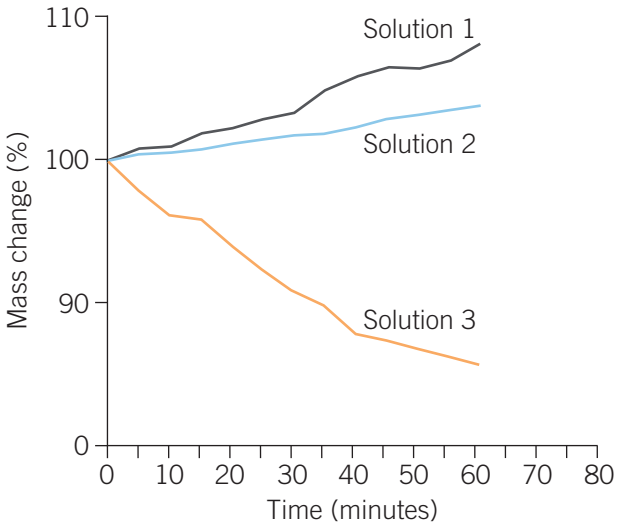
This leaves just the plasma membrane undamaged and the cell contents intact. Shells were removed in this way from several eggs and each egg was placed in one of three solutions:

Solution 1 – distilled water

Solution 2 – 0.5 M sucrose

Solution 3 – 1.5 M sucrose

The mass of the eggs was recorded at regular intervals at room temperature over one hour. The results are presented below.

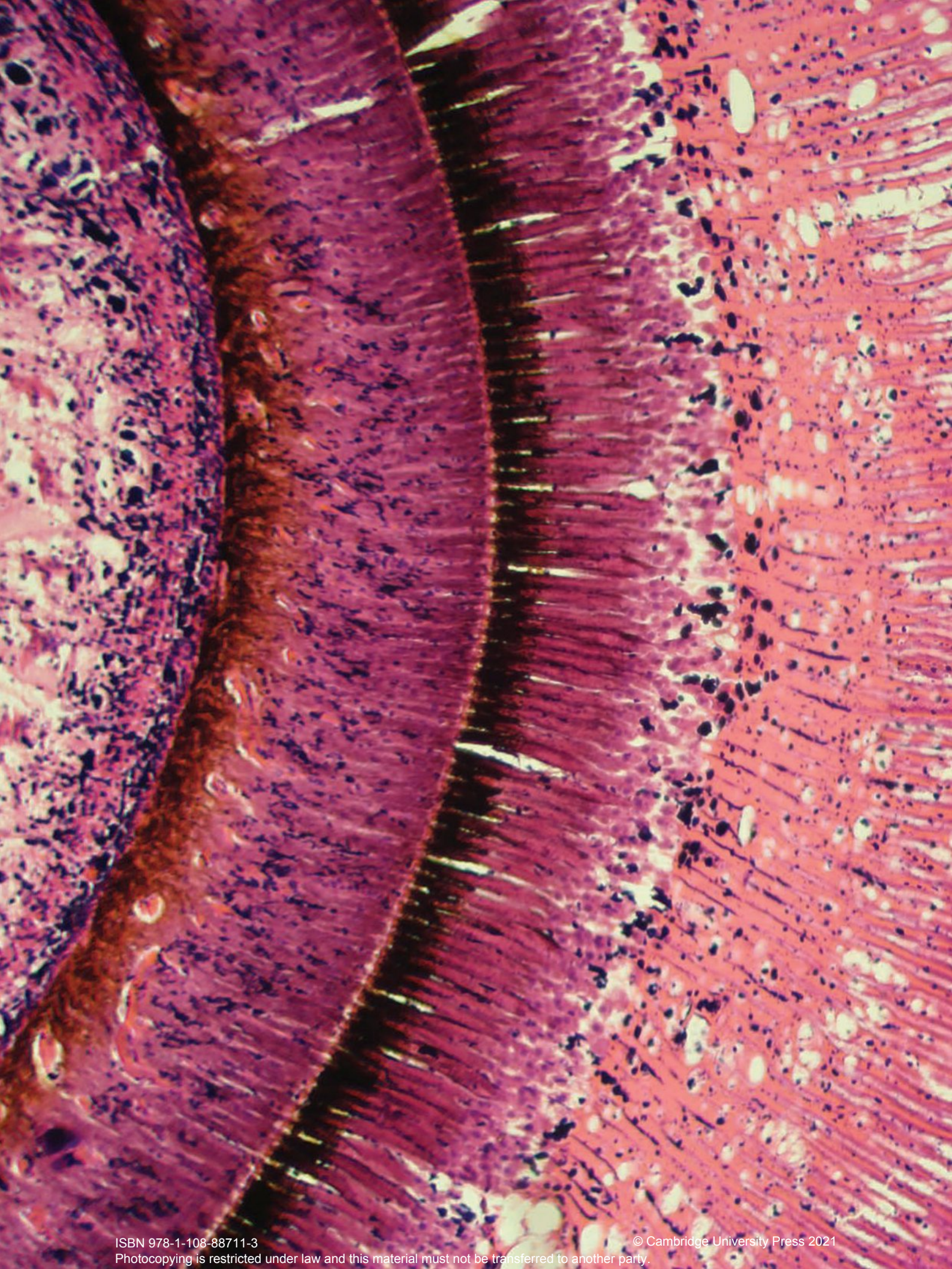



**a** Explain why there is a difference between the results for the eggs placed in distilled water and eggs placed in 0.5 M sucrose. (3 marks)

**b** Name and describe the conditions in which an egg would show neither an increase nor a decrease in mass. (2 marks)

**19** Give reasons why cells are so small. (2 marks)

ISBN 978-1-108-88711-3



ISBN 978-1-108-88711-3

UNIT 1

HOW DO ORGANISMS REGULATE THEIR FUNCTIONS?

CHAPTER 3

# CELLULAR REGENERATION AND REGULATION

## Introduction

A cell's ability to self-replicate is fundamental to life. In this chapter, you will learn how pre-existing cells generate new cells in the development of embryos and in later growth and repair. You will investigate the nature and role of stem cells in this process, and how these stem cells differentiate to form all the different cells that make up the various tissues and organs of the human body. Stem cells also have tremendous potential in the field of regenerative medicine, and their many applications in the treatment of injury and disease are explored here.

In this chapter, you will also explore the events of the cell cycle in eukaryotic cells and the differences in division between eukaryotic and prokaryotic cells. You will become familiar with the importance of cellular division in the growth and development of organisms, as well as the role of the cell cycle in the repair and maintenance of old or damaged cells. The key events of the cell cycle in the lead-up to cell division are described, along with the characteristics of each phase of mitosis. Cytokinesis, the final stage in the division of a cell, is explained in the context of plant and animal cells, with key differences highlighted.

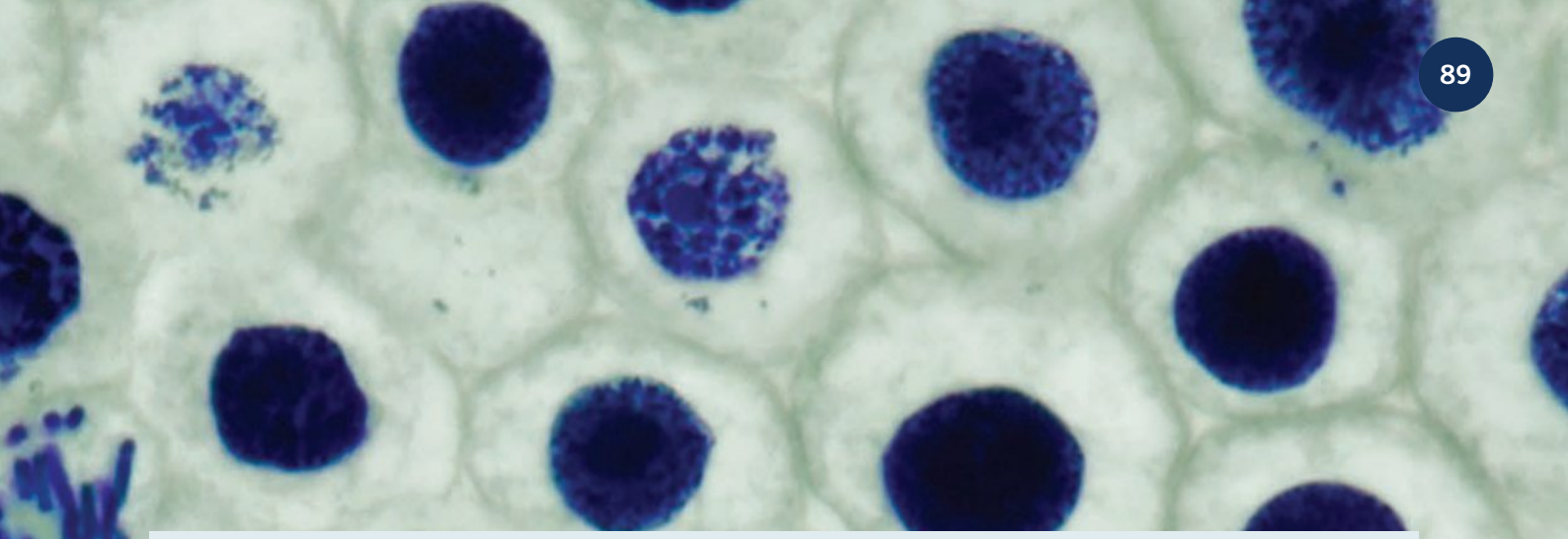
The final section of this chapter focuses on regulatory mechanisms that ensure the smooth progress of a cell through the cell cycle. The role of checkpoints and their respective regulatory proteins in detecting damaged or faulty cells is discussed, as well as the need for programmed cell death (apoptosis) to safely remove these cells. Finally, the development of cancer is explained, with a particular focus on the relationship between regulatory checkpoint failure and the onset of the disease.

## Curriculum

**Area of Study 1 Outcome 1**
**The cell cycle and cell growth, death and differentiation**

| Study Design | Learning intentions – at the end of this chapter I will be able to: |
|---|---|
| • Properties of stem cells that allow for differentiation, specialisation and renewal of cells and tissues, including the concepts of pluripotency and totipotency | **3A Where do new cells come from?**<br>**3A.1** Identify the key cellular stages of prenatal development from fertilisation to foetus (zygote, morula, blastocyst, gastrula, embryo and foetus)<br>**3A.2** Define the key development terms: zygote, morula, blastocyst, gastrula, embryo and foetus<br>**3A.3** Label the key features of a blastocyst and explain the significance of the inner cell mass in the development of an individual |

ISBN 978-1-108-88711-3



| Study Design | Learning intentions – at the end of this chapter I will be able to: |
|---|---|
| | **3A.4** Describe the role of stem cells in multicellular organisms<br>**3A.5** Explain the role of stem cells in the formation of the three primary germ layers<br>**3A.6** Identify the types of tissues that are generated by the endoderm, mesoderm and ectoderm within an organism<br>**3A.7** Understand the concept of critical periods in the normal development of an embryo<br>**3A.8** Describe the properties of stem cells, including self-renewal and potency<br>**3A.9** Distinguish between the different types of stem cell potencies (unipotent, pluripotent, multipotent and totipotent)<br>**3A.10** Distinguish between embryonic, adult and induced pluripotent stem cells in terms of potency and the locations they can be sourced from<br>**3A.11** Describe the potential applications of each type of stem cell in regenerative medicine<br>**3A.12** Describe the various ethical issues associated with the use of stem cells in medical and scientific research |
| • Binary fission in prokaryotic cells<br>• The eukaryotic cell cycle, including the characteristics of each of the sub-phases of mitosis and cytokinesis in plant and animal cells | **3B The cell cycle**<br>**3B.1** Derive that all cells arise from pre-existing cells, through the cell cycle<br>**3B.2** Describe the role of mitosis in growth and repair<br>**3B.3** Describe and diagrammaticality represent the role of binary fission in prokaryotic asexual reproduction<br>**3B.4** Recognise mitosis as a prelude to cellular differentiation<br>**3B.5** Identify and describe the key cell cycle events in eukaryotes, including reference to: growth (G1, G2), DNA replication (S), mitosis and cytokinesis<br>**3B.6** Recognise DNA replication (including via images of DNA structure) as a necessary precursor to cell division<br>**3B.7** Describe and identify from diagrams, the stages in mitosis: prophase, metaphase, anaphase and telophase<br>**3B.8** Describe and explain the similarities and differences in cytokinesis between plant and animal cells |

ISBN 978-1-108-88711-3

| Study Design | Learning intentions – at the end of this chapter I will be able to: |
|---|---|
| • Apoptosis as a regulated process of programmed cell death<br>• Disruption to the regulation of the cell cycle and malfunctions in apoptosis that may result in deviant cell behaviour: cancer and the characteristics of cancer cells | **3C Cell cycle regulation and apoptosis**<br>**3C.1** Correctly identify key checkpoints on a diagram of the cell cycle and describe their purpose as regulatory mechanisms<br>**3C.2** Explain the role of regulatory proteins at cell cycle checkpoints<br>**3C.3** Define apoptosis and its importance in normal biological development<br>**3C.4** Describe the key events of the apoptosis pathway<br>**3C.5** Distinguish between the intrinsic and extrinsic apoptosis pathways including the circumstances that would lead to the activation of each pathway<br>**3C.6** Distinguish between apoptosis and necrosis<br>**3C.7** Describe the significance of an abnormal regulatory protein (p53) in the onset of cancer<br>**3C.8** Give examples of factors that can contribute to the development of abnormal regulatory proteins<br>**3C.9** Explain how disruption to the regulation of the cell cycle can give rise to uncontrolled cell division and lead to the development of cancer<br>**3C.10** Identify the key differences between cancer cells and normal cells, including in different cell types |

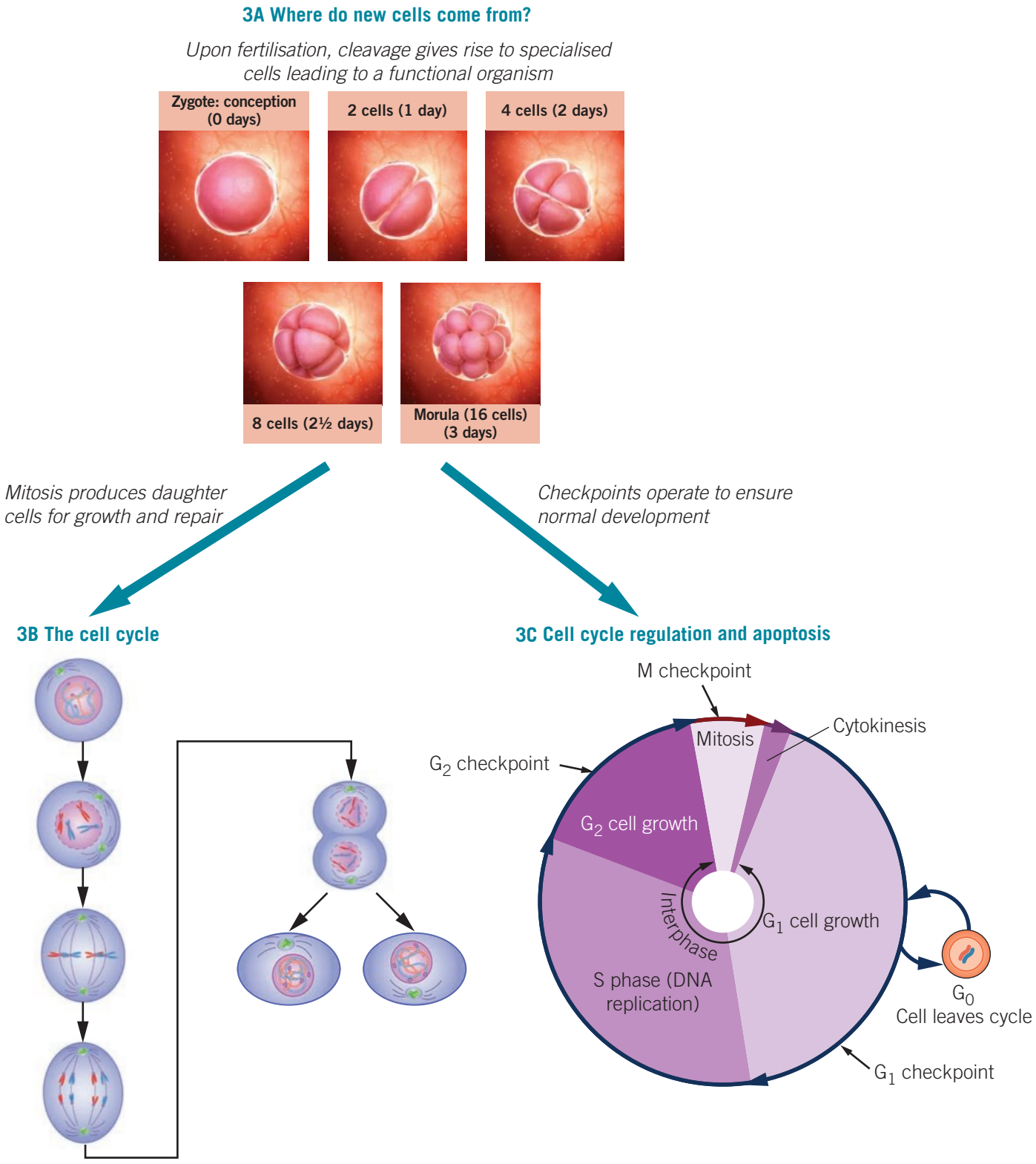


## Glossary

Adult stem cells
Anaphase
Angiogenesis
Apoptosis
Apoptotic bodies
Benign
Binary fission
Blastocyst
Bleb
C (cytokinesis) phase
Cancer
Caspases
Cell cycle checkpoints
Cell plate
Centromere
Centrosome
Chromatid
Chromatin
Chromosomes
Cleavage furrow
Complementary base pairing
Critical periods
Culture
Cytokinesis
Deoxyribonucleic acid (DNA)
Diploid
DNA packaging
Double chromosome
Ectoderm
Embryo
Embryonic germ layers
Embryonic stem cell
Endoderm
Extrinsic pathway
Foetus
G0 phase
G1 checkpoint
G1 (first gap) phase
G2 checkpoint
G2 (second gap) phase
Gastrula
Gastrulation
Gestation period
Haematopoietic stem cell
Induced pluripotent stem cells (iPSCs)
Inner cell mass
Interphase
Intrinsic pathway
Kinetochore
M checkpoint
M (mitosis) phase
Malignant
Mesoderm
Metaphase
Metastasis
Mitosis
Morula
Multipotent
Necrosis
Nucleosome
Nucleotide
p53 protein
Phagocytic cell
Pluripotent
Prophase
Purine
Pyrimidine
Regenerative medicine
Regulatory proteins
Reproduction
Self-renewal
Single chromosome
S (synthesis) phase
Stem cell
Stem cell therapy
Telophase
Totipotent
Trophoblast
Tumour
Unipotent
Uterus
Zygote

ISBN 978-1-108-88711-3

## Concept map




*See the Interactive Textbook for an interactive version of this concept map interlinked with all concept maps for the course, and for a quiz of prior knowledge from Years 9 & 10 science.*

ISBN 978-1-108-88711-3


# Where do new cells come from?

**Study Design:**
Properties of stem cells that allow for differentiation, specialisation and renewal of cells and tissues, including the concepts of pluripotency and totipotency

**Glossary:**
Adult stem cells
Blastocyst
Critical periods
Ectoderm
Embryo
Embryonic germ layers
Embryonic stem cell
Endoderm
Foetus
Gastrula
Gastrulation
Gestation period
Haematopoietic stem cell
Induced pluripotent stem cells (iPSCs)
Inner cell mass
Mesoderm
Morula
Multipotent
Pluripotent
Regenerative medicine
Self-renewal
Stem cell
Stem cell therapy
Totipotent
Trophoblast
Unipotent
Uterus
Zygote

## ENGAGE

### Xenobots and stem cells

For thousands of years, humans have been shaping the development of organisms for our own gain. Generations of dairy farmers have been breeding cows that produce the most milk, and wheat farmers have been selecting the tallest and most robust wheat to produce the next generation. More recently, technology has allowed us to further manipulate the evolutionary path of organisms by direct manipulation of DNA. For example, we can alter the DNA of salmon to make them grow faster or introduce a trait into apples that stops them going brown. Our ability to exploit the features of organisms for our own benefit has just been taken a step further, with scientists at the University of Vermont, United Sates, using artificial intelligence (AI) (a computer system with human-like thinking capabilities) and the stem cells of frogs to create the world's first living robot, the xenobot.

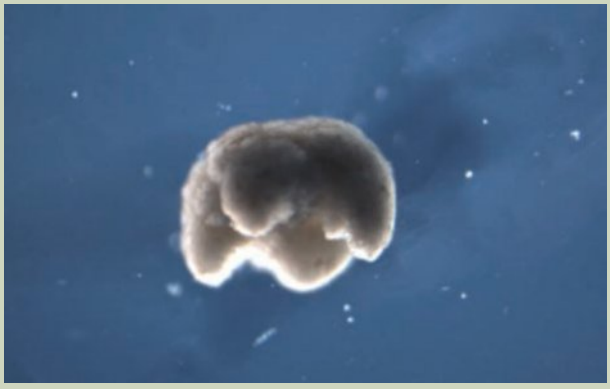


**Figure 3A–1** The xenobot is smaller than a pinhead, less than 1 mm.

Scientists harvested frog stem cells, taken later in development, that would normally develop into skin (to form the architecture) or heart tissue (to contract and relax, allowing movement). They then used AI to test thousands of combinations of heart and skin tissue to work out how these configurations and shapes would behave in the real world. The AI combinations that showed positive simulation results were then built in the laboratory by scientists, using the harvested frog stem cells. The end result of this work was the xenobot.

ISBN 978-1-108-88711-3

The xenobot is unable to eat or reproduce and survives for only a week. However, it is capable of walking, swimming, pushing or carrying objects, working cooperatively in a group and repairing itself if damaged. Scientists are hoping that studying the xenobot will help them to crack the code on how different types of cells communicate with each other. There is also hope that, in the future, xenobots may be further developed and built from a human patient's own cells, to be used for delivering drugs, to repair tissue or target cancer.

The potential of stem cells is not limited to the computerised world of AI. In this section, you will learn about the role of stem cells in the early stages of development as well as the many possibilities they provide in the field of medicine.

**EXPLAIN**

## Early development

It takes approximately 8 weeks for a human **embryo** to develop into a **foetus** and another 32 weeks for the foetus to develop into a fully functional child. This complex period of growth and development is known as the **gestation period** and takes about 40 weeks, but as you can see in Figure 3A–2 there is considerable variation in gestational time throughout the animal kingdom.

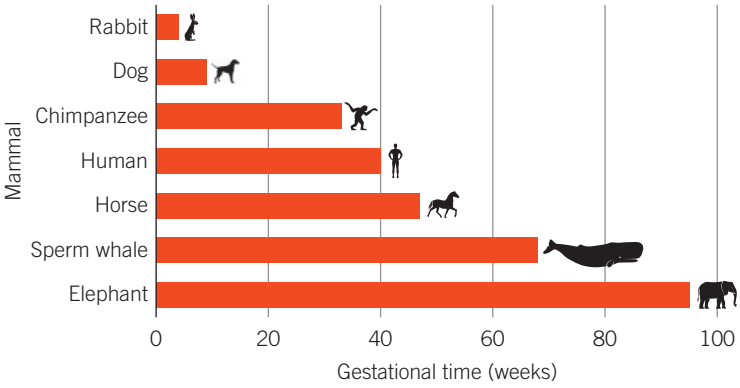



**Figure 3A–2** Gestational time for various mammals

**Embryo**
an early stage of development from weeks 2 to 8 of pregnancy

**Foetus**
the unborn offspring of a mammal more than 8 weeks after conception

**Gestation period**
the time during which a foetus develops inside the mother's body, beginning at fertilisation and ending at birth

**Zygote**
a diploid cell formed when the nuclei of an ovum and a sperm fuse during fertilisation

## Development of an embryo

All human life begins at the point of conception. Conception occurs in the fallopian tubes of a female when the sperm from a male fertilises an ovum (egg), producing a complete single cell. This single cell is known as a **zygote**.

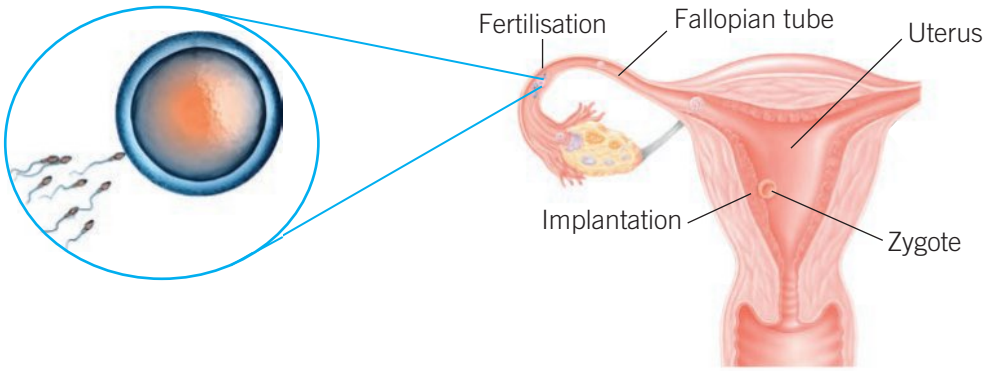



**Figure 3A–3** Left: Sperm approaches an ovum. Only one sperm will fertilise the ovum, forming a zygote. Right: Fertilisation occurs in the fallopian tube of a female and produces a single cell known as a zygote. Over the next few days, the zygote migrates to the uterus, where it implants into the uterine lining.

ISBN 978-1-108-88711-3

3B THE CELL CYCLE LINK

In a matter of hours the zygote undergoes mitosis and cleaves (divides) into two cells. Once this has occurred, it is no longer referred to as a zygote. Cleavage through mitosis continues and by day 3, there are 16 cells. This group of cells, called a **morula**, moves from the fallopian tube into the **uterus**.

**Morula**
a ball of 16 (to 32) cells that results from the cleavage of a fertilised ovum

**Uterus**
an organ in females, where offspring gestate before birth

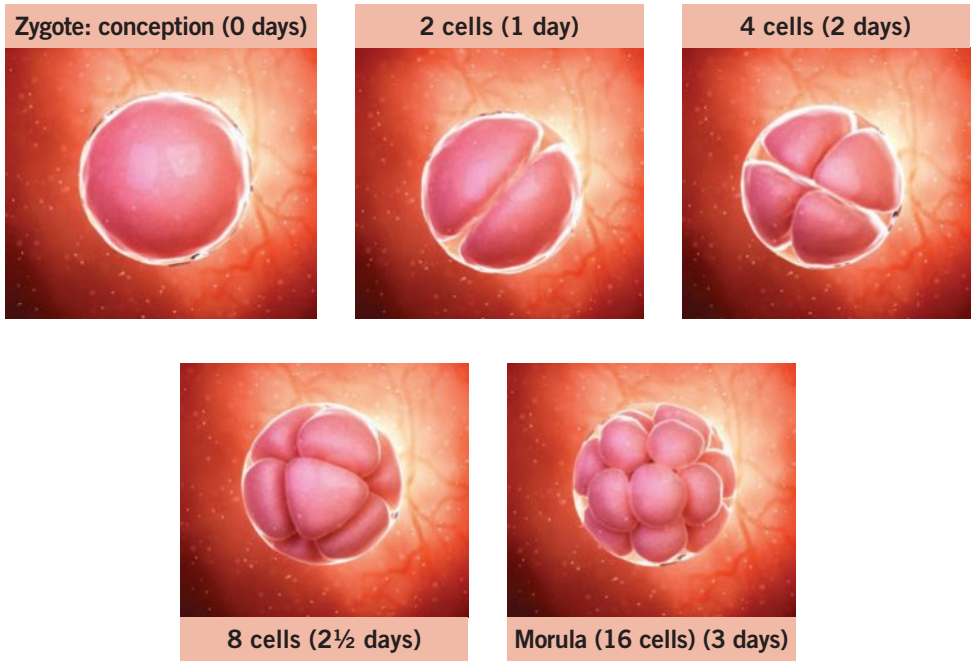



**Figure 3A–4** Illustrations of the early embryonic cleavage that produces a 16-cell morula from a single cell (zygote)

**Blastocyst**
a stage of embryonic development, in which some differentiation of cells has occurred

**Trophoblast**
the outer layer of cells in a blastocyst

**Inner cell mass**
the inner cluster of cells in a blastocyst

In the uterus, cleavage of cells of the morula continues. By day 4 there are 58 cells and the cell mass is now a **blastocyst**. By day 5 the blastocyst contains about 100 or more cells, consisting of two different types:

- an outer cell layer known as a **trophoblast**
- an inner group of cells known as the **inner cell mass**.

The development of cells into two types marks a major organisational change in embryological development. There is also a clear arrangement of cells into the two layers rather than the mass of cells characteristic of the previous stages. Cells of the inner cell mass will go on to form the body of the embryo, while cells of the trophoblast will give rise to the placenta and supportive membranes.

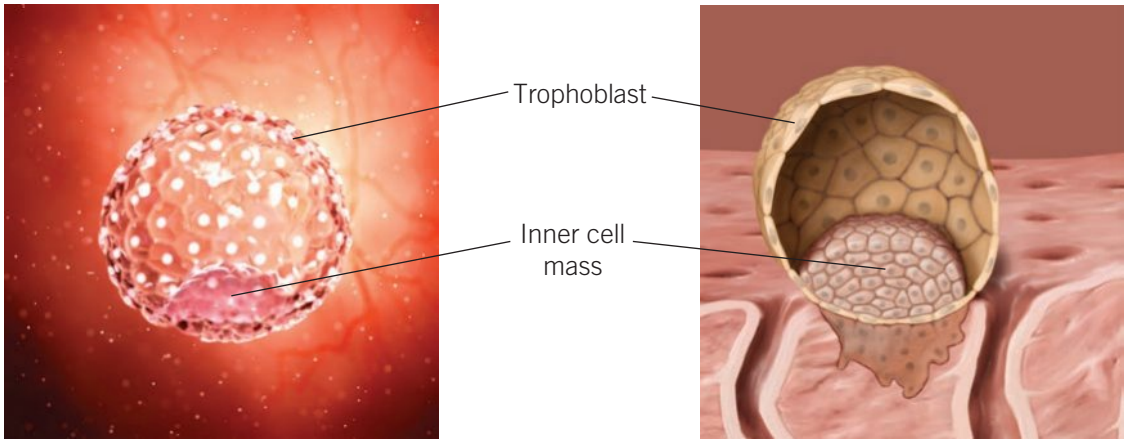



**Figure 3A–5** Cells of the morula continue to cleave, giving rise to a blastocyst. The blastocyst must implant into the uterine wall for development to continue.

ISBN 978-1-108-88711-3

Approximately 6–7 days after fertilisation, the blastocyst implants into the uterine wall. After implantation, a process called **gastrulation** occurs, in which three layers of tissue are formed. Gastrulation lasts for approximately 5 days and the end result is a **gastrula**. By the beginning of week 3, the gastrula becomes an embryo, marked by the formation of critical organs and body structures. By the start of week 9, the embryo resembles a human and is called a foetus. The foetal stage continues until birth (approximately 30 weeks) and in this period the critical structures already formed continue to grow and develop before becoming fully functional.

**Gastrulation** the process that results in the formation of the three primary embryonic germ layers

**Gastrula** an embryo at the stage following the blastocyst, when it has differentiated into three layers of cells

**Table 3A–1** A summary of early embryological development

| Age | Name | Key characteristic(s) | |
|---|---|---|---|
| 0 (conception) | Zygote | 1 cell | |
| 3 days | Morula | 16 cells | |
| 4 days | Early blastocyst | 58 cells | |
| 5 days | Late blastocyst | 107 cells<br>(Implants into uterine wall) | |
| 5+ days | Gastrula | Formation of the three primary germ layers | |
| Beginning of week 3 | Embryo | Formation of critical structures | |
| Beginning of week 9 (until week 38) | Foetus | Growth and development of critical structures | |

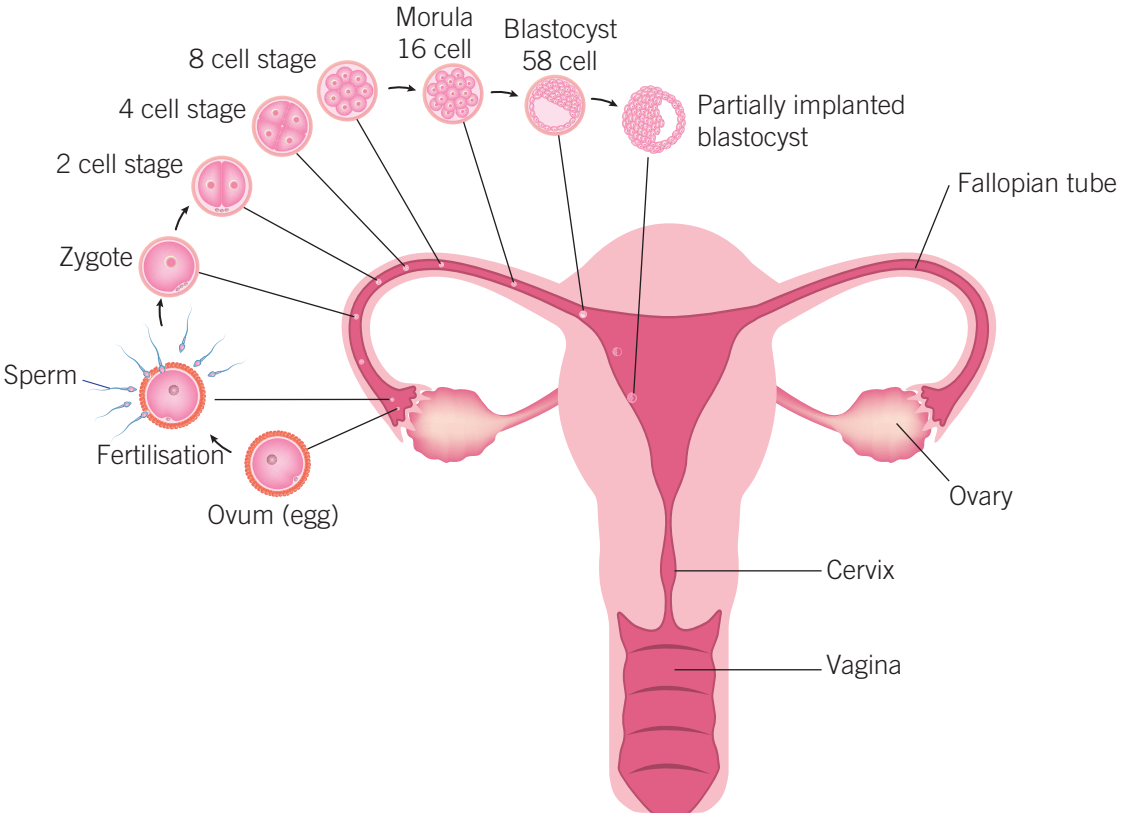



**Figure 3A–6** A diagrammatic summary of embryological development up to the late blastocyst stage

ISBN 978-1-108-88711-3

## Check-in questions – Set 1

1 What is the difference between a zygote and a morula?
2 Distinguish between a morula and a blastocyst.
3 At what point does the blastocyst implant into the uterine wall? What process commences after implantation?

**Embryonic germ layers** the three layers of differentiated cells that the inner cell mass of the blastocyst gives rise to

**Ectoderm** the outer primary embryonic germ layer

**Mesoderm** the middle primary embryonic germ layer

**Endoderm** the inner primary embryonic germ layer

## Gastrulation: germ layer development

Gastrulation occurs shortly after the implantation of the blastocyst into the uterine wall. It results in the single-layered blastocyst developing into a three-layered gastrula. To do this, the inner cell mass of the blastocyst subdivides by folding in upon itself. This gives rise to three primary **embryonic germ layers**:

- **ectoderm** (outer layer)
- **mesoderm** (middle layer)
- **endoderm** (inner layer).

As you can see in Figure 3A–7, the three primary germ layers are supported by two membranes:

- the *amnion* – gives rise to the amniotic sac, which is full of fluid. It surrounds the baby, acting as a shock absorber against potentially damaging impacts
- the *yolk sac* – surrounds the yolk, which is full of nutrients that are used by the developing baby.

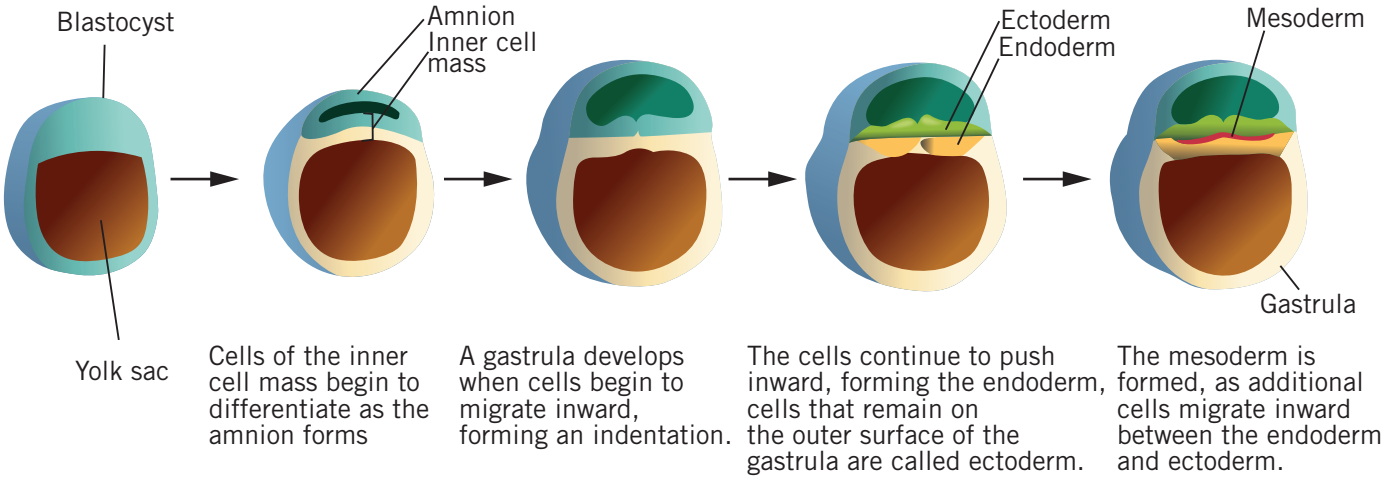



**Figure 3A–7** In gastrulation, cells of the blastocyst fold inwards, forming three embryonic germ layers.

Each of the three primary germ layers gives rise to its own unique specialised cells that will form the tissue and organ systems of the baby. The formation of these critical structures is the developmental milestone that results in the gastrula becoming an embryo.

### Cell specialisation

The inner cell mass of the blastocyst contains true embryonic stem cells. Embryonic stem cells are capable of forming all the different types of specialised cells needed for a fully functional foetus at birth. Given that the primary germ layers arise from the inner cell mass

ISBN 978-1-108-88711-3

of the blastocyst, it makes sense that these germ layers produce the variety of specialised cells needed to create the complex tissue and organ systems of a human. Each primary embryonic germ layer will give rise to very specific types of specialised cells, as indicated in Figure 3A–8.

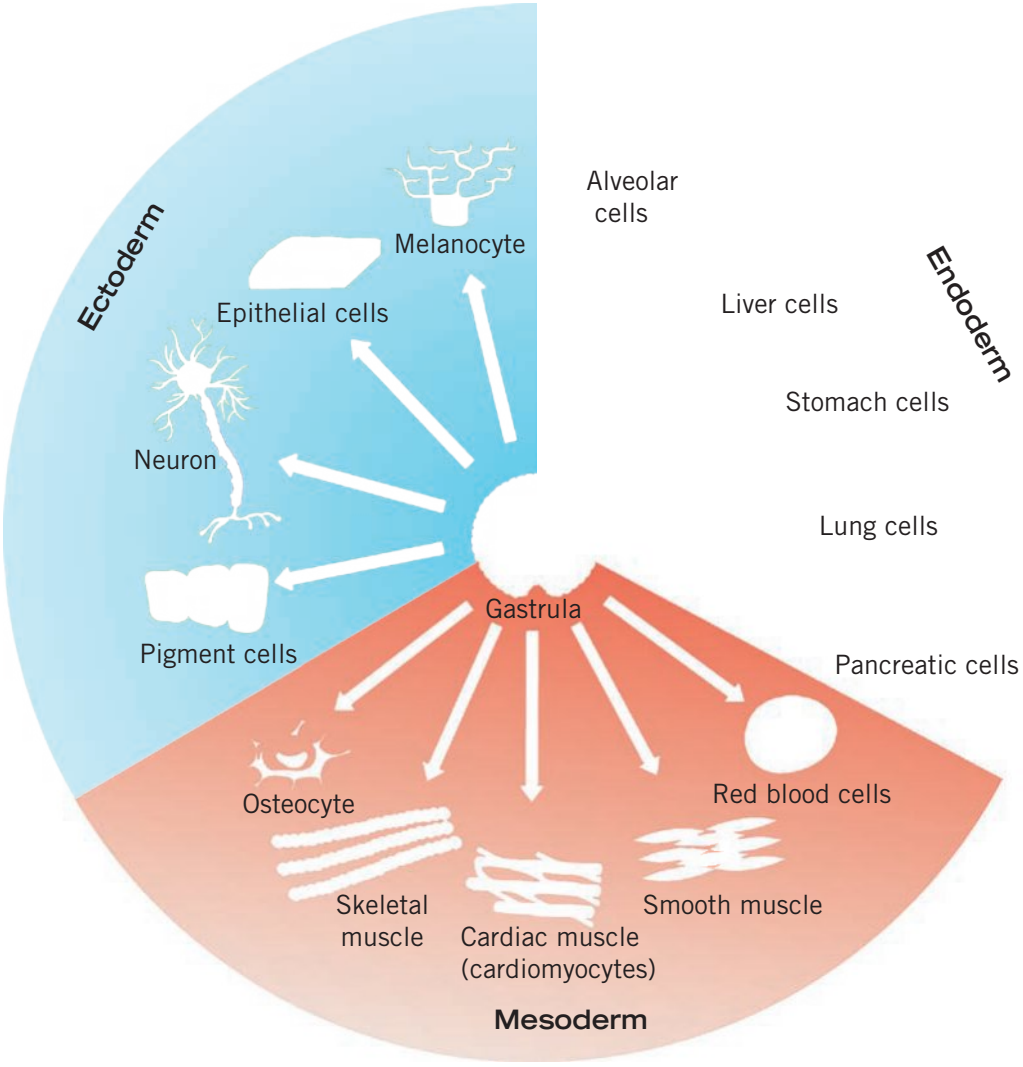



**Figure 3A–8** Cell specialisation: mammalian cell types derived from primary embryonic germ layers

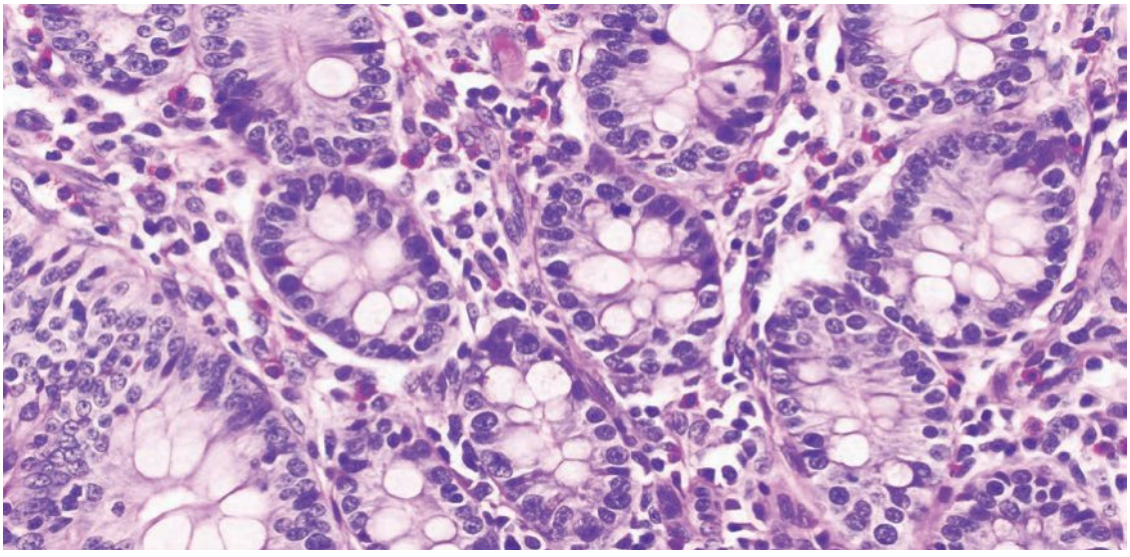


**Figure 3A–9** Microcope image of pancreatic cells, which come from the endoderm embryonic germ layer

ISBN 978-1-108-88711-3

## Critical periods of development

The 40-week gestation period in a human can be categorised into three stages:

1 The *germinal stage* begins at fertilisation and lasts until the blastocyst implants into the uterine wall about two weeks later.

WORKSHEET 3A–1 EARLY EMBRYOLOGICAL DEVELOPMENT

2 The *embryonic stage* begins at the end of the germinal stage and lasts until about 2 months after fertilisation. In this period, all major organs form and the cell mass is considered an embryo.

3 The *foetal stage* is the last stage. It begins 2 months after fertilisation and concludes at birth. The foundations laid in the earlier stages develop further and begin to function. The embryo has progressed to be classified as a foetus.

**Critical periods** periods of time during an organism's development when it is more susceptible to developmental abnormalities

Along the way, there are **critical periods** of development. The embryonic stage is particularly fragile, as this is when all the major organ systems form. Any exposure to chemicals, drugs, alcohol, smoking or viruses (to name just a few) at this point can result in serious birth abnormalities or death. The longer the system's period of development, the more susceptible it is to abnormalities. Figure 3A–10 shows the most critical periods of a baby's development.

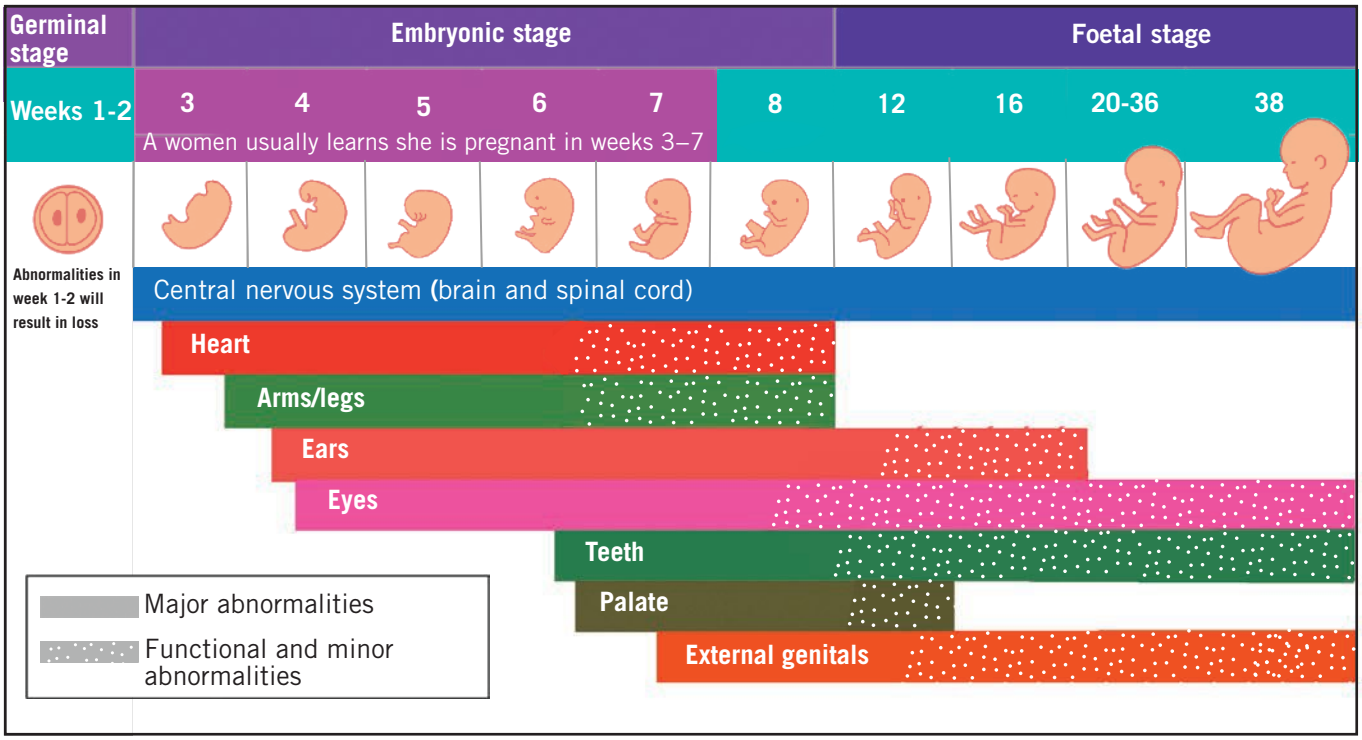



**Figure 3A–10** Critical periods of a baby's development

## Check-in questions – Set 2

1 Name the three germ layers (from outer to inner) that are produced as result of gastrulation.
2 Which of the three gestation stages is the most critical in terms of healthy development? Justify your response.
3 Which system takes the longest to develop and therefore has the longest critical period?

ISBN 978-1-108-88711-3

## Stem cells

A **stem cell** is a type of cell that is capable of giving rise to any type of specialised cell in the body of a multicellular organism. It does not yet have a specific role within the organism, instead differentiating into almost any type of cell when the body needs it (Figure 3A–11). Stem cells are also capable of **self-renewal**, which means they can replicate themselves, giving rise to more of the same type of stem cell.

**Stem cell**
a type of cell that is capable of differentiating into a range of specialised cells within an organism

Embryonic stem cells are usually sourced from extra embryos around 3–5 days old that arise from IVF (in-vitro fertilisation) programs.

LINK 9A GENETIC AND REPRODUCTIVE TECHNOLOGIES

**Self-renewal**
the ability of stem cells to regenerate by giving rise to exact copies of themselves

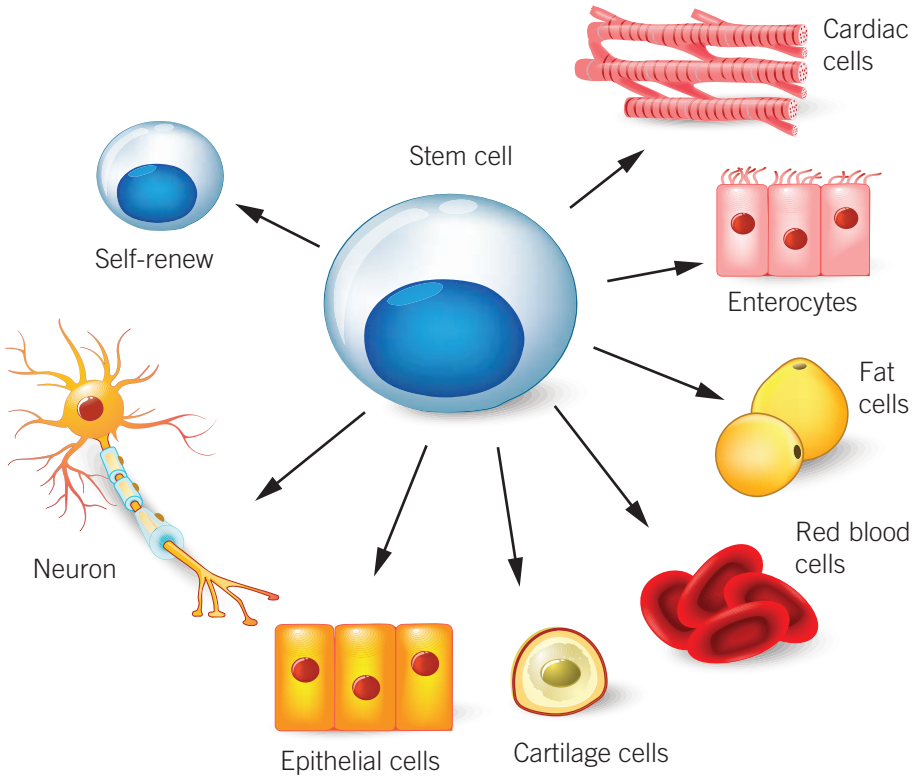



**Figure 3A–11** Stem cells are capable of dividing into a wide variety of specialised cells as they are needed, including more stem cells (self-renewal).

## Sources of stem cells

Stem cells can be classified into two types according to where they can be sourced from. The origin of each type of stem cell determines its properties.

### Embryonic stem cells

**Embryonic stem cells** are found in an embryo prior to implantation in the uterus – that is, from the zygote to blastocyst stage. Before the formation of the inner cell mass at the blastocyst stage, stem cells are capable of differentiating into all types of cells. By day 5, the cells have arranged themselves into a blastocyst, with embryonic stem cells forming the inner cell mass. Prior to implantation, stem cells of the inner cell mass are capable of developing into almost any type of cell, but once implantation occurs and these cells differentiate into the three primary germ layers and form a gastrula, the cells become more specialised and do not give rise to such a wide variety of cells.

**Embryonic stem cell**
a type of stem cell that is found in an embryo, in the developmental stage prior to uterine implantation

ISBN 978-1-108-88711-3

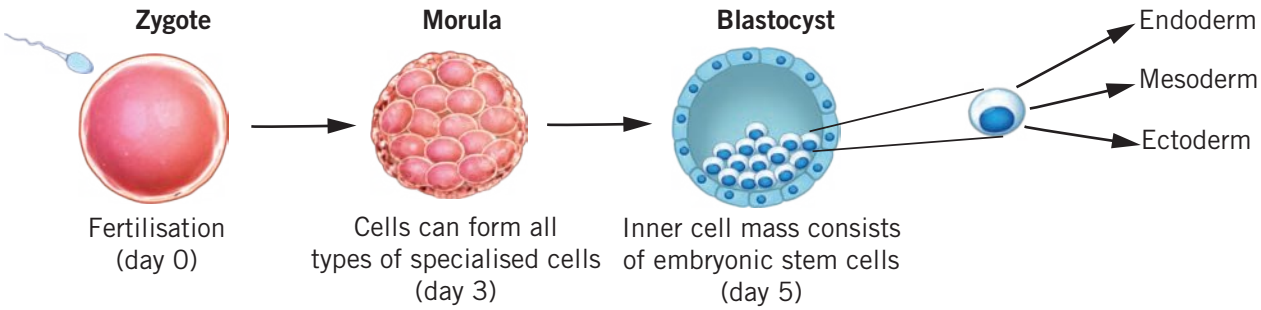



**Figure 3A–12** Embryonic stem cells can be sourced during the period from the formation of the zygote to the formation of the blastocyst prior to implantation in the uterine wall.

## Adult stem cells

**Adult stem cells** undifferentiated cells that are found in certain tissue throughout the life of an individual

**Haematopoietic stem cell** a type of multipotent stem cell found in bone marrow that can differentiate into any type of blood cell

**Adult stem cells** (or somatic stem cells) are undifferentiated cells that are found in certain tissues throughout the life of an individual. Scientists have recently discovered evidence of adult stem cells in more locations than was previously thought. These locations include (but are not limited to):

- the brain
- bone marrow
- skin
- liver
- blood vessels
- spinal cord
- heart
- hair follicles.

The primary purpose of adult stem cells is the repair and maintenance of damaged or old body tissue (e.g. repairing a graze on the skin). While adult stem cells are still considered to be non-specific, they are more specialised than embryonic stem cells as they give rise to a more limited variety of cells. For example, Figure 3A–13 shows how **haematopoietic stem cells** found in bone marrow can only give rise to the different types of blood cells.

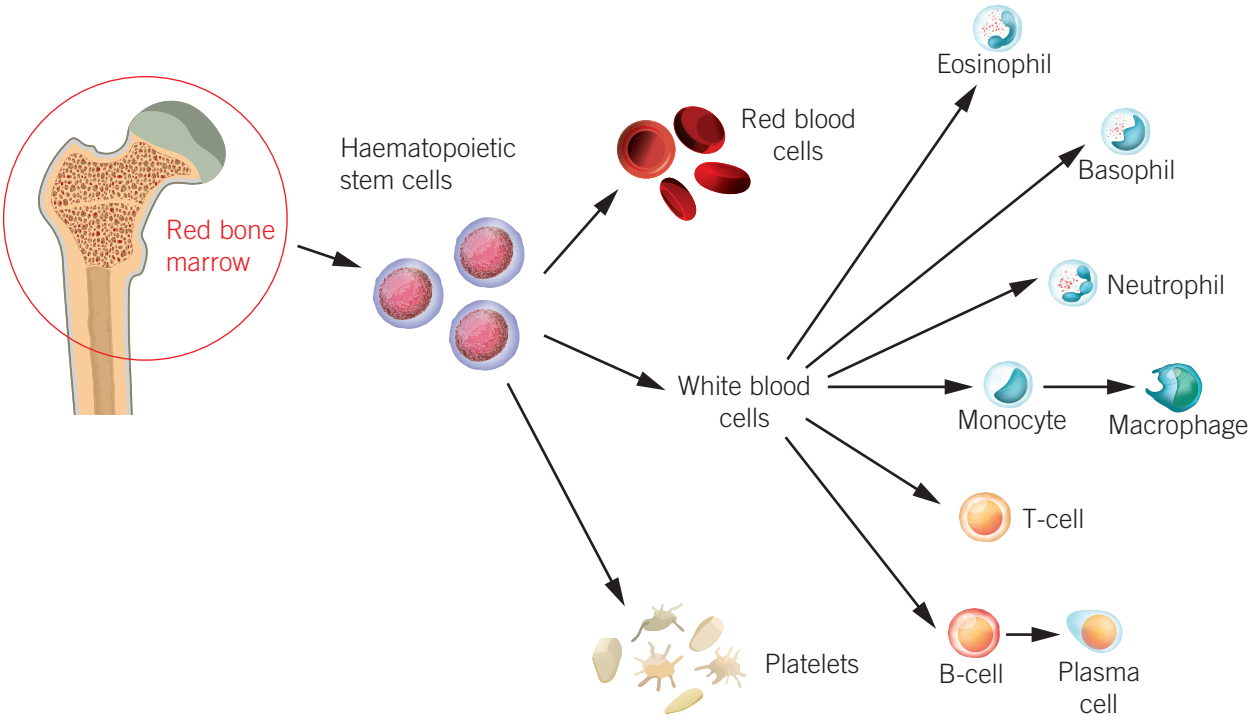



**Figure 3A–13** Haematopoietic stem cells found in bone marrow can only give rise to different types of blood cells.

ISBN 978-1-108-88711-3

## Types of stem cells

Scientists also classify stem cells according to their *potency* – that is, their ability to differentiate into other types of cells. The higher the potency of a stem cell, the greater its potential to form a variety of cell types. Stem cell potencies are explained in Table 3A–2.

**Table 3A–2** Summary of stem cell potency

| Potency | Definition | Key information |
|---|---|---|
| **Totipotent** | Can differentiate into *all* possible cell types | Embryonic stem cells that form the zygote through to the morula are the only cells that are considered totipotent. These cells can even produce another embryo. |
| **Pluripotent** | Can differentiate into almost any type of cell | The embryonic stem cells that form the inner cell mass of the blastocyst are pluripotent, as they go on to form the three primary germ layers of the foetus.<br>They are *not* considered totipotent as they cannot form the embryonic membrane layers or cells of the placenta. These are formed by the trophoblast (outer cell layer) of the blastocyst. |
| **Multipotent** | Can differentiate into a variety of closely related types of cells | Haematopoietic stem cells found in bone marrow are classed as multipotent. While they produce a range of different cells, all these cells are varieties of blood cells.<br>The stem cells of the differentiated germ layers also fit this category of potency. |
| **Unipotent** | Can only produce one type of cell, their own | These cells are still considered stem cells as they are capable of self-renewal. All somatic cells are unipotent; for example, skin or muscle stem cells are able to self-renew, which allows them to repair tissue. |

Decreasing potency

**Totipotent**
able to differentiate into any type of cell

**Pluripotent**
able to differentiate into almost any type of cell

**Multipotent**
able to differentiate into a variety of closely related types of cells

**Unipotent**
able to produce only one type of cell, its own

ISBN 978-1-108-88711-3

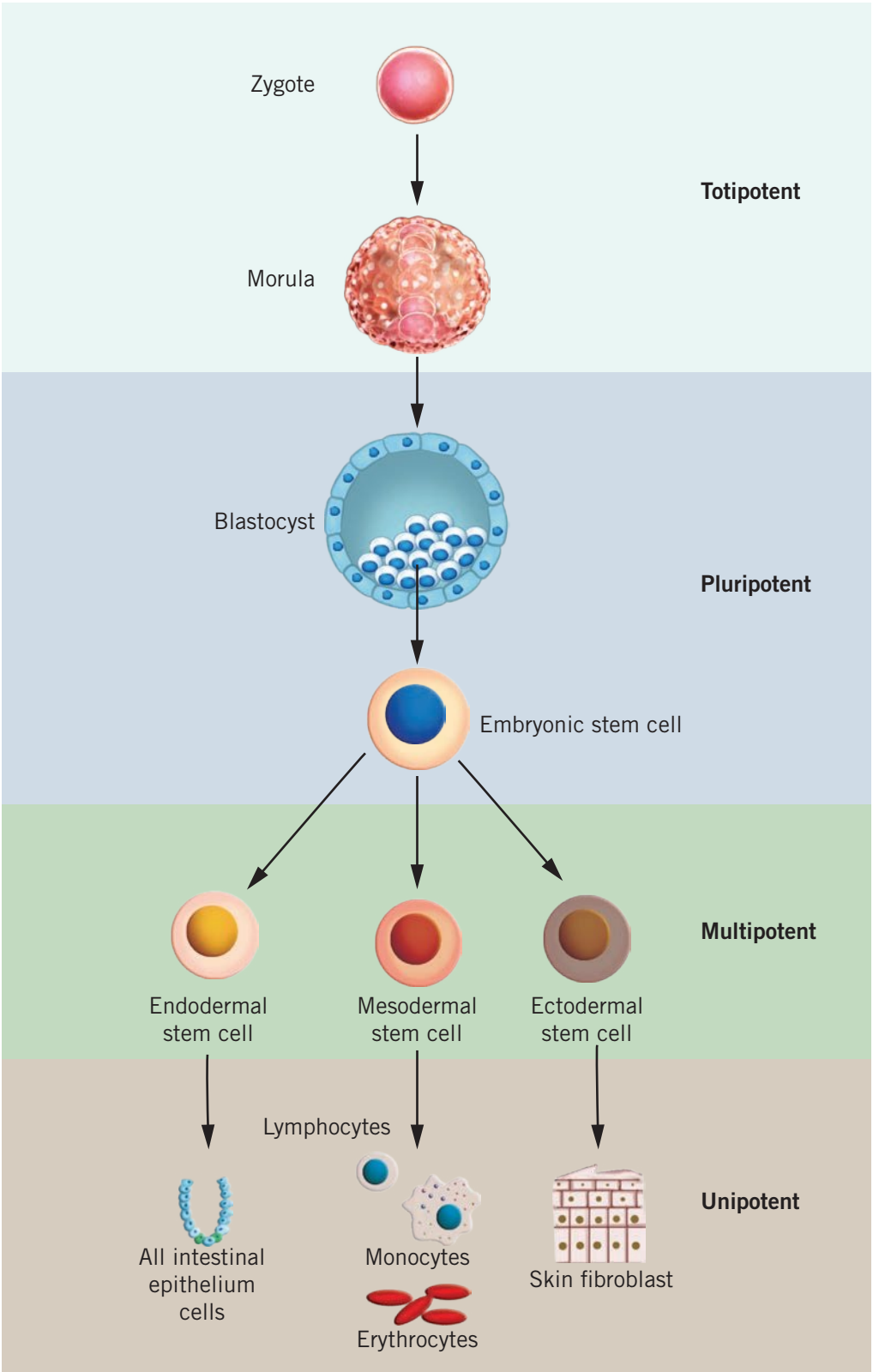



**Figure 3A–14** Stem cells take on different levels of potency through the developmental process.

ISBN 978-1-108-88711-3

**Table 3A–3** Comparison of embryonic and adult stem cells

| Embryonic stem cells | Adult stem cells |
|---|---|
| Totipotent or pluripotent | Multipotent or unipotent |
| Found in early embryological development (zygote to blastocyst) | Found in differentiated tissue but are not differentiated themselves |
| Large numbers can be harvested from embryos | More limited in numbers, so harder to isolate |
| Role is to differentiate into all specialised cell types to create a functional organism | Primary role is to repair and maintain old or damaged tissue |
| Easily grown in laboratory conditions | Very difficult to grow in laboratory conditions |

## Check-in questions – Set 3

1 State the different areas or stages that embryonic and adult stem cells can be sourced from.
2 List the stem cell potency terms in order from least potent to most potent.
3 Why are the embryonic stem cells that form the inner cell mass considered to be pluripotent rather than totipotent?

## Stem cell therapy

Researchers are trying to understand how stem cells work. It is hoped that, if scientists can harness and manipulate the capacity of stem cells to differentiate into different types of cells, this will lead to revolutionary breakthroughs in the treatment and prevention of a range of conditions and diseases. This area of medical science is known as **stem cell therapy**.

**Stem cell therapy** the treatment and prevention of disease through the use of stem cells

**VIDEO 3A–1** STEM CELL THERAPIES

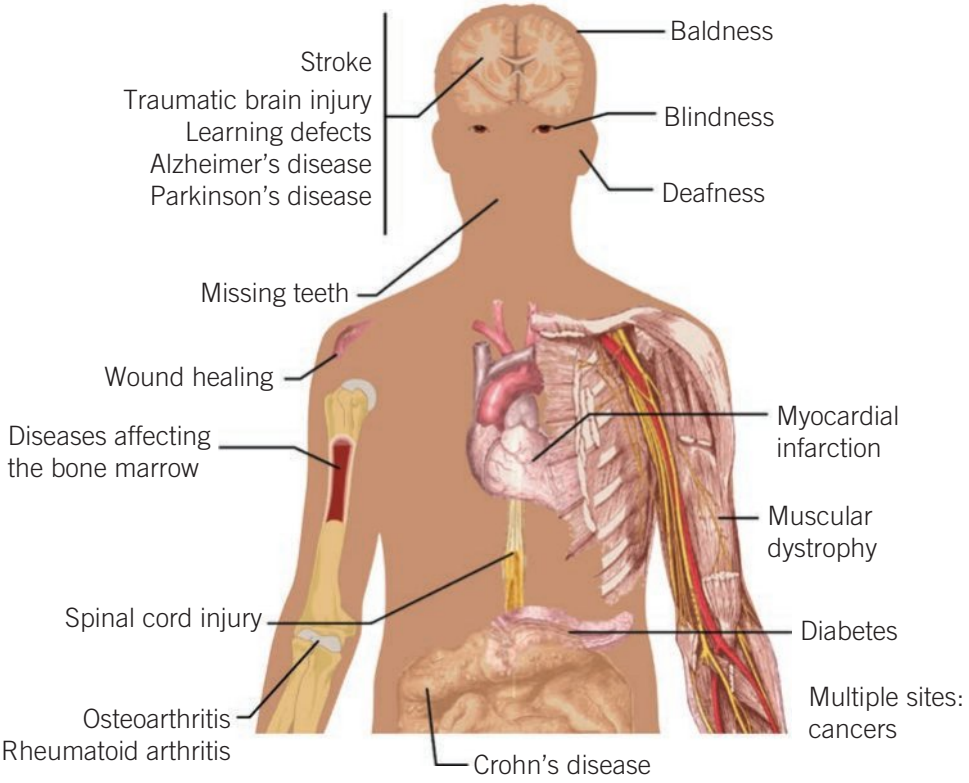



**Figure 3A–15** Some of the diseases and conditions that stem cell therapy could treat and possibly cure

ISBN 978-1-108-88711-3

## Sourcing stem cells

Stem cell therapy requires access to an infinite supply of stem cells, both embryonic and adult. So where do scientists access these cells?

### Embryonic stem cells

As you read earlier in this chapter, embryonic stem cells are present in the developing embryo up to 5 days after fertilisation. The only way to source these types of cells is to harvest them from early embryos that have been donated for research purposes with the informed consent of their owners. In a laboratory, embryonic stem cells are transferred from the early embryo into a culture dish that contains a nutrient-rich medium (Figure 3A–16). If these stem cells are grown in favourable conditions, they will remain undifferentiated indefinitely. When scientists want to generate specific types of cells (such as heart, liver or muscle), they manipulate the growing conditions of the cells to get the desired outcome. They do this in the following ways:

- changing the chemical composition of the medium that the cells are grown in
- altering the nutrients provided to the cell
- directly modifying the stem cells by inserting genes.

Being able to reliably dictate the specialisation pathway of embryonic stem cells would significantly affect the treatment of many diseases.

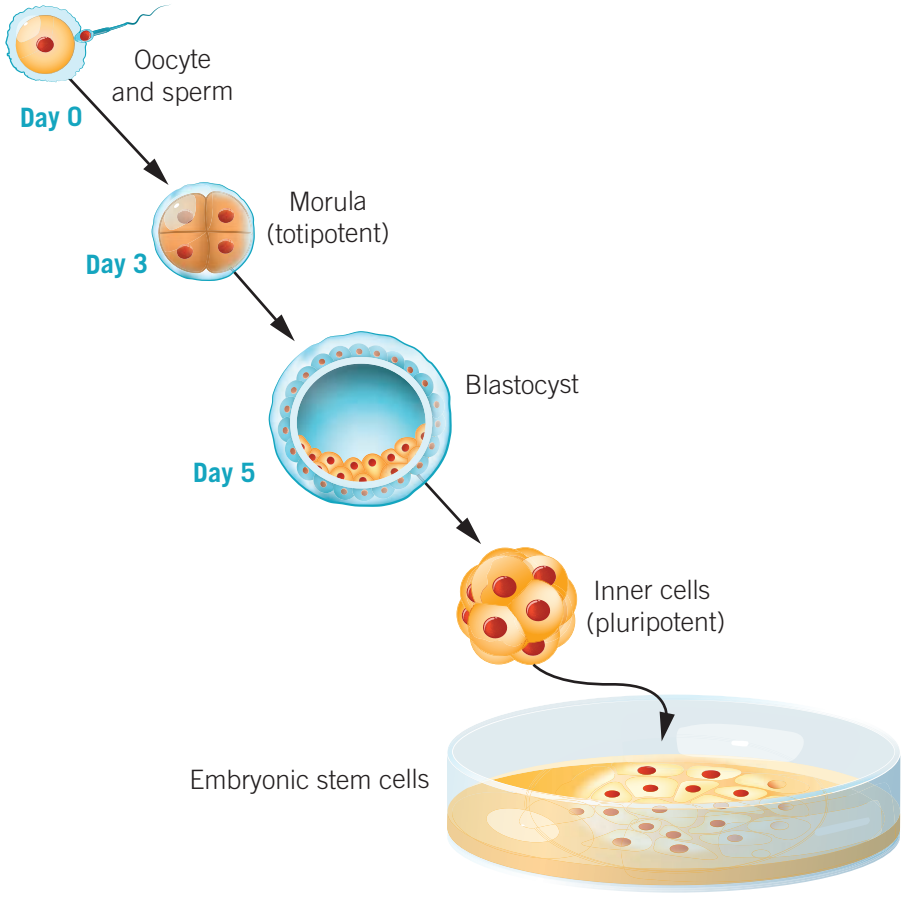



**Figure 3A–16** The transfer of embryonic stem cells from an early embryo to a laboratory culture dish, where cells can be manipulated to form specific types of specialised cells

ISBN 978-1-108-88711-3

## Adult stem cells

Adult stem cells can be more readily sourced than embryonic stem cells. The procedures involved in accessing adult stem cells are outlined below.

### Bone marrow

Haematopoietic stem cells are most commonly obtained from donor bone marrow. These cells will form all types of blood cells, including those that support our immune system. In this procedure the donor is placed under general anaesthetic and the doctor inserts a hollow needle into the hip or the pelvic bone to access the bone marrow.

LINK UNIT 4

Another option is for the donor to receive several small injections that cause the bone marrow to release stem cells into the blood. The blood is then passed through a machine that separates out the stem cells before the blood is returned to the body.

### Umbilical cord blood

The collection of blood from the umbilical cord and placenta of newborn babies has become more common in recent years. This 'cord' blood contains the same type of haematopoietic stem cells as those isolated from bone marrow. Cord blood is easy to collect, with no harm to the mother or baby. It has been used for more than 20 years to successfully treat a range of blood disorders. Perhaps the greatest advantage is that, if an individual has had their cord blood stored and requires a transplant at any time in their life, their own stem cells can be used, and these stem cells are considerably less likely to be rejected than those from a donor.

LINK UNIT 4

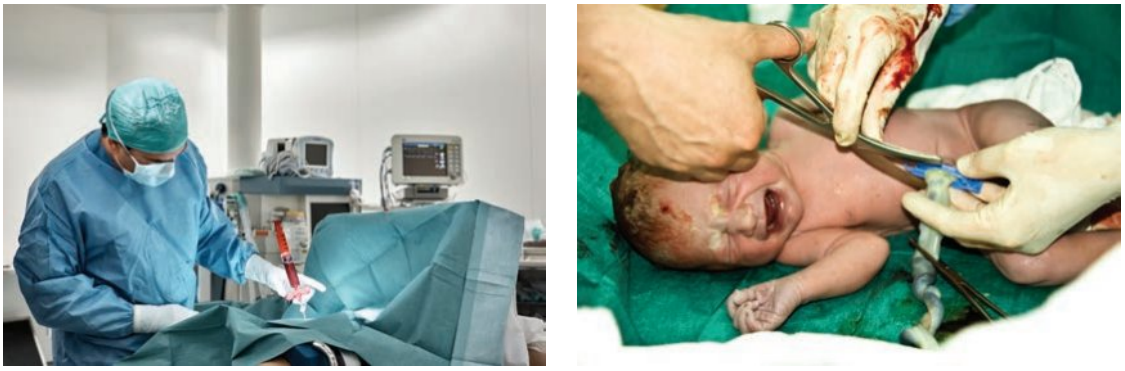


**Figure 3A–17** Two sources of haematopoietic stem cells. Left: A surgeon monitors the extraction of bone marrow from a patient. Right: The umbilical cord of a newborn baby is being cut.

### Induced pluripotent stem cells

In 2007, scientists first reported the use of a new type of human stem cell, known as **induced pluripotent stem cells** or **iPSCs**. An iPSC is a type of adult cell that is capable of being genetically programmed to revert back to an embryonic stem cell state. By turning on specific genes, scientists are able to 'trick' the cell into expressing the pluripotent characteristics of embryonic stem cells instead of the multi- or uni-potent features of adult stem cells.

LINK UNIT 3

The discovery of iPSCs has been hailed as the 'holy grail' for cell biologists. Not only do iPSCs help to overcome the ethical issues associated with the use of true embryonic stem cells, but preliminary testing suggests that they will revolutionise the field of regenerative medicine.

**Induced pluripotent stem cells (iPSCs)** typical adult cells that have been genetically reprogrammed to revert to an embryonic stem cell state

ISBN 978-1-108-88711-3

## Applications of stem cell therapy

**Regenerative medicine** a new field of medicine that replaces, regenerates or engineers human cells, tissues or organs to restore normal function

The ability of stem cells to differentiate into many cell types makes them a vital asset in the treatment of a wide range of disorders. As technology develops, and our understanding of the way in which stem cells operate improves, the medical possibilities seem almost endless.

Perhaps the area of medicine that will benefit most from our developing stem cell knowledge is **regenerative medicine**. This is a relatively new field involving the replacement, regeneration or engineering of human cells, tissues or organs to restore or establish normal function.

Below are some examples of the many ways in which stem cells are being used to help restore function.

**Figure 3A–18** A doctor prepares a skin graft grown from human stem cells for transfer to a patient.

### Tissue regeneration

Tissue regeneration is used primarily for the regeneration of skin in burns victims. The skin is able to repair itself after damage by using its own epithelial stem cells. In burns victims, the patient's own epithelial stem cells are harvested and grown in a laboratory. Once new layers of skin have formed, these are grafted directly onto the patient in areas where the skin has been lost.

In 2013, a team of researchers reported that they had successfully used human stem cells to create blood vessels in mice. While this procedure is yet to be trialled in humans, doctors are optimistic that in the near future the technique will be used to replace damaged blood vessels in humans and treat a range of cardiovascular disorders.

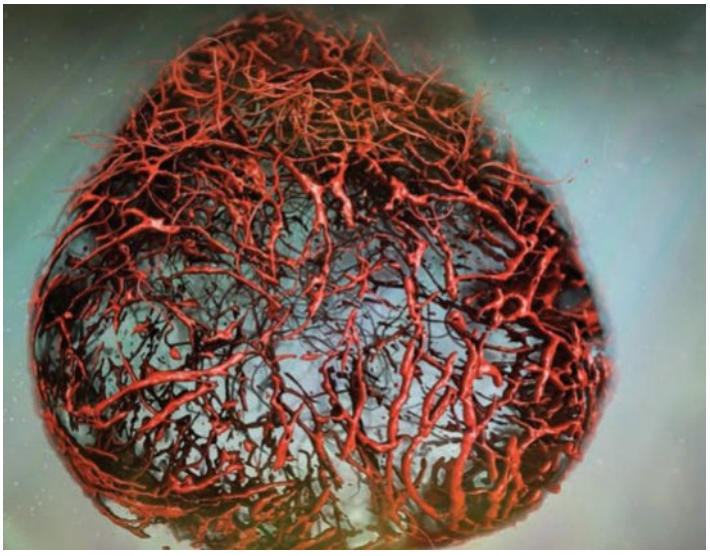


**Figure 3A–19** Laboratory-grown human blood vessels

### Cell deficiency treatment

Many disorders are the result of a deficiency in a particular type of cell within an organ. Examples are type 1 diabetes, which results when specialised pancreatic cells fail to produce insulin, and Alzheimer's, which is caused by the death of a specific type of cell within the brain. Scientists are hopeful that, by developing stem cells into specific types, they will be able to introduce these new healthy cells into the problematic organs and repair the damaged tissue, restoring normal function. For example, macular degeneration, a disorder that causes 50% of all blindness in Australia, is caused by the death of a specific type of retinal cell. If scientists can grow these retinal cells from stem cells in a laboratory and then introduce them into the retina, the new cells should be able to repopulate the damaged area and restore the person's sight.

ISBN 978-1-108-88711-3

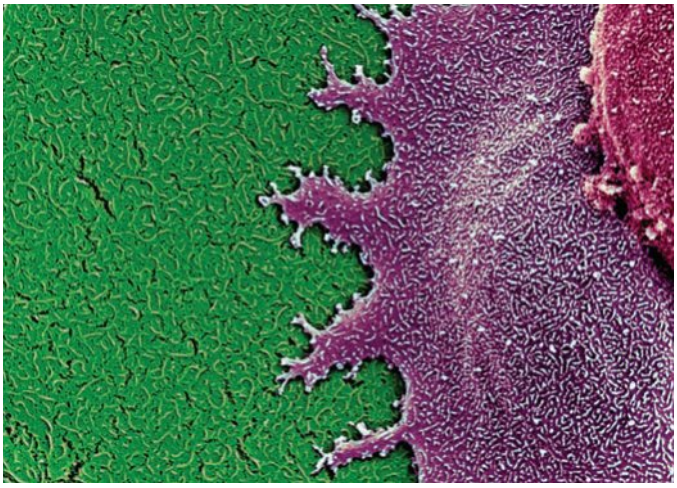


**Figure 3A–20** A scanning electron microscope image of retinal stem cells (pink and purple) growing on feeder cells (green). Retinal stem cells have the potential to restore damaged retinal tissue and restore sight in many disorders.

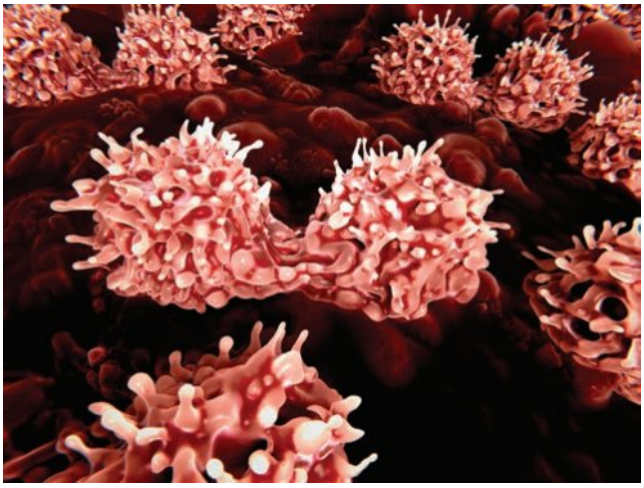


**Figure 3A–21** Dividing haematopoietic stem cells in bone marrow. These cells are currently used to treat a wide range of blood disorders.

Haematopoietic stem cells harvested from bone marrow (or cord blood) are used routinely by doctors to treat a wide range of blood disorders caused by cell deficiencies. In the case of leukaemia (cancer of the blood) treatment, doctors use chemotherapy to destroy the patient's existing bone marrow. They then introduce donor haematopoietic stem cells into the patient's bone marrow, restoring the person's ability to produce healthy blood cells. Haematopoietic stem cells are also used in the treatment of many types of anaemia, as well as a range of cancers that involve the use of chemotherapy or radiation treatment.

## Organ transplants

Around 1400 Australians are currently on a waiting list for an organ transplant. The waiting time for transplants ranges from 6 months to 4 years, but in some situations the recipient must wait even longer. Stem cell technology offers hope for these patients. Scientists are hopeful that they will one day be able to use stem cells, not only to grow tissue, but to replicate the organ itself. Using stem cells in this way has the added benefit of reducing the risk of transplant rejection, as doctors will be able to use the patient's own stem cells to grow the organ.

In 2015, American scientists used induced pluripotent stem cells to grow the first miniature beating heart. While hearts developed in this way are still a long way from replicating the exact structure of the human heart, this was an important breakthrough and has the medical community excited about the potential use of stem cells in organ donation.

## Research

LINK UNIT 4

Stem cell therapy is not the only way in which stem cells are used. They also offer a wide range of research possibilities. Current areas of interest in stem cell research include:

- manipulation of stem cell genes to determine how signals cause differentiation
- how abnormal differentiation produces cancer cells
- development of new drugs – testing side effects on human tissue generated by stem cells instead of human test subjects
- use of stem cells to combat the biological causes of mental health problems (such as depression or anxiety)
- anti-ageing treatments.

ISBN 978-1-108-88711-3

9B ETHICAL, SOCIAL, LEGAL AND ECONOMIC CONSIDERATIONS LINK

## Ethics and stem cell therapy

The main ethical concern about stem cells relates to the use of embryonic stem cells. Some people believe that life begins at conception and that harvesting embryonic stem cells from a blastocyst is the equivalent of destroying the life of a potential human being. Harvesting techniques have come a long way, and now scientists are able to isolate one embryonic stem cell from the blastocyst, leaving the rest intact. The use of induced pluripotent stem cells also helps to overcome the ethical issues associated with early embryonic harvesting, as adult cells are manipulated to mimic the properties of embryonic stem cells.

There are also concerns about the use of animals in stem cell research. Often, human stem cells are inserted into other animals, most commonly mice. This raises ethical questions about the possible creation of an organism that is part human and part other species.

The use of adult stem cells does not cause the same objections as that of embryonic stem cells. Adult stem cells are harvested from donors who are able to give their full informed consent, and so there is no objection regarding where the cells have been sourced from.

Table 3A–4 summarises the advantages and disadvantages of using different types of stem cells.

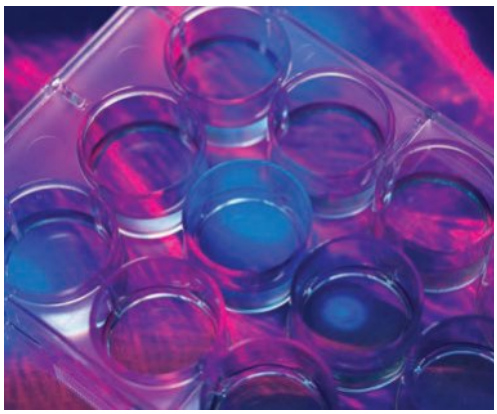


**Figure 3A–22** Stem cells developing in culture

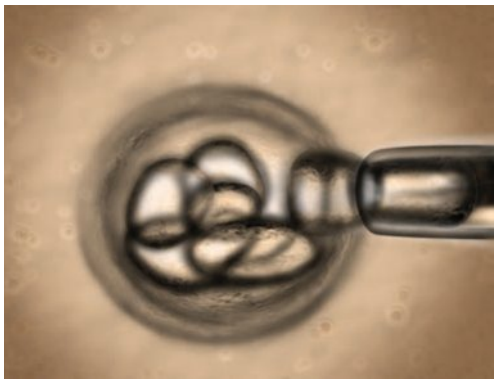


**Figure 3A–23** Embryonic stem cell being drawn from an eight-cell embryo under a microscope

**Table 3A–4** Advantages and disadvantages of stem cell use

| Type of stem cell | Advantages | Disadvantages |
|---|---|---|
| Embryonic | Can differentiate into all types of specialised cells<br>Easy to source (donated from IVF)<br>Can divide indefinitely, leading to large growth in culture | Can be seen to involve the destruction of life<br>Pure embryonic stem cell cultures are difficult to develop and maintain<br>Can be unstable and mutate readily in culture, leading to tumour growth |
| Adult | Does not involve the destruction of 'life'<br>Research is more advanced, as it began before other stem cell studies | Difficult to obtain from tissue<br>Slower growing in lab culture<br>Stem cells for all cell types are yet to be isolated, so differentiation potential is limited<br>Present in very small quantities in adults and numbers decline further with age<br>Cells have limited ability to divide |
| Induced pluripotent | Fewer ethical concerns<br>*In theory*, can differentiate into all cell types<br>Easy to obtain as they are derived from normal adult somatic cells<br>More compatible with recipient as the patient's own cells can be reprogrammed<br>Less chance of rejection | Expensive to develop as it takes more time and technology<br>Risk of activating the gene that causes cancer<br>Greater risk of mutations<br>Still a work in progress and research is at an early stage |

ISBN 978-1-108-88711-3

## Check-in questions – Set 4

1 Using an example, explain what stem cell therapy is.
2 How do induced pluripotent stem cells (iPSCs) differ from traditional embryonic and adult stem cells?
3 What is the major ethical concern associated with the use of embryonic stem cells?

## 3A SKILLS

VIDEO 3A–2 SKILLS: DIFFERENTIATION OF GERM LAYERS

**Differentiation of germ layers**

A common area of assessment in this topic is likely to focus on your understanding of the differentiation of the three primary germ layers in gastrulation.

Recall from earlier in this chapter that after implantation of the blastocyst into the uterine wall, a process known as gastrulation occurs. As the third week of pregnancy commences, the inner cell mass of the blastocyst begins to differentiate, giving rise to the three different layers of cells.

Note that, prior to gastrulation, cells that make up the inner mass of the blastocyst are pluripotent. Once gastrulation commences and germ layers begin to form, the stem cells begin to lose their 'specialisation power' and become multipotent.

It can be tricky to remember which germ layers give rise to which areas of the body. Below are some tips to help you with this.

***Ectoderm***

Of the three layers, the *ectoderm* is the outermost layer. The prefix *ecto* means 'outer' or 'external', so it makes sense that this is the germ layer that gives rise to everything that is visible on the outside. An easy way to remember this is to think of the ectoderm as the 'attracto-derm'. What traits usually attract you to someone? Their eyes, hair, nails, skin? These are all exterior traits. Or perhaps you are attracted to people who show intelligence. The brain and nervous system also develop from the ectoderm.

***Mesoderm***

The next layer is the middle layer, the *mesoderm*. This one is the easiest of the three to remember. Think M for 'mesoderm' and also for 'muscle'. The mesoderm gives rise to muscles and everything associated with muscle, such as bone, cartilage and ligaments. The mesoderm is also responsible for producing the blood and vessels of our cardiovascular system. If you remember that muscles are needed to move blood through veins, this will help you to link these different areas. In addition, much of the excretory and genital systems are made of muscle (the bladder, for example), so they belong in this germ layer too.

LINK 4D THE EXCRETORY SYSTEM: ELIMINATING WASTE

***Endoderm***

Finally, the *endoderm* consists of everything else. The prefix *endo* means 'inner', so this germ layer gives rise to the innermost parts of an organism – that is, the digestive tract, a 'tube' that runs from our mouth to our anus, and all the organs (and their linings) in between. This tube has an early branching point that forms the trachea, and then lungs, which are also formed by the endoderm germ layer.

LINK 4B THE DIGESTIVE SYSTEM: GETTING THE NUTRIENTS WE NEED

ISBN 978-1-108-88711-3

Sometimes there is no better memory aid than a good diagram. Creating your own version of the diagram below is a great way to visually present germ layer differentiation.

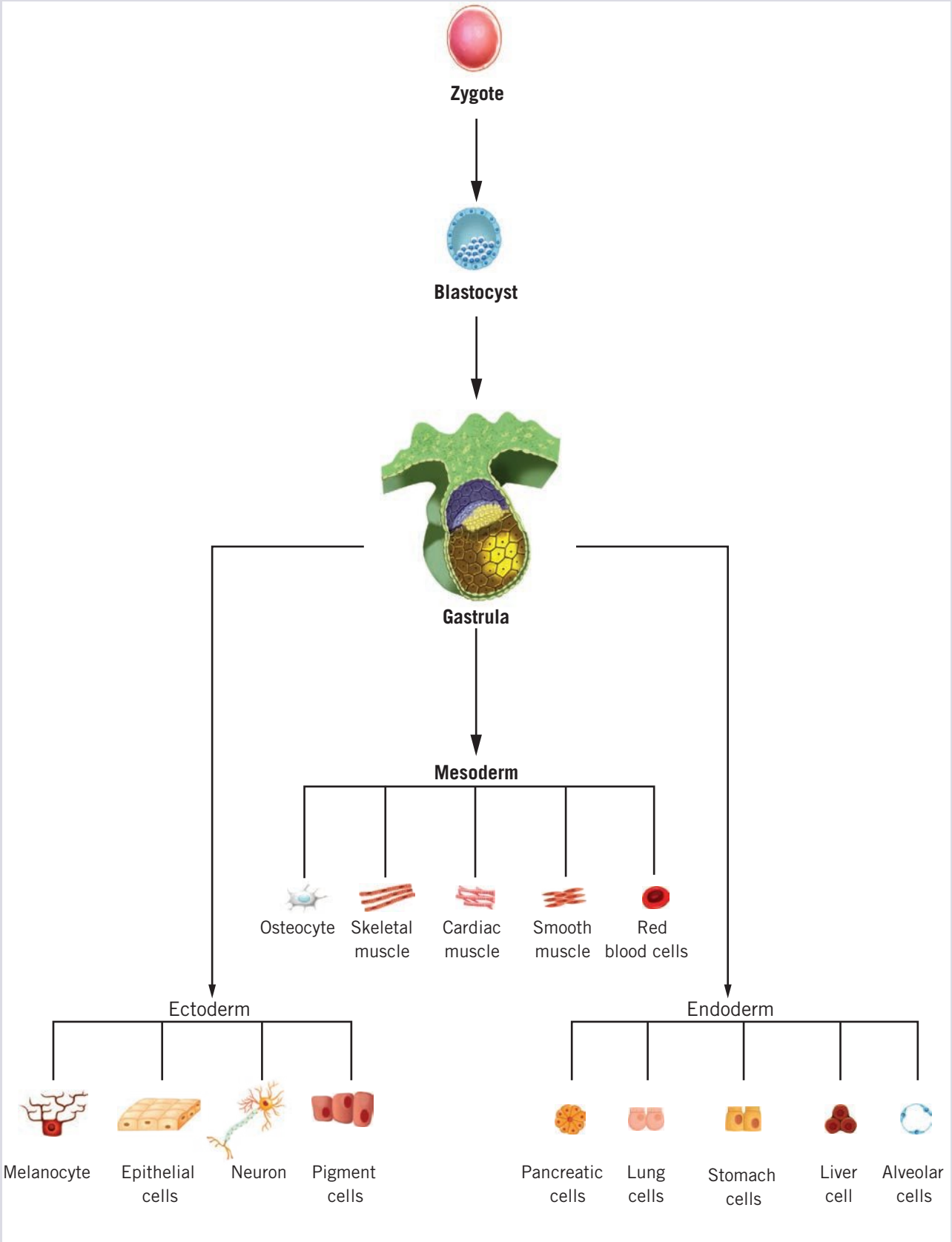



**Figure 3A–24** Differentiation of the three embryonic germ layers

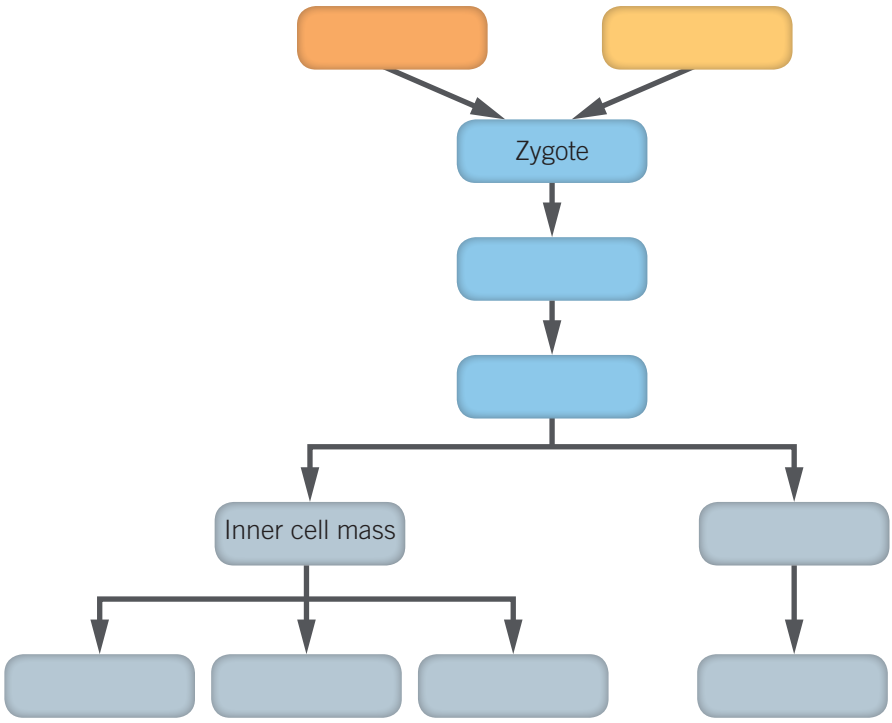
ISBN 978-1-108-88711-3

## Section 3A questions

**1** Order the following developmental stages from least to most developed by placing the numbers 1–5 in the table. (1 = least developed, 5 = most developed).

| Developmental stage | Level of development |
|---|---|
| Gastrula | |
| Foetus | |
| Zygote | |
| Morula | |
| Ovum | |

**2** Complete the flow chart.




**3** Why is cell specialisation critical for the development and growth of a healthy baby from a fertilised ovum?

**4** Having bone marrow extracted can be very painful for the donor patient, during the procedure and for some time afterwards. Justify whether it is more or less ethically acceptable to take stem cells from bone marrow from a consenting donor than from a 4-day-old embryo donated from IVF.

**5** Is the statement below true or false? Explain your reasoning. If you believe the statement to be false, rewrite it so that it is correct.

'The primary difference between pluripotent and totipotent cells is that only pluripotent cells can differentiate into all the body structures and tissues of a healthy individual.'

ISBN 978-1-108-88711-3

6 Human stem cells were isolated from the inner cell mass of a blastocyst and transferred to a culture jar for growth in the laboratory.
   a A few days later, the medical scientist came back to check on his work and realised that he had unknowingly placed the cells into a hypotonic solution. How would he have reached this conclusion? Use a diagram to support your response.
   b How would the cells have looked had the solution been hypertonic?

**Figure 3A–25** Working in a laboratory

7 Cord blood banking is becoming increasingly common in Australia, with many parents opting to collect their baby's stem cells from the umbilical cord at birth. These cells are then stored away for future use, in case a stem cell transplant is ever needed.
   a What is the advantage of treating a patient with their own cord stem cells rather than those of a donor?
   b Why would it not be possible to treat a genetic disorder in a child using their own umbilical cord stem cells? How would stem cell treatment be different in this situation?

8 Gastrulation results in the formation of the three primary embryonic germ layers: ectoderm, mesoderm and endoderm.
   a Describe two possible consequences for an individual if problems arose with the formation of the ectoderm.
   b What types of cells or parts of the body do each of the three primary embryonic germ layers give rise to? You may use a table to answer this question.

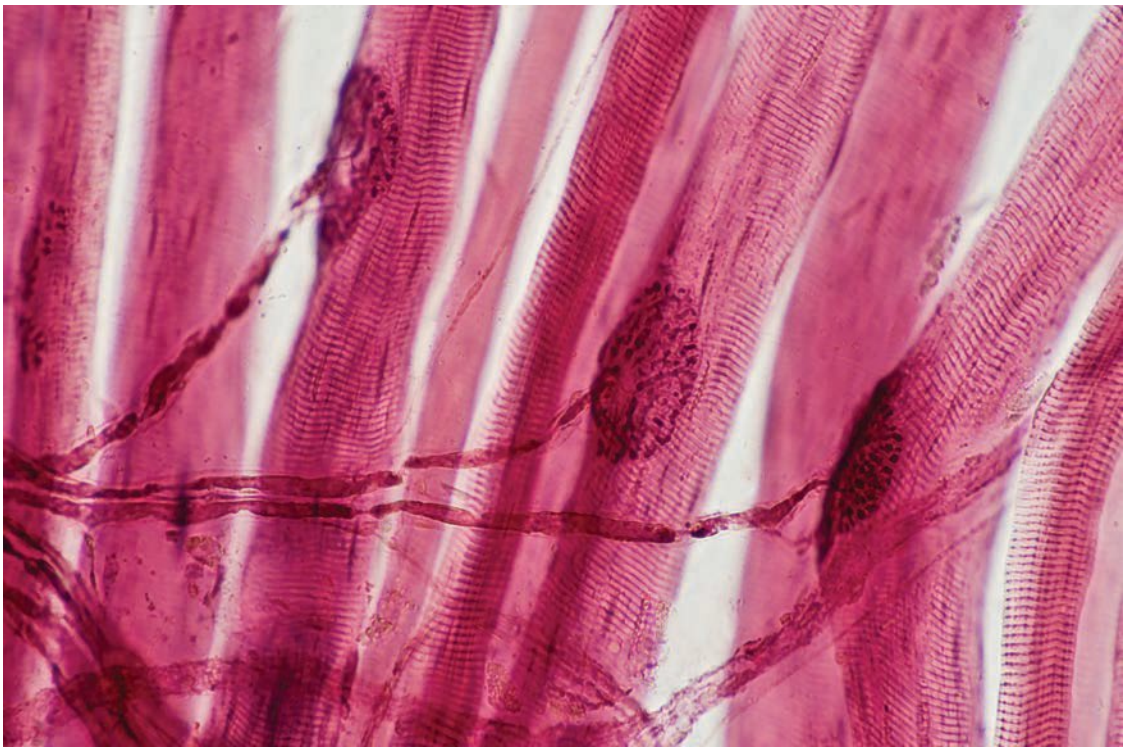
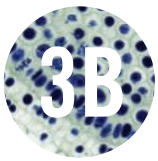


**Figure 3A–26** Skeletal muscle cells at ×100 magnification

ISBN 978-1-108-88711-3




# The cell cycle

**Study Design:**

- Binary fission in prokaryotic cells
- The eukaryotic cell cycle, including the characteristics of each of the sub-phases of mitosis and cytokinesis in plant and animal cells

**Glossary:**

Anaphase
Binary fission
Cell plate
Centromere
Centrosome
Chromatid
Chromatin
Chromosomes
Cleavage furrow
Complementary base pairing
Cytokinesis
Deoxyribonucleic acid (DNA)
Diploid
DNA packaging
Double chromosome
G0 phase
G1 phase
G2 phase
Interphase
Metaphase
Mitosis
M (mitosis) phase
Nucleosome
Nucleotide
Prophase
Purine
Pyrimidine
Reproduction
S phase
Single chromosome
Telophase

## ENGAGE

### The lifespan of your cells

Did you know there is research to suggest that the human body is replaced every seven years? Essentially, this makes you a brand new human being. The average life expectancy of an Australian is currently about 82 years, which means that a typical Australian will create over eleven versions of themselves in their lifetime.

While it is true that cells have a limited lifespan, it is not as easy as just applying a simple seven-year rule to them. Some cells will last your entire lifetime, while others may only survive for a matter of hours. The table below shows the lifespans of many different types of cells in your body.

| Type of cell | Lifespan of cell |
|---|---|
| Stomach lining cell | 2–9 days |
| Red blood cell | 4 months |
| White blood cell | 10 hours to decades |
| Skin cell | 2–4 weeks |
| Bone cell | 10 years |
| Fat cell | 25 years |
| Neuron (nerve cell) | Lifetime |
| Lens cell | Lifetime |

Why do you think these differences exist? For example, why do cells that line the stomach only last a matter of days but cells in the centre of the lens of the eye last a lifetime?

Information research on the internet may help provide answers.

This section focuses on the process that cells undergo in order to replicate, giving rise to the next generation.

ISBN 978-1-108-88711-3

## EXPLAIN

# DNA structure

**Deoxyribonucleic acid (DNA)** a type of nucleic acid that carries the organism's genetic information

Let's begin by revisiting Year 10 genetics. Picture a molecule of **deoxyribonucleic acid (DNA)**. What comes to mind? Did you picture an image similar to the one shown here?

Figure 3B–1 shows the characteristic double helix shape of DNA. The DNA molecule consists of two antiparallel strands of nucleic acids that wrap around each other, giving rise to its 'twisted ladder' form.

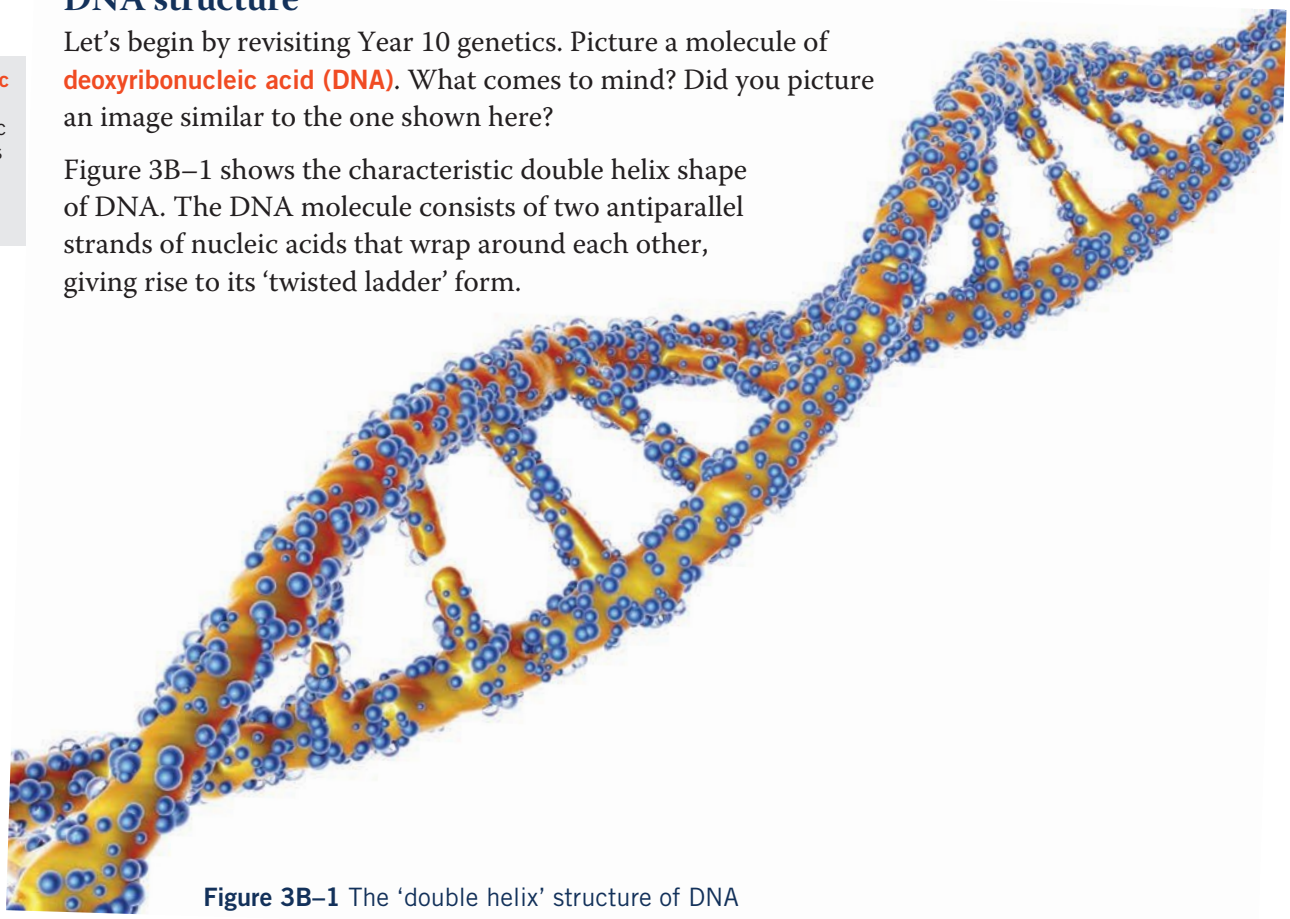


**Figure 3B–1** The 'double helix' structure of DNA

**Nucleotide** the basic structural unit of nucleic acids

**Purine** a nucleotide with a two-ring structure (adenine and guanine)

**Pyrimidine** a nucleotide with a single-ring structure (cytosine and thymine)

**Complementary base pairing** the pairing of nitrogenous bases in DNA, with adenine and thymine always paired and cytosine and guanine always paired

Each strand of the DNA molecule is made up of many repeating subunits (monomers), known as **nucleotides**. Each nucleotide has three main components:

- a negatively charged phosphate group
- a five-carbon deoxyribose sugar
- one of four nitrogenous bases – adenine (A), cytosine (C), guanine (G) or thymine (T).

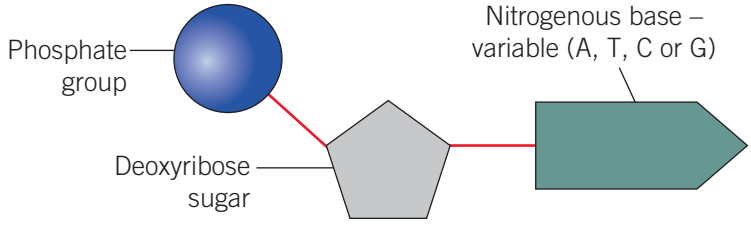



**Figure 3B–2** The structure of a typical nucleotide, the monomer of a DNA molecule

Nitrogenous bases can be classified as either purines or pyrimidines, according to their chemical structure. Adenine and guanine have a two-ring structure, which makes them **purines**, while thymine and cytosine have a single-ring structure, making them **pyrimidines**. **Complementary pairing rules** in DNA mean that a purine (larger in structure) will always pair with a pyrimidine (smaller in structure), which helps to strengthen and stabilise the DNA helix. Therefore, adenine and thymine always pair together, and guanine and cytosine always pair together.

ISBN 978-1-108-88711-3

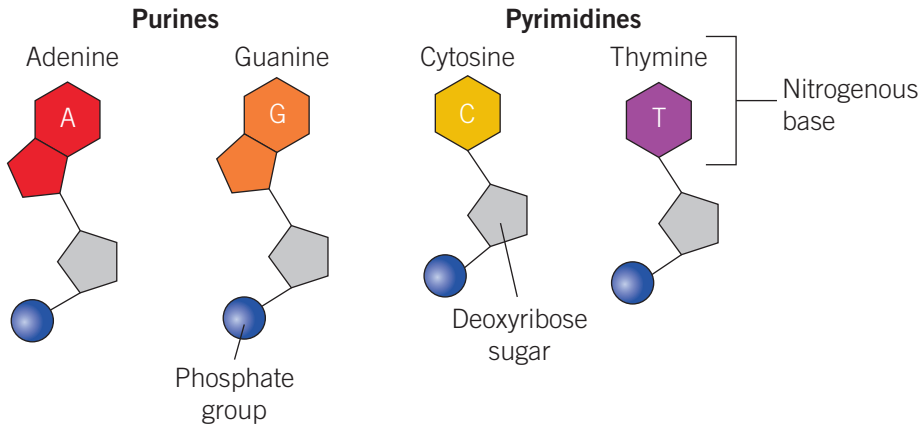



**Figure 3B–3** The four different nucleotides in DNA, showing the purines (double rings) and pyrimidines (single rings) that form the nitrogenous base component and give each nucleotide its identity

The sides of the DNA 'ladder' (the strands) are formed by the alternating phosphate and deoxyribose sugar groups of the nucleotides, giving rise to the sugar–phosphate backbone. The nitrogenous bases form the 'rungs' of the ladder by orientating themselves towards the centre of the molecule. Hydrogen bonds form between complementary nitrogenous bases of the two opposing strands, and these bonds hold the molecule in its double helix form.

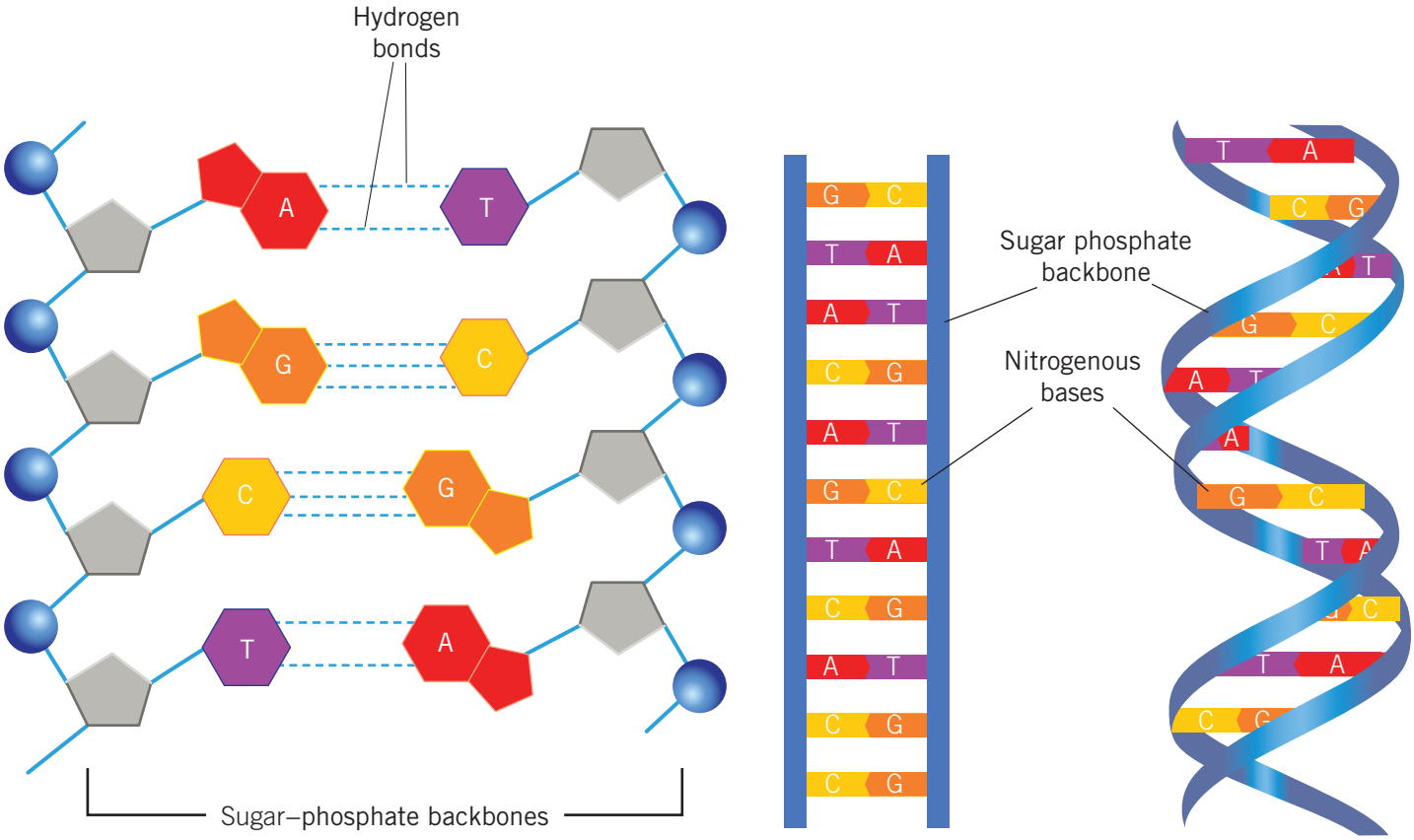



**Figure 3B–4** Left: How the nitrogenous bases A, T, G, C link the two sugar–phosphate backbones into a ladder structure. Note the difference in the number of hydrogen bonds between complementary bases, which explains why A and T only and always bond together, and why G and C only and always bond together. Right: A simplified version of the ladder structure, showing how it is twisted into the double-helix structure of DNA.

ISBN 978-1-108-88711-3

1D ORGANELLES LINK

## Packaging of DNA

The body of a typical human contains approximately 37.2 trillion cells. Housed within the nucleus of each of these cells is more than 2 metres of DNA. Fitting all this DNA into the nucleus of a cell, which is only 6 µm in diameter, is the equivalent of fitting 40 kilometres of thread into a tennis ball! This is accomplished through a process known as **DNA packaging**.

Although DNA is described as having a double helix structure, this is not what you see when you look at DNA within the nucleus of a eukaryotic cell. Rather, it appears as a tightly compacted, threadlike mass known as **chromatin**. Chromatin consists of two substances: DNA and proteins (known as histones). Each cell's DNA wraps tightly around these histones, forming structures known as **nucleosomes**. A nucleosome consists of DNA wrapped around eight histones and is the subunit of chromatin. The formation of these highly organised DNA–protein subunits results in more than 2 metres of DNA being neatly packaged into the nucleus.

**DNA packaging** the process in which DNA is compacted and packaged into the nucleus of a eukaryotic cell

**Chromatin** a condensed structure, made of DNA and protein, found in the nucleus of eukaryotic cells

**Nucleosome** a set of eight histone proteins with DNA coiled tightly around them

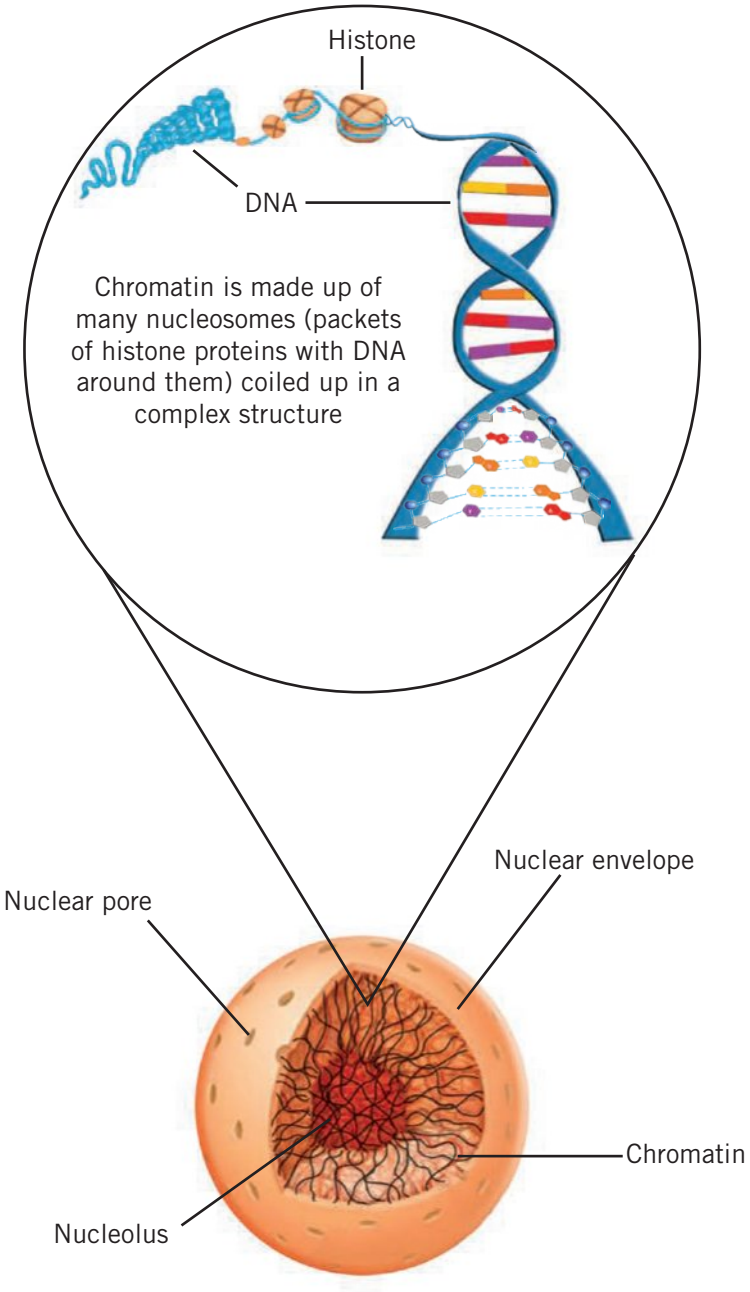



**Figure 3B–5** The packaging of DNA into the nucleus of a (eukaryotic) cell. A schematic diagram of the chromatin unravelled and enlarged to expose the nucleosomes, and unravelled and enlarged even more to show the nucleotides.

ISBN 978-1-108-88711-3

## Chromatin to chromosomes

For most of a eukaryotic cell's lifespan, DNA is packaged into the nucleus in the form of chromatin. As a cell moves into the division phase of its lifecycle, the chromatin must condense further. As chromatin reaches its most condensed state, it gives rise to the distinct, X-shaped structures we recognise as **chromosomes**. If chromosomes are visible in the nucleus when viewed under a microscope, we can determine that the cell has entered the 'division' phase of its life cycle.

**chromosomes** the highly compact form of DNA that is visible in eukaryotic cells as they divide

WORKSHEET 3B–1 DNA STRUCTURE

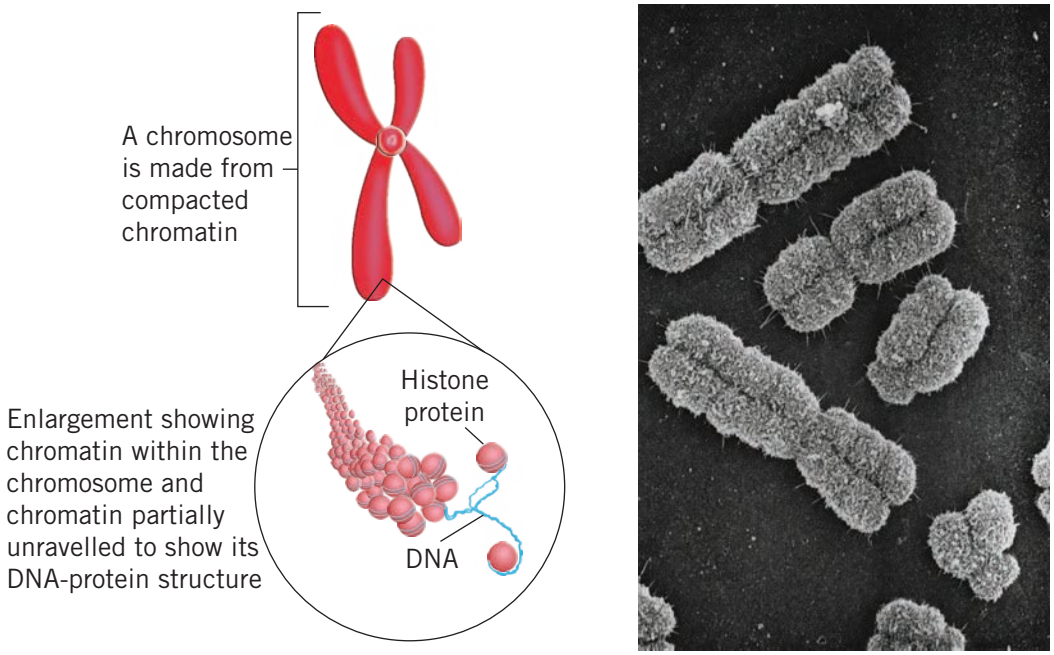



**Figure 3B–6** Left: The highly compacted packaging of DNA in chromatin, which is then packed into a chromosome. Right: Scanning electron microscope image of human chromosomes

## Check-in questions – Set 1

1 Recall the three components of a DNA nucleotide.
2 Write the complementary base sequence for this section of DNA: AATTCGTATTCG.
3 List the following in order from most condensed to least condensed: chromatin, chromosome, double helix.

ISBN 978-1-108-88711-3

**Mitosis**
the division of a eukaryotic cell's nucleus

**Binary fission**
a type of asexual reproduction in prokaryotic cells

1C CELL TYPES LINK

## The purpose of cell division

Cell division occurs when a single parent cell divides into two genetically identical daughter cells. The fundamental purpose of replication is the passing on of genetic material (DNA) to the next generation of offspring. In eukaryotic cells, cellular division is referred to as **mitosis**. Prokaryotic cells use a much simpler method known as **binary fission**.

In multicellular eukaryotes (plants, fungi, animals), the two main reasons for cellular replication are growth and repair.

### Growth

All forms of life begin as a single cell. For some organisms, this is also where it ends. Others, such as yourself, grow and develop from a single, fertilised egg cell into a complex organism – consisting of more than 37 trillion cells. Mitosis is responsible not only for the division of cells that results in this growth, but also for the development of these 37 trillion cells into the 210 specialised types of cells inside your body.

**Figure 3B–7** Once a new multicellular organism is created by an egg cell being fertilised, growth and repair happens by mitosis.

### Repair

As you read in the introduction to this section, cells don't all have the same lifespan. The neurons that make up your brain tissue are thought to last a lifetime, but the cells that line your stomach only last for a maximum of 5 days, because of the highly acidic environment they are in. Your skin cells also have a short duration. At best they will last 4 weeks, but if you get a paper cut or graze your knee, this lifespan is cut drastically short. Thankfully, mitosis replaces worn-out or damaged cells, ensuring that, among other things, organs such as our stomach and our skin remain intact.

**Reproduction**
the production of offspring

7A ASEXUAL REPRODUCTION LINK

Single-celled (unicellular) organisms such as bacteria (prokaryotes) and protists (eukaryotes) do not divide for the purpose of growth or repair. Instead, they undergo cell division as a means of **reproduction**. These unicellular organisms reproduce asexually. You will read about the variety of methods of asexual reproduction in Section 7A. This chapter focuses on the bacterial method of cell replication: binary fission.

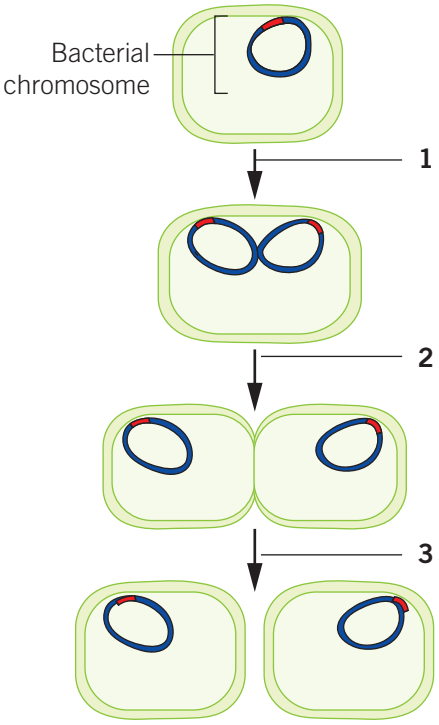
ISBN 978-1-108-88711-3

## Cell division in prokaryotes

### Binary fission

As you learned in Section 1C, prokaryotic cells such as bacteria are simple cells that lack membrane-bound organelles. This means that the process of cell division for bacteria is less complicated than it is for eukaryotic cells. Bacteria use a method of cell division called *binary fission*. This method of division is outlined below.

LINK 1C CELL TYPES




**1** *Replication* – bacterial DNA is a single circular chromosome located in the nucleoid region of the cell. This chromosome attaches to the plasma membrane at approximately the midpoint of the cell and is copied, resulting in two identical circular chromosomes.

**2** *Elongation* – the parent cell elongates, which assists in the separation of the two identical chromosomes.

**3** *Division* – once the two chromosomes are located on opposite sides of the cell, a septum forms along the middle of the cell, giving rise to new cell walls. The membrane of the cell then pinches inwards until the parent cell splits into two, creating two daughter cells.

**Figure 3B–8** The process of binary fission, shown here in a prokaryote

Binary fission is an asexual process, as only one parent is required to give rise to offspring. The advantage of this is that there is no need to spend time looking for a suitable mate, and division can therefore occur very quickly. Bacterial cells such as *E. coli* can divide once every 20 minutes in favourable circumstances. However, the disadvantage of this is that all offspring are genetically identical not only to each other but also to their parent cells. This results in very limited genetic variability, making the population susceptible to changes in the environment (such as disease) and therefore at risk of being wiped out.

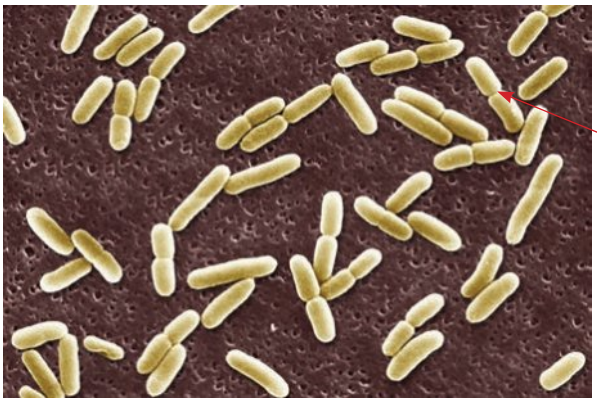



**Figure 3B–9** Scanning electron microscope image of an *Escherichia coli* bacterial colony

LINK UNIT 4

ISBN 978-1-108-88711-3

## Check-in questions – Set 2

1 Explain the different outcomes of cell replication in unicellular and multicellular organisms.
2 Briefly summarise the three steps of binary fission. (You may wish to use a diagram.)
3 What are the advantages and disadvantages for bacteria that replicate by binary fission?

## Cell division in eukaryotes

The presence of membrane-bound organelles within a eukaryotic cell makes the division of these cells more complex compared to prokaryote cells.

### The cell cycle

The cell cycle is the process that most eukaryotic cells undergo to multiply. Recall from earlier in this section that eukaryotic cells divide for the purpose of growth and repair. The cell cycle consists of distinct stages that cells progress through in an orderly manner in preparation for division. As the parent cell gives rise to two genetically identical daughter cells, these daughter cells immediately commence their own pathway through the stages – hence the term 'cycle'. On average, a typical human cell takes approximately 24 hours to progress through the cycle, although this can vary depending on the type of cell. The stages of the cell cycle are shown in Figure 3B–10, and outlined on the following pages.

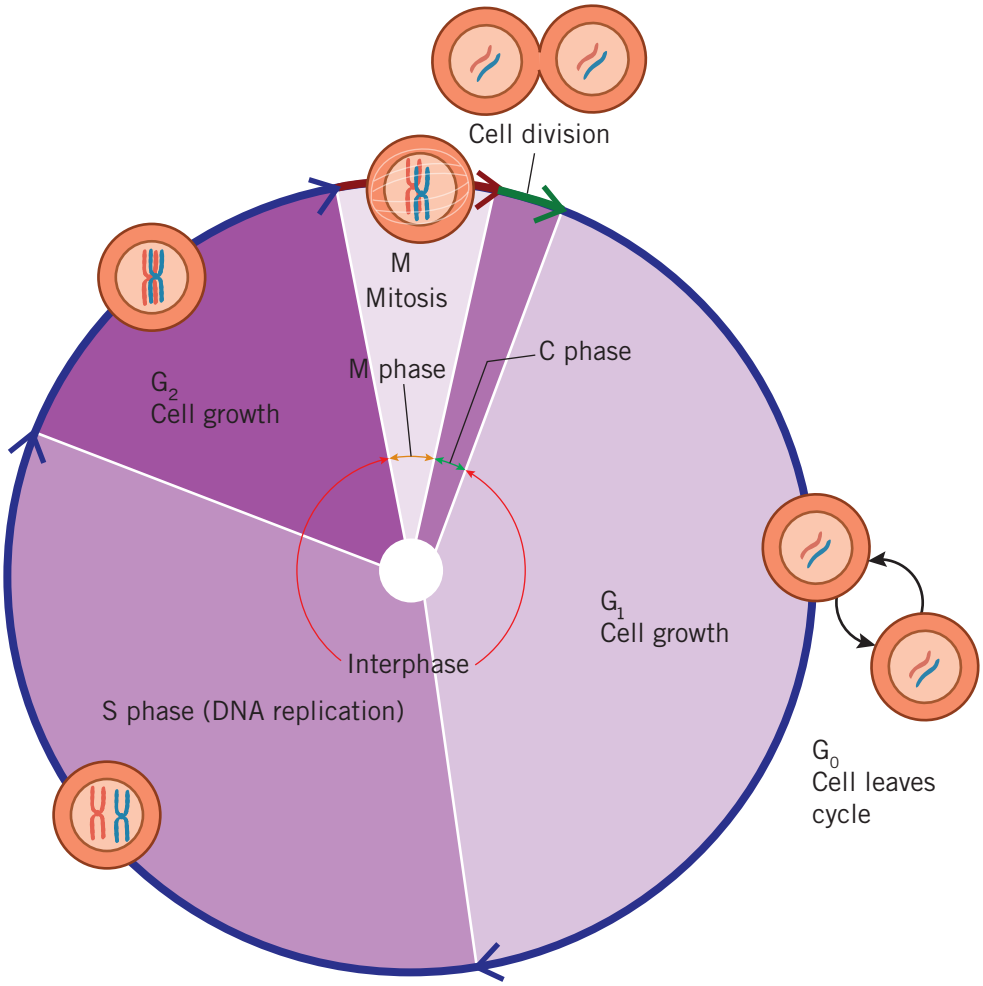



**Figure 3B–10** Phases of the eukaryotic cell cycle. 'M phase' means 'mitotic phase' and 'C phase' means 'cytokinetic phase', 'S phase' means 'synthetic phase', '$G_1$' and '$G_2$' are the first and second gap phases, while '$G_0$' zero is a resting phase.

ISBN 978-1-108-88711-3

## NOTE

In this course, the numbers in the abbreviations for cell cycle phases and checkpoints may be written as subscripts such as $G_0$, $G_1$ etc., or as normal text, G0, G1 etc. Subscripts are normally used in academic papers.

## Interphase

**Interphase** is the portion of the cell cycle in which a typical cell will spend most of its time. It consists of the G1, S, G2 and, in some cells, G0 phases of the cell cycle. During interphase, the cell undergoes several important changes in preparation for division: it grows, replicates its DNA to produce two sets of chromosomes, as well as multiplying organelles so that it is ready to move out of interphase and into the division portion of the cycle, which consists of M phase and C phase. It is important to note that, in interphase, chromosomes are *not* visible and the nucleus appears as a dark mass of chromatin. The key features of each interphase stage are described in detail below.

**Interphase**
the period of the cell cycle that consists of the G1, S and G2 phases

**G1 (first gap) phase**
the first period of cell growth in the cell cycle

LINK 1D ORGANELLES

**G0 phase**
('G zero') the resting phase of the cell cycle that some cells may enter

### *G1 phase*

In the **G1 phase** (or **first gap phase**), the cell grows larger and almost doubles in size. This growth is important as it allows for the conservation of cell size once division has occurred. It is also the point in the cycle where organelles are copied so that daughter cells will be equipped with the necessary 'machinery' to sustain their own survival. This is the longest phase of the cell cycle and therefore most cells are seen in this stage when viewed under a microscope.

### *G0 phase*

Not all cells progress through the whole cell cycle. Some cells exit the cycle in G1 and enter a resting state called the **G0 phase**. For some cells, this resting state is not permanent and they eventually re-enter the cycle and divide normally. For other cells, such as neurons, this state of rest is permanent, which explains why damage to the nervous system is very difficult to treat.

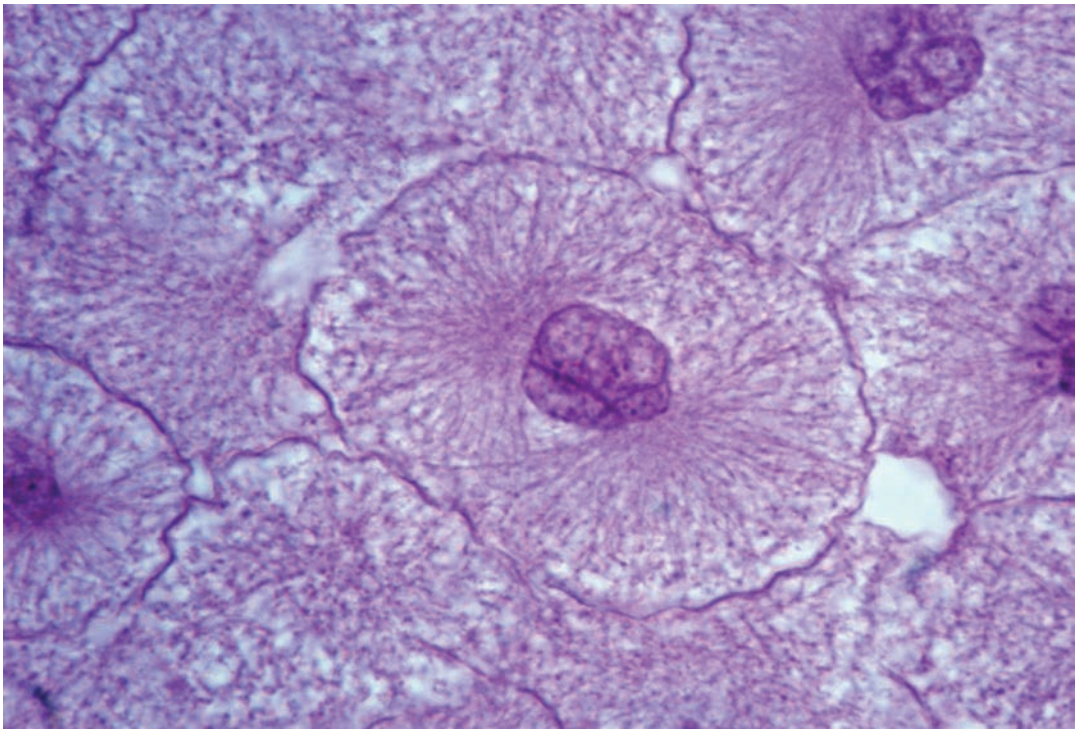


**Figure 3B–11** Whitefish embryo cell with a nucleus in the centre, filled with chromatin; in interphase chromosomes are not visible

ISBN 978-1-108-88711-3

**S (synthesis) phase**
the DNA replication phase of the cell cycle

**Single chromosome**
a highly condensed, single molecule of DNA

**Double chromosome**
a highly condensed, replicated molecule of DNA consisting of two identical chromatids joined by a centromere

**Chromatid**
one of two strands of a double chromosome formed when a single chromosome is replicated prior to mitosis or meiosis; when two chromatids are joined at a centromere, they are called sister chromatids and are identical

**Centromere**
the structure in a chromosome where the two chromatids are held together; also the point of attachment of the kinetochore, which the spindle microtubules attach to

### *S phase*

Following G1 is the **S phase** (or **synthesis phase**). It is here that the DNA within the nucleus of a cell is replicated, creating two identical copies of DNA. Even though chromosomes are not present in this stage of the cycle, it is easier to explain by imagining that they are. During DNA replication, **single chromosomes** become **double chromosomes** consising of two sister **chromatids** joined by a **centromere** (see Figure 3B–12). The two sister chromatids contain identical genetic information that is passed into the two daughter cells when cell division occurs at the end of M phase.

In a typical human cell, before the replication of DNA in S phase, there are 46 *single* chromosomes present within a nucleus. At the end of S phase, the replication of DNA means that the nucleus now consists of 46 *double* chromosomes.

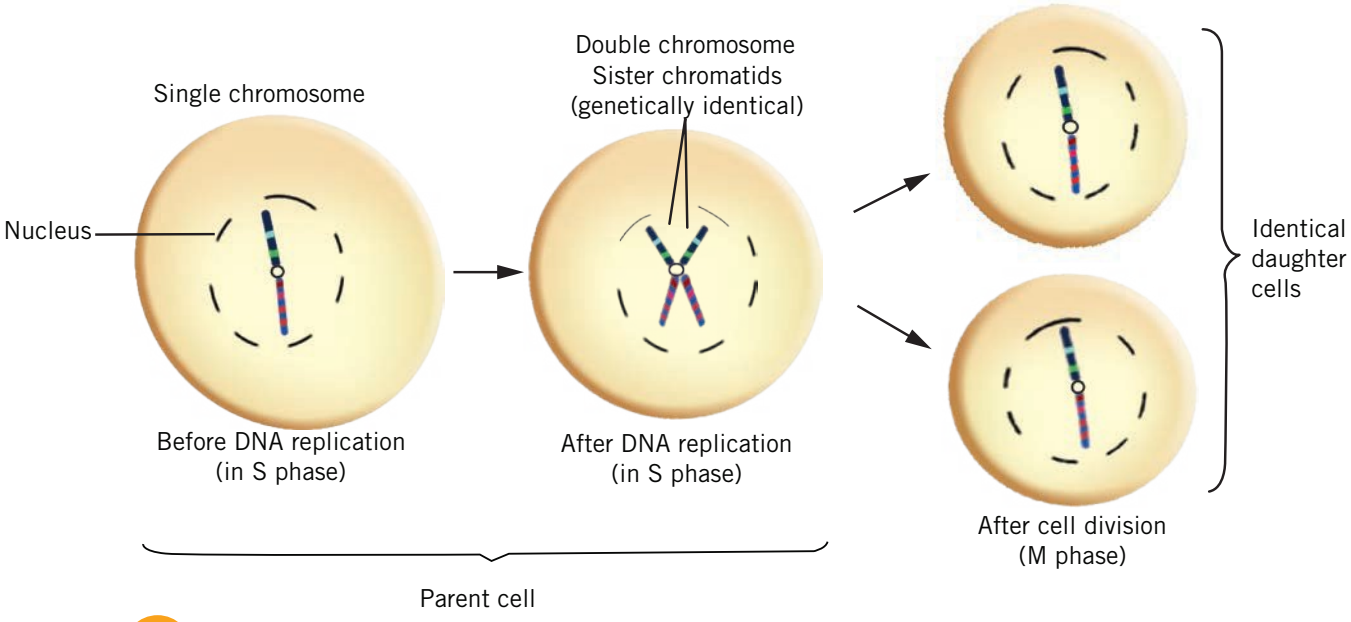



**Figure 3B–12** The replication of DNA in S phase results in genetically identical daughter cells.

**G2 (second gap) phase**
the second period of cell growth in the cell cycle

**M (mitosis) phase**
the portion of the cell cycle that includes mitosis

**C (cytokinesis) phase**
the portion of the cell cycle that includes cytokinesis

### *G2 phase*

The **G2 phase** (or **second gap phase**) is the final stage of interphase. In the G2 phase, the cell once again enters a period of growth, as well as increasing its energy store in preparation for division. Metabolic activity also increases as proteins needed for division are synthesised.

### M phase

Following the G2 portion of interphase, the cell progresses to **M (mitosis) phase**, which involves mitosis. Mitosis consists of its own set of distinct phases. These processes are described in detail later in this section.

### C phase

Immediately after M phase, the cell continues to **C (cytokinesis) phase**, which consists of cytokinesis. In this stage, the cytoplasm splits, forming two genetically identical daughter cells.

ISBN 978-1-108-88711-3

## Check-in questions – Set 3

1 Draw a labelled diagram of the cell cycle.
2 Briefly summarise the key events that occur in each phase of the cell cycle.
3 Explain the difference between a single chromosome and a double chromosome, with reference to S phase in your answer.

### Mitosis: division of the nucleus

Mitosis is the stage of the cell cycle that results in the nucleus of the parent cell splitting into two. It is responsible for the growth and development of an organism as well as the repair or replacement of damaged and worn-out cells. Prior to division, the parent cell contains a **diploid** number ($2n$) of chromosomes. This means that the cell contains two sets of chromosomes, one set from each parent and the chromosomes in the pair are called **homologous chromosomes**. This number is conserved through the division process, with each of the two daughter cells also containing a diploid number of chromosomes.

**Diploid** containing two complete sets of chromosomes, one set from the mother (maternal) and one set from the father (paternal); pairs of chromosomes are called homologous chromosome

**Homologous chromosomes** chromosomes that have matching structural features (size, banding pattern, centromere location) and gene loci, one from each parent

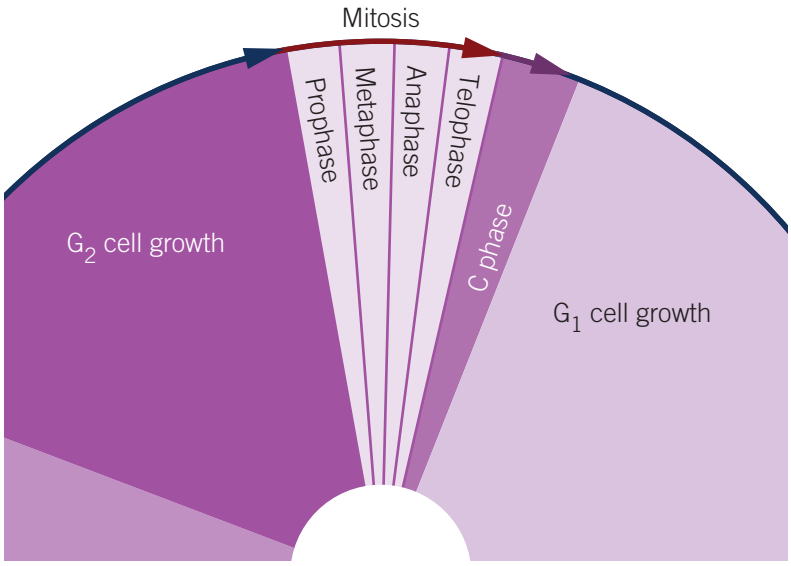



**Figure 3B–13** The mitosis component of M phase consists of four subphases, each with its own distinct characteristics.

Mitosis consists of four distinct subphases, each with its own unique characteristics. It can be easy to confuse the order of the subphases, so the acronym PMAT is used:

**P** – prophase **M** – metaphase **A** – anaphase **T** – telophase.

**VIDEO 3B–1** THE CELL DIVISION – MITOSIS

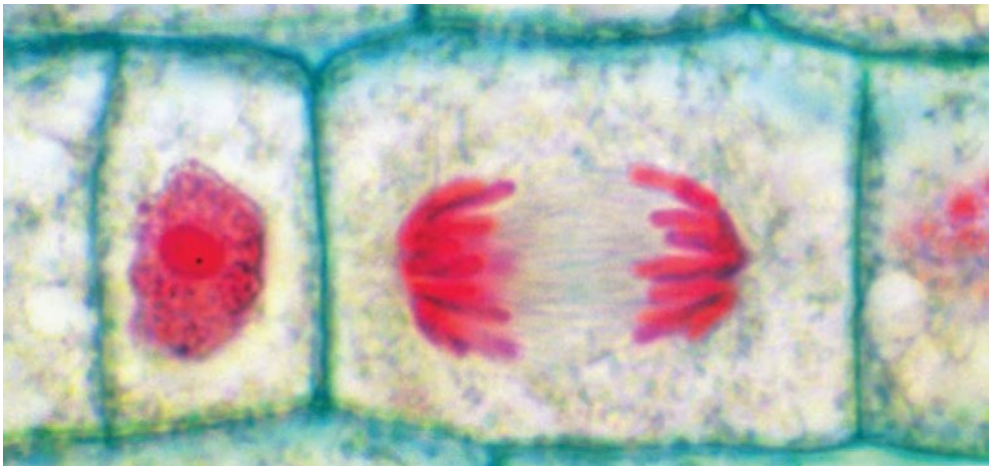
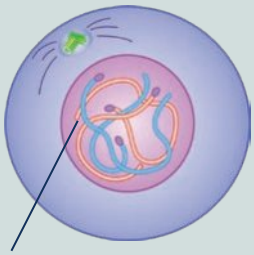
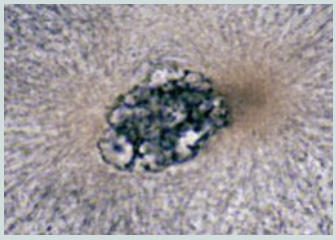
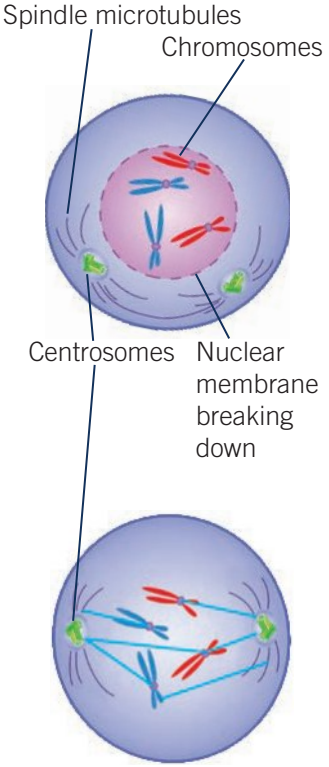
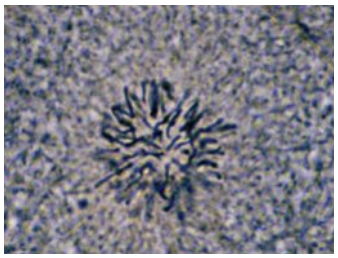
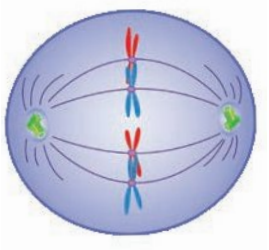
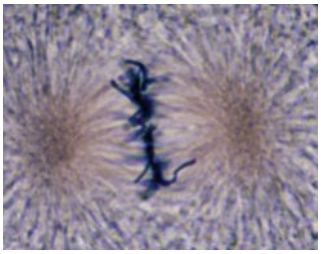


**Figure 3B–14** Mitosis in a plant cell

ISBN 978-1-108-88711-3

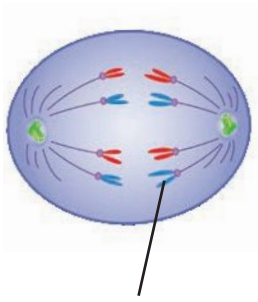
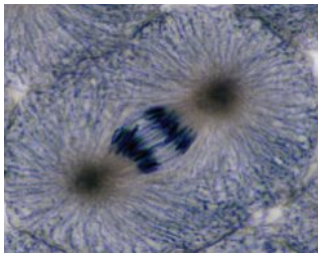
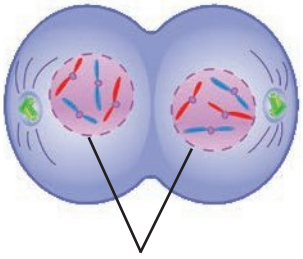
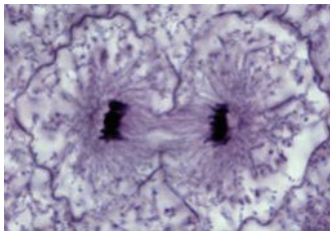
Table 3B–1 outlines the key characteristics of each subphase of mitosis.

**Table 3B–1** The stage before mitosis followed by the subphases of mitosis

| Stage/subphase of mitosis | Key characteristics | Diagram | Microscope view |
|---|---|---|---|
| Before mitosis | Interphase (G1, S and G2)<br>Over a 24-hour cell cycle time:<br>• G1 = 11 hours<br>• S = 8 hours<br>• G2 = 4 hours |  |  |
| Mitosis (1 hour)<br>**Prophase**<br><br>**Prophase** the first mitotic phase; involves the breakdown of the nuclear membrane and the appearance of distinct chromosomes<br><br>**Centrosome** an organelle from which spindle microtubules develop during cell division; contains the centrioles | ***Early prophase***<br>• Chromatin condenses into individual chromosomes, which now appear as discrete shapes, and are visible under a microscope<br>• In the cytoplasm, **centrosomes** (duplicated in S phase) begin moving to opposite poles (ends) of the cell<br>***Late prophase***<br>• Nuclear membrane of cell has completely broken down<br>• Centrosomes are now at opposite ends of the cell<br>• Spindle microtubules produced by the centrosomes enter the nuclear area and make contact with the chromosomes |  |  |
| **Metaphase**<br>M = middle<br>*(chromosomes are visible when viewed under a microscope)*<br><br>**Metaphase** the second mitotic phase; involves the lining up of chromosomes along the middle (equator) of the cell | • Chromosomes are forced into the centre of the cell by the attachment of spindle microtubules to each chromosome's centromere<br>• Chromosomes line up along the metaphase plate in the middle of the cell<br>• Chromosomes appear stationary but they are being tugged towards opposite poles of the cell by the microtubules |  |  |

ISBN 978-1-108-88711-3

**Table 3B–1** *Continued*

| Stage/subphase of mitosis | Key characteristics | Diagram | Microscope view |
|---|---|---|---|
| **Anaphase**<br>A = apart<br>*(chromosomes move away from each other)*<br><br>**Anaphase**<br>a mitotic phase in which double chromosomes separate and the sister chromatids are pulled apart to opposite sides of the cell | • The centromere holding the sister chromatids of each double chromosome is split apart by the opposing microtubule forces<br>• The two sister chromatids (each now a single chromosome) begin moving to opposite poles of the cell, centromere first<br>• Microtubules from each centrosome retract and get smaller (much like a fishing line being reeled in), resulting in chromosomes being pulled further apart |  <br>Chromatids (now referred to as chromosomes) |  |
| **Telophase**<br>T = two<br>*(there are two nuclei within the cell)*<br><br>**Telophase**<br>the final mitotic phase, in which two nuclei are formed and the cell prepares to divide | • The now single chromosomes arrive at opposite poles of the cell<br>• The chromosomes revert back to chromatin<br>• Spindle microtubules disassemble<br>• Nuclear membranes re-form around the two groups of chromosomes on opposite sides of the cell |  <br>Nuclear membrane re-forming |  |

When you look through a microscope, what you see will be similar to the micrograph of a dividing plant root tip shown in Figure 3B–15.

How many stages of mitosis can you identify in Figure 3B–15? Use the micrographs of the cells in various stages of division from Table 3B–1 to help you.

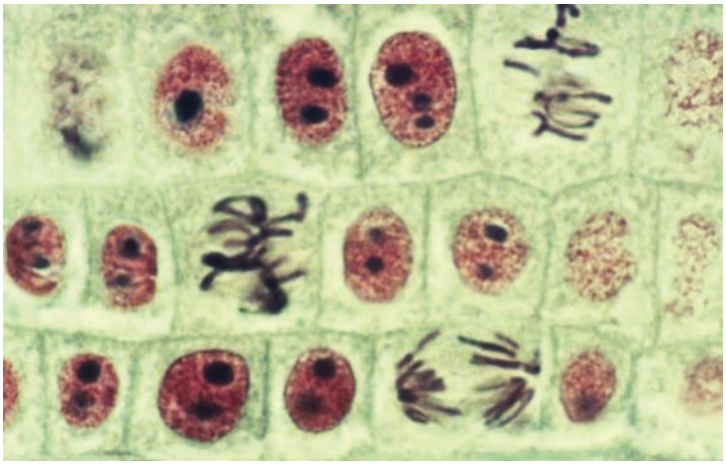


**Figure 3B–15** A section of a dividing plant root tip that shows cells at various stages of mitosis.

ISBN 978-1-108-88711-3

2C SURFACE AREA TO VOLUME RATIO LINK

## Cytokinesis

The final stage of the cell cycle is **cytokinesis**, which is the splitting of the cytoplasm. It occurs after telophase in mitosis. Cytokinesis is important because it restores the original size of the cell, maintaining the all-important SA:V ratio, and it also divides organelles between the two daughter cells, ensuring that these cells will be able to survive once separated. At the end of cytokinesis, the parent cell will have completed its passage through the cell cycle, which is marked by the presence of two genetically identical daughter cells.

**Cytokinesis** the final stage of the cell cycle, in which the cytoplasm splits, giving rise to two genetically identical daughter cells

**Cleavage furrow** the indentation of the cell's plasma membrane as it pinches inwards to split the cell into two

### Cytokinesis in animal cells

In animal cells, the plasma membrane pinches inwards on both sides, giving rise to a **cleavage furrow**. This cleavage furrow continues as the plasma membrane constricts inwards until both ends meet and the cell separates into two individual cells.

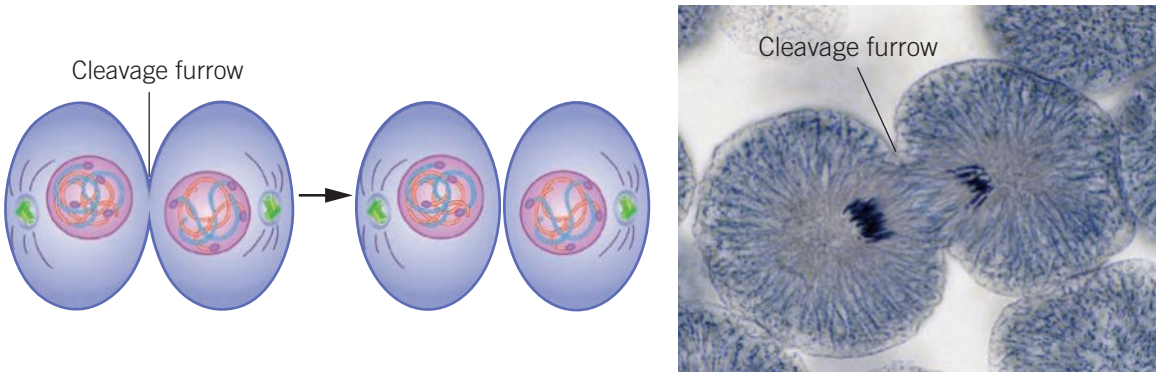



**Figure 3B–16** Animal cells undergoing cytokinesis. Left: Diagram of cells splitting. Right: Microscope view of fish embryo cells about to complete cytokinesis and separate

1D ORGANELLES LINK

**Cell plate** a structure that forms during cytokinesis in plant cells and gives rise to the new cell walls of the daughter cells at the conclusion of division

### Cytokinesis in plant cells

The presence of a rigid cell wall in plant cells means that, unlike an animal cell, a plant cell cannot simply pinch into daughter cells. Instead, a new cell wall must be formed and the foundation for this begins in telophase. During telophase, a structure known as the **cell plate** begins to form along the midline of the parent cell. The plate is formed using vesicles that arise from the Golgi apparatus. By the conclusion of cytokinesis, a complete new cell wall and plasma membrane have assembled across the cell plate, giving rise to two daughter cells.

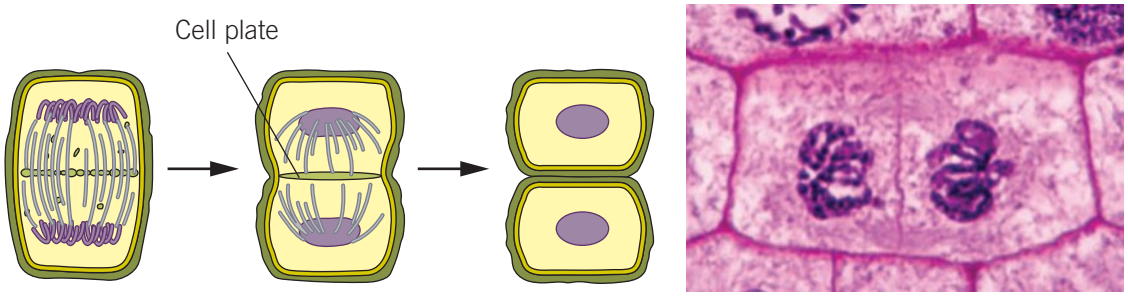



**Figure 3B–17** Plant cells undergoing cytokinesis. Left: The presence of a rigid cell wall means that a cell plate must develop to form the new cell wall and plasma membrane. Right: The cell plate is clearly visible in this micrograph of a dividing onion cell.

ISBN 978-1-108-88711-3

## The cell cycle: summary

A summary of the cell cycle is shown below.

WORKSHEET 3B–2
MITOSIS

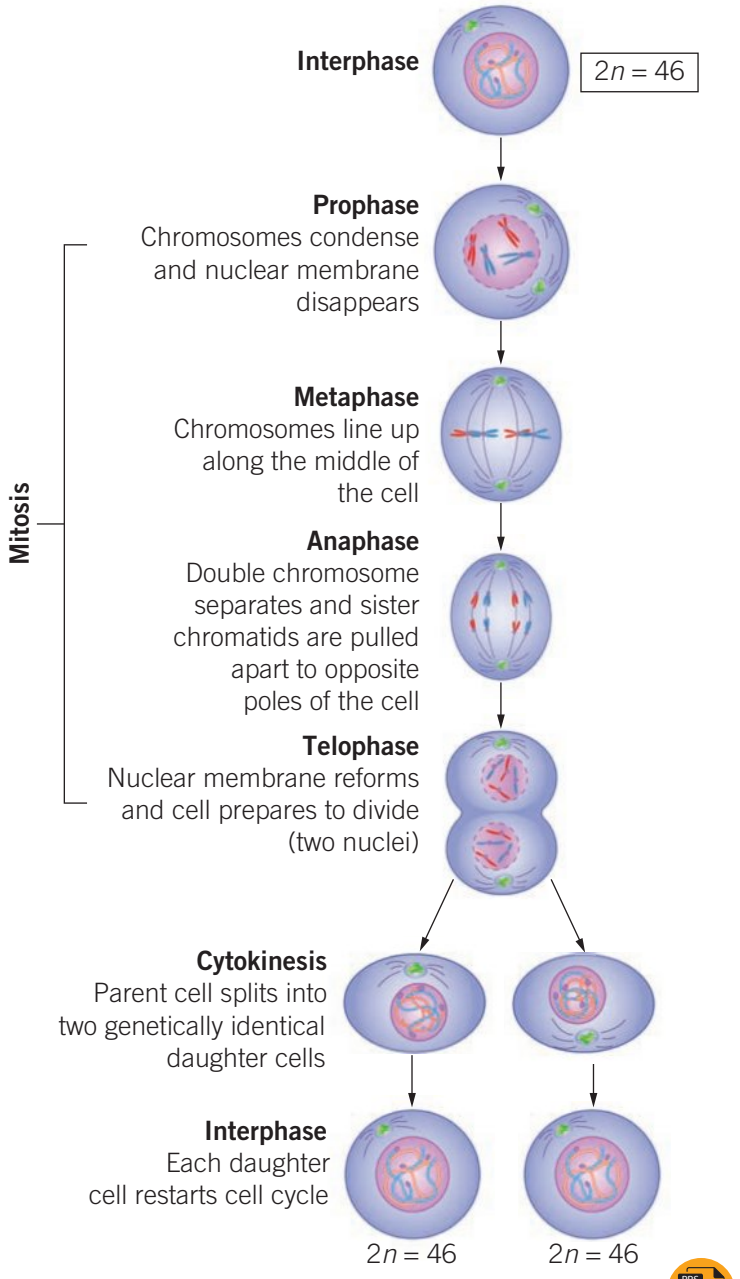



**Figure 3B–18** Stages of the cell cycle in an animal cell

## Cell cycle regulation: checkpoints

Throughout the cell cycle, several checkpoints act to ensure that cellular processes have been carried out accurately prior to division. Any errors that occur along the way would otherwise be passed on to the next generation of daughter cells, which could have devastating effects on an organism. The next section of this chapter takes an in-depth look at the importance of these checkpoints.

LINK 3C CELL CYCLE REGULATION AND APOPTOSIS

## Check-in questions – Set 4

1 Draw a simple diagram of each of the four stages of mitosis (PMAT).
2 Define 'cytokinesis'.
3 Explain the difference in cytokinesis between animal cells and plant cells.

ISBN 978-1-108-88711-3

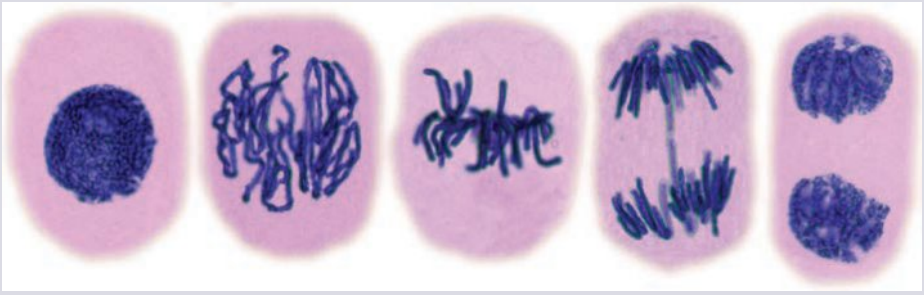
**VIDEO 3B–2**
SKILLS: DISTINGUISHING BETWEEN PROPHASE AND INTERPHASE IN DIAGRAMS

## 3B SKILLS

**Distinguishing between prophase and interphase in diagrams**

One of the more difficult skills you need to master in this topic is the ability to distinguish between interphase and prophase when looking at diagrams or micrographs. As DNA does not completely condense into chromosomes until late prophase, it can look very similar in the different stages, making it difficult to correctly identify the stage(s) shown in a question.

Take the following micrograph images, for example:



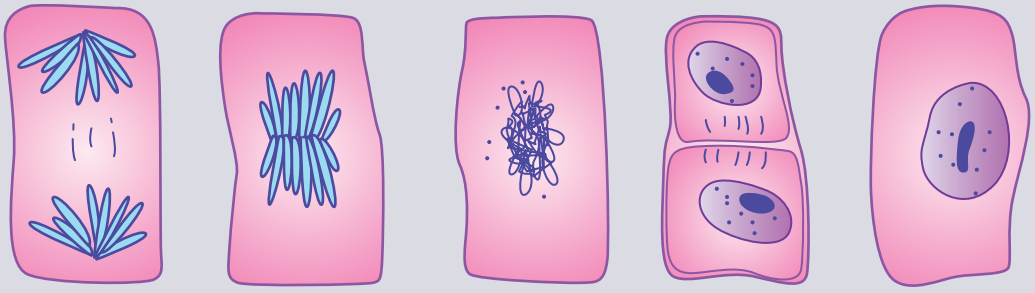
A B C D E

It is easy to identify C as metaphase (chromosomes lined up along the metaphase plate in the middle), D as anaphase (chromosomes being pulled towards opposite poles) and E as telophase (two nuclei within the parent cell). Some students, however, find it difficult to determine whether cell A or B would be prophase. So how do you distinguish between them?

First, you may have already realised that the cells are lined up in the order in which the cell would progress through each stage (that is, PMAT). This then makes A interphase and B prophase. However, in most cases, the question will not be kind enough to line up the subphases in sequential order for you, so how else can you distinguish between the two stages accurately?

Remember that prophase marks the breakdown of the nuclear membrane. This is the *key* distinguishing feature between prophase and interphase and should always be your point of reference for accurate identification of these two stages. In cell A there is a clear nucleus visible, so it must be in interphase. Cell B, on the other hand, does not have a visible nucleus and therefore must be in (late) prophase.

Now look at the diagrams below:



I II III IV V

ISBN 978-1-108-88711-3

This time the cells are not shown in PMAT order. You should, however, still find it easy to recognise I as anaphase, II as metaphase and IV as telophase. That leaves cells III and V to be prophase and interphase. Using the presence of a clearly visible nucleus as the key distinguishing feature, this should direct you to identifying cell III as prophase and cell V as interphase.

While it may seem straightforward, many students have confused these two cells under assessment conditions and named them the other way around. With this in mind, remember to always use the presence of a clear nucleus as the determining factor between a cell in interphase and a cell in prophase.

**Using key terminology**

VIDEO 3B–3
SKILLS: USING KEY TERMINOLOGY

When describing the phases of the cell cycle, it is important to use precise key terminology, and not oversimplify your language. Take the following question, for example:

*Question*: Describe the event(s) that occur in metaphase.

*Answer*: Chromosomes line up down the middle of the cell.

While this is not wrong, the language used is not specific enough for the level of detail expected in VCE. A more accurate answer would be:

*Answer*: The double chromosomes line up along the metaphase plate/equator of the cell.

Let's try another one, this time using the S phase.

*Question*: Describe the events that occur in the S phase of the cell cycle.

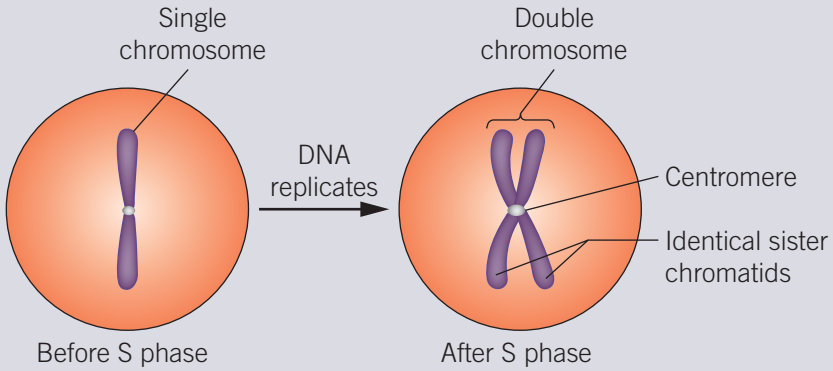
*Answer*: DNA replicates.

Again, this answer is not nearly technical enough for VCE level. A suitable response would be:

*Answer*: DNA replicates, resulting in the transformation of a single chromosome into a double chromosome that contains two identical sister chromatids held together by a centromere.

*Note:* Remember, chromosomes are not actually visible in the S phase. It is just easier to discuss the transformation that occurs in the context of chromosomes.

Keep in mind that a clearly labelled diagram would also be an acceptable response to either of these questions. For example:




ISBN 978-1-108-88711-3

## Section 3B questions

**1** Complete the table by indicating the phase in which each event occurs.

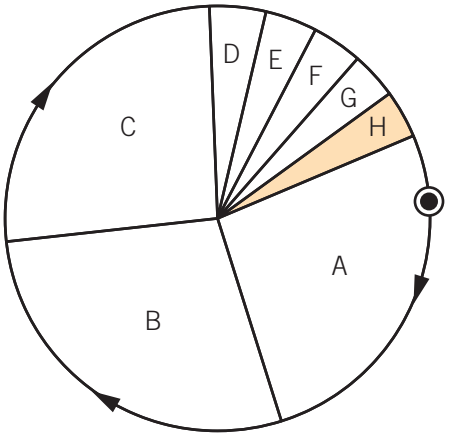
| Event | Interphase | Mitosis |
|---|---|---|
| Cell grows. | | |
| Nucleus divides. | | |
| Chromosomes are distributed equally to daughter cells. | | |
| Protein production is high. | | |
| Chromosomes are duplicated. | | |
| DNA replicates. | | |
| Cytoplasm divides immediately after this stage. | | |
| Mitochondria and other organelles are made. | | |

**2** Number the following parts of the cell in order of size. Use 1 for smallest and 5 for largest.

Nucleotide Chromatin Nucleus Chromosome Cell

**3** The diagram shows the stages of the cell cycle in a somatic cell, but the labels have been replaced with letters A to H. Identify the stage(s) that make up:

**a** interphase
**b** S phase
**c** M phase.




**4** The chromosome shown here was present in a cell prior to S phase. Draw what this chromosome would look like in the prophase stage of mitosis.

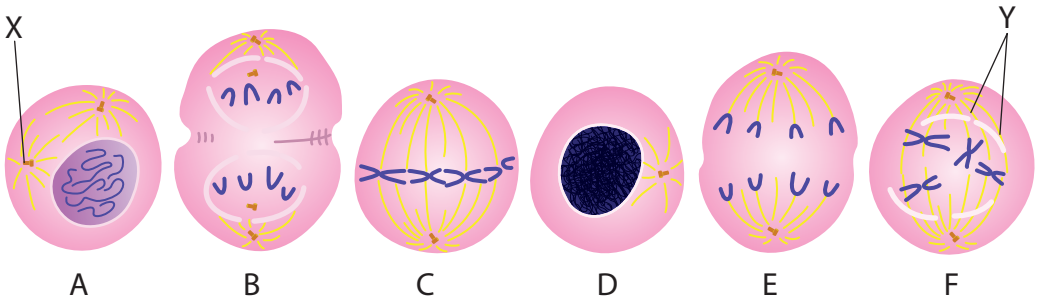
ISBN 978-1-108-88711-3

**5** Skin cells undergo mitosis regularly in order to repair and maintain damaged or old cells.

- **a** If one skin cell undergoes four mitotic divisions, how many daughter cells will this produce?
- **b** If there are 15 centromeres within the nucleus of a skin cell, how many chromosomes are there?
- **c** If a skin cell had 92 chromatids at the beginning of mitosis, how many chromosomes would this cell have at the completion of cytokinesis?
- **d** DNA mass is measured using a unit known as a picogram ($10^{-12}$ of a gram). If a cell was found to have a mass of 9 picograms following cytokinesis, how much DNA would the cell have at the end of S phase?

**6** Interphase is often referred to as the 'resting phase' of the cell cycle. Is this is an accurate description of interphase? Justify your answer, by referring to the events that occur in the three subphases of interphase.

**7** The stages of mitosis shown here are not in the correct order. Use these diagrams to answer the questions below.



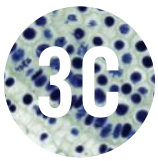

- **a** Which cell is in metaphase?
- **b** Cells A and F show an early and late stage of the same subphase of mitosis. What subphase is it?
- **c** In cell A, what is the structure labelled X?
- **d** In cell F, what is the structure labelled Y?
- **e** Which cell is not in a phase of mitosis?
- **f** What two main changes are taking place in cell B?
- **g** List the diagrams A to F in the correct order of events that occur in the cell cycle. In your answer, include a description of the main events that occur in each stage.
- **h** What is the end product of mitosis?

**8** Use your knowledge of the cell cycle and neurons to explain why damage to the spinal cord in quadriplegics is difficult to treat.

**9** **a** Draw a fully labelled diagram outlining the key events in the replication of prokaryotic cells.

- **b** What is the name of the process you drew in part **a**?
- **c** Compare the replication of prokaryotic and eukaryotic cells.

ISBN 978-1-108-88711-3




# Cell cycle regulation and apoptosis

**Study Design:**

- Apoptosis as a regulated process of programmed cell death
- Disruption to the regulation of the cell cycle and malfunctions in apoptosis that may result in deviant cell behaviour: cancer and the characteristics of cancer cells

**Glossary:**

Angiogenesis
Apoptosis
Apoptotic bodies
Benign
Bleb
Cancer
Caspases
Cell cycle checkpoints
Culture
Extrinsic pathway
G1 checkpoint
G2 checkpoint
Intrinsic pathway
Kinetochore
M checkpoint
Malignant
Metastasis
Necrosis
p53 protein
Phagocytic cell
Regulatory proteins
Tumour

## ENGAGE

### Vaccinating against cancer

Did you know that the world's first cancer vaccine was developed in Australia? Professor Ian Frazer led a team of researchers at the University of Queensland in developing a world-first vaccine against cervical cancer. Professor Frazer's work explored the relationship between the human papilloma virus (HPV) and its links to a range of cancers in both women and men.

UNIT 4 LINK

Cervical and other HPV-related cancers are one of the few human cancers known to be the direct result of a viral infection. The vaccine mimics proteins found on the surface of the virus. When the vaccine is administered, the individual's immune system responds by producing a protective protein known as an 'antibody'. If a vaccinated individual is exposed to the real form of HPV, then these antibodies will prevent the virus from infecting cells, which is known to cause DNA mutations that result in cancer.

**Figure 3C–1** Professor Ian Frazer at work in a biomedical laboratory. The cervical cancer vaccine his team developed has been shown to be 100% effective in preventing the most common form of cervical cancer.

In 2007 the Australian government added the HPV vaccine to the National Immunisation Program for girls, with boys being added to the program in 2013. In Victoria, the vaccine is routinely given to all Year 7 students, offering them almost 100% protection from nine strains of HPV. These strains are responsible for 90% of cervical cancers in women and

ISBN 978-1-108-88711-3

95% of HPV-related cancers in men. The significance of these results earned Professor Frazer the title of 2006 Australian of the Year.

In this section, you will learn about mechanisms in place that aim to prevent the development of cancerous cells. While previous sections of this chapter have focused on the important role of cell division in maintaining 'life', this section focuses on the importance of programmed cell death in the healthy development of an organism.

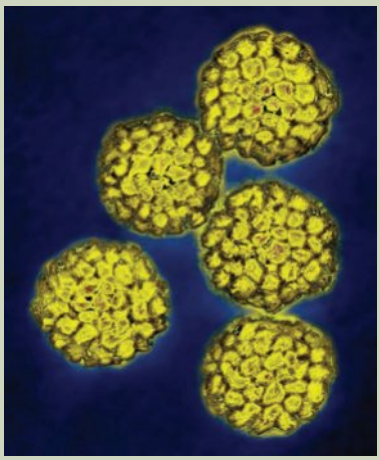


**Figure 3C–2** HPV viewed under a transmission electron microscope

## EXPLAIN

# Cell cycle regulation

LINK 3B THE CELL CYCLE

As you learned in Section 3B, the eukaryotic cell cycle consists of a series of stages resulting in the production of two genetically identical daughter cells. Cells progress through the cell cycle in a highly regulated way, and this process depends on a variety of internal and external signals. These incoming signals ensure that the division of cells occurs under favourable conditions that will only benefit the organism. This regulation is achieved through 'checkpoints' at various locations throughout the cell cycle.

**Cell cycle checkpoints** control points within the cell cycle that ensure accurate division of the cell

## Cell cycle checkpoints

**Cell cycle checkpoints** are the controlling factors that process internal and external signals before determining whether a cell can proceed to the next stage of division. Not only do these checkpoints monitor the proper division of cells, they also ensure that a compromised cell does not continue to divide and pass on its defects (damaged or mutated DNA) to the next generation. If conditions are not favourable or if cell defects are identified, the cell cycle can be halted until any issues are rectified.

There are many checkpoints throughout the cell cycle. This chapter focuses on the three most important ones, shown in Figure 3C–3.

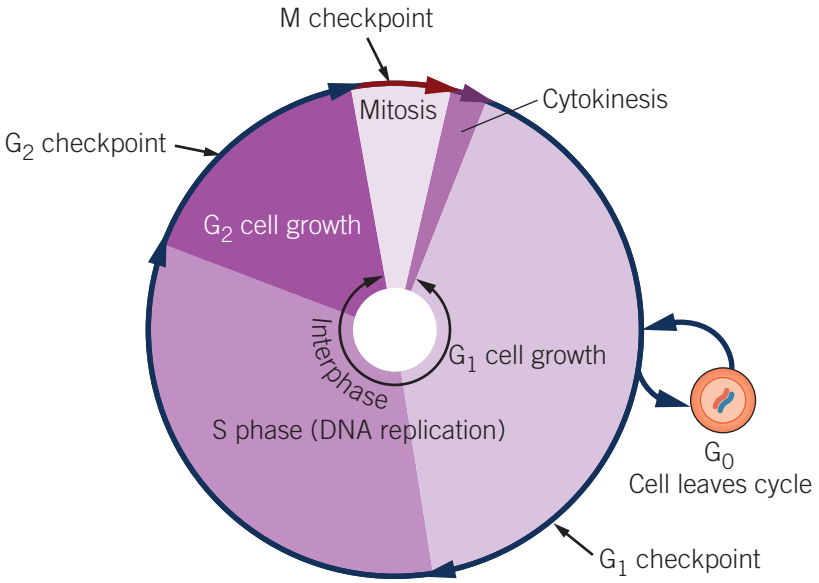



**Figure 3C–3** Checkpoints in the eukaryotic cell cycle

ISBN 978-1-108-88711-3

**G1 checkpoint** the first checkpoint of the cell cycle; commits the cell to the rest of the cycle

## G1 checkpoint

The **G1 checkpoint** (also referred to as the restriction point) checks for:

- cell size
- nutrient/energy stores
- DNA damage
- growth factors.

3B THE CELL CYCLE LINK

The G1 checkpoint is the first checkpoint of the cell cycle. It occurs at the transition of G1 into S phase and is the primary checkpoint of the cell. Its role is to ensure that all conditions are favourable for division, and it does this by monitoring a wide range of internal and external signals. For the cell to progress to the next phase of the cycle, it must be large enough to divide, have faultless DNA and enough nutrients and energy to sustain the cell through the division process. The G1 checkpoint also monitors the growth factor signals a cell is receiving. Growth factors are important in stimulating the onset of division and there must be enough of these signals present to drive the cell through the cycle.

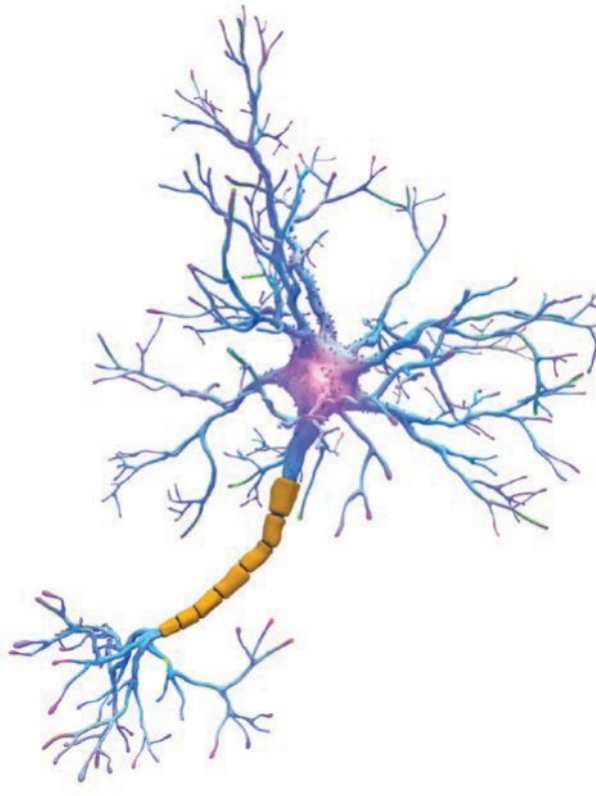


**Figure 3C–4** Neurons are an example of a cell that will pass into G0 even if undamaged. This state of arrest is permanent in neurons, meaning that they do not have the capacity to repair or replicate themselves.

If a cell fails to meet all these requirements, it will not progress to S phase. If this occurs, it will either attempt to rectify the error or pass into the G0 state of cell cycle arrest. If favourable conditions that will allow the cell cycle to progress do not eventuate, then the cell will remain in G0 permanently.

Receiving the 'all clear' from the G1 checkpoint will result in the cell irreversibly committing to the rest of the cell cycle. Only extenuating circumstances (such as replication errors) will prevent the cell from completing the cycle and producing two daughter cells.

## G2 checkpoint

The **G2 checkpoint** checks for:

- DNA damage
- DNA replication accuracy
- cell size.

**G2 checkpoint** the second checkpoint of the cell cycle; ensures the DNA is suitable for entry into mitosis

**Apoptosis** the systematic and controlled death of cells; occurs as a normal part of an organism's development (programmed cell death)

The G2 checkpoint is the second checkpoint of the cell cycle, occurring before the cell enters mitosis. At this checkpoint, cell size will again need to be deemed adequate for division. More importantly, the cell's DNA is assessed. Prior to the cell reaching the G2 checkpoint it will have undergone S phase, where the DNA has been replicated. The most important role of this checkpoint is to make sure that the cell's DNA has been accurately and completely copied without any damage.

If damage or errors are detected, then the checkpoint will halt the cell's progression through the cycle until DNA replication is completed or the damaged DNA is repaired. If the damage cannot be fixed, then the cell will be 'tagged' for destruction through a controlled process known as **apoptosis**. This will ensure that no faulty DNA is passed onto the next generation of daughter cells.

ISBN 978-1-108-88711-3

### M checkpoint

The **M checkpoint** (also known as the spindle checkpoint) checks for spindle attachment to chromosomes. It occurs in the mitosis portion of the cell cycle, specifically between the metaphase (hence the letter M) and anaphase subphases. Its role is to ensure that double chromosomes lined up along the metaphase plate of the cell are correctly attached to the spindle microtubules at their centromeres prior to the commencement of anaphase. The attachment of spindles to a chromosome's centromere gives rise to a complex known as a **kinetochore** (Figure 3C–5). Correct formation of the kinetochore is essential to the accurate separation of each double chromosome's sister chromatids during anaphase.

Rather than check for the correct formation of a kinetochore in all chromosomes, the M checkpoint scans the cell for any loose chromosomes not in the correct position. If such chromosomes are identified, the cell will cease mitosis, giving the spindle microtubules time to attach to the deviant chromosome and align it correctly along the metaphase plate. Once the chromosome is aligned, anaphase will proceed, resulting in the formation of two healthy daughter cells. If alignment does not occur, then the cell will undergo apoptosis to prevent errors being passed on to the next generation of cells.

**M checkpoint** the final cell cycle checkpoint; ensures that spindle microtubules are correctly attached to chromosomes

**Kinetochore** a complex of proteins that assembles on the centromere and to which spindle microtubules attach during mitosis

**Regulatory proteins** a group of proteins that operate at cell cycle checkpoints to allow healthy cells to progress in the cycle

## Checkpoint proteins

Now that you know what the major cell cycle checkpoints do, it is important to understand that the checkpoints work in highly complex ways. Inside each cell is a core set of **regulatory proteins** that form the cell cycle control system. These proteins keep the cell cycle steps in order, allowing the cell to operate normally. They do this by responding to internal and environmental signals. Under normal circumstances, signals will activate the regulatory proteins, causing the cell to progress in the cycle. However, if a problem arises, the regulatory proteins will become inactive and block the progression of the cell to the next stage of the cycle.

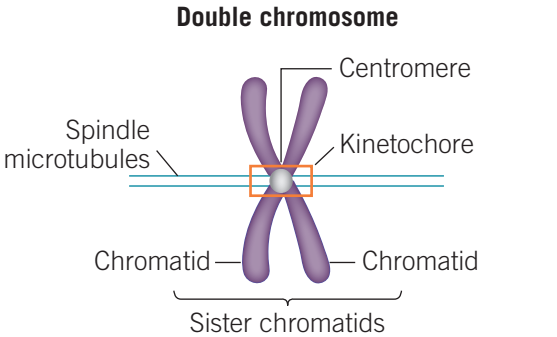



**Figure 3C–5** Each chromosome's kinetochore must consist of a centromere anchored to at least two spindle fibres that arise from opposite poles within the cell. This will ensure correct separation of the sister chromatids to each pole.

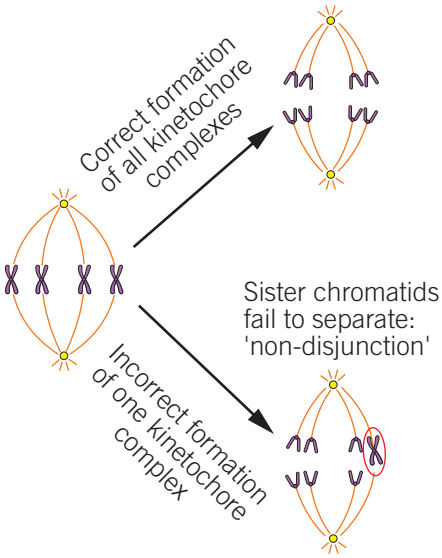



**Figure 3C–6** The mitotic checkpoint checks that all kinetochore complexes have correctly formed during metaphase, and so it allows the cell to progress into anaphase where sister chromatids are separated.

ISBN 978-1-108-88711-3

## Check-in questions – Set 1

1 What is a checkpoint?
2 Draw a diagram that indicates the location of each cell cycle checkpoint. Annotate the diagram to show the function of each checkpoint.
3 What does the cell cycle control system consist of?

## Apoptosis: programmed cell death

Apoptosis, or programmed cell death, is a highly controlled process that results in a eukaryotic cell committing 'cellular suicide'. While the death of cells does not sound like it would be good for an organism, it is in fact extremely important in maintaining the overall health and balance of the organism.

### The role of apoptosis

UNIT 4 LINK

Apoptosis performs three key functions within a eukaryotic organism.

#### Protection

As you know, the cell cycle checkpoints can halt the progression of a cell through the cycle if they detect that the cell is faulty. While the cell is given an opportunity to rectify the issue, if it cannot fix the problem it will be tagged for destruction and apoptosis will commence. This ensures that unhealthy or damaged cells do not divide and pass on their defect to the daughter cells. It also helps in the removal of cells that may become cancerous, which is discussed in detail later in this chapter.

Apoptosis is also crucial for our immune system. When cells infected with viruses are identified and destroyed through apoptosis, the viral infection can be contained and the threat to the organism eliminated.

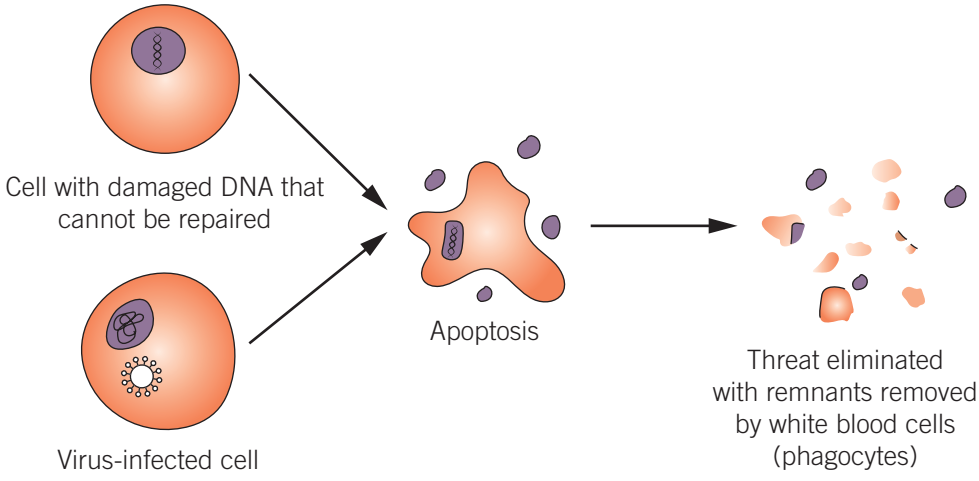



**Figure 3C–7** Apoptosis ensures that any cells that pose a threat to the health of an organism are destroyed so that they cannot divide and pass on their flaw to the next generation.

ISBN 978-1-108-88711-3

### Development

LINK 3A WHERE DO NEW CELLS COME FROM?

Apoptosis is also important in the normal development of an organism. For instance, during embryonic development, hands and feet start out as blocks of tissue. For fingers and toes to form, apoptosis must act to 'sculpt' these blocks by removing the webbing between digits, resulting in the formation of distinct fingers and toes. If apoptosis fails to occur, the fingers and toes remain fused together, a condition known as syndactyly.

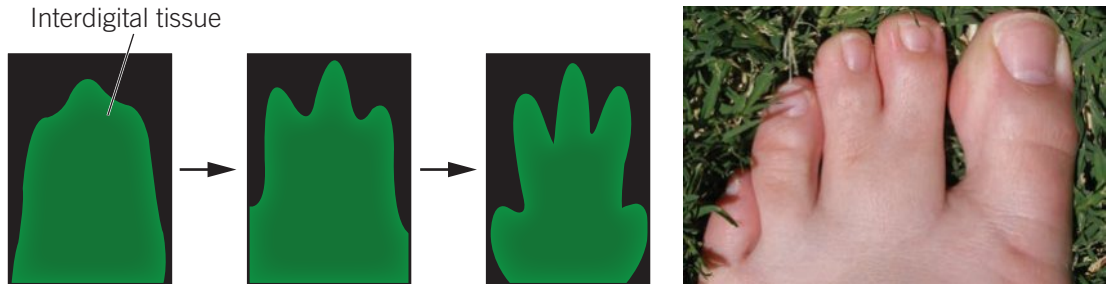



**Figure 3C–8** Left: Formation of the human hand through the process of apoptosis. Right: Webbing between the second and third toes failed to dissolve during development.

Below is a list of some other developmental features that apoptosis is responsible for:

- the removal of a tadpole's tail as it undergoes metamorphosis to become a frog
- the shedding of a female's uterus lining at the beginning of her menstrual cycle
- the removal of immune cells that could attack healthy cells that belong to the organism
- the elimination of excess neurons to allow for proper synaptic connections to form between neurons in the brain.

### Balance

Apoptosis assists an organism to maintain balance. Old cells that need to make way for new cells, or cells that are needed only for a temporary role, are removed through apoptosis. This ensures that organs and tissues retain their desired size and that unnecessary cells don't create 'traffic' within the organism and slow down important reactions that sustain life.

## Apoptosis in action

For a cell to undergo apoptosis, it must receive the correct combination of signals from its internal and external environment. The signals that all cells receive can be classified into two broad categories:

- *positive signals* – necessary for the continued survival of a cell
- *negative signals* – indicate the need to activate the apoptosis pathway.

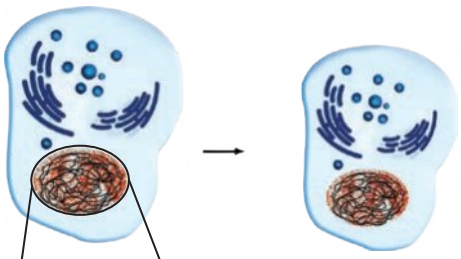
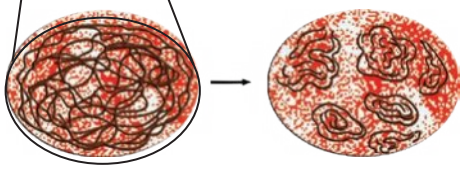
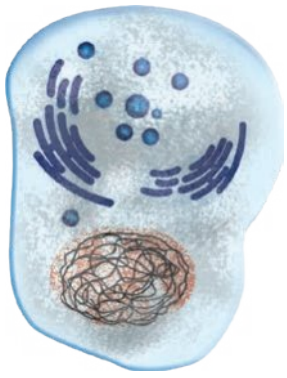
Ultimately, what will make a cell commit suicide is not only the receipt of negative signals but also the withdrawal of the positive signals it would usually receive.

The correct combination of signals will result in the cell entering apoptosis. The apoptosis pathway is a highly controlled, orderly set of steps that results in the neat packaging of the cell into small membrane-bound structures that are then engulfed and disposed of by phagocytic immune cells. A step-by-step account of the apoptosis pathway is given in Table 3C–1.

LINK UNIT 4

ISBN 978-1-108-88711-3

**Table 3C–1** The execution pathway of apoptosis

| Execution pathway step | Summary of event | Diagram |
|---|---|---|
| 1 | The cell responds to signals that trigger apoptosis and it begins to shrink. |  |
| 2 | Chromatin inside the cell's nucleus is irreversibly condensed, DNA fragments. |  |
| 3 | A class of enzymes known as **caspases** are activated. A specific type of caspase breaks down the mitochondria, which releases a protein complex known as cytochrome c.<br>The release of these proteins is an important step in the initiation of the rest of the process.<br>(Cytochrome c is an important part of aerobic cellular respiration). |  |
| 4 | The release of cytochrome c activates other caspase enzymes which commence the breakdown of the nucleus and other organelles.<br>This triggers the release of stress signals that attract **phagocytic cells**. |  |

**Caspases** a class of protease enzymes that cleave (cut up) proteins; referred to as 'executioners' because they bring about the cascade of reactions that destroy the cell

UNIT 4 LINK

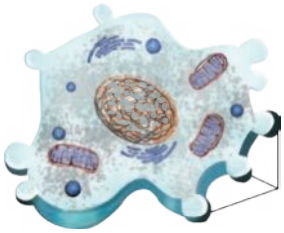
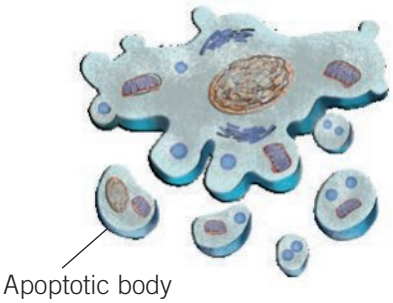
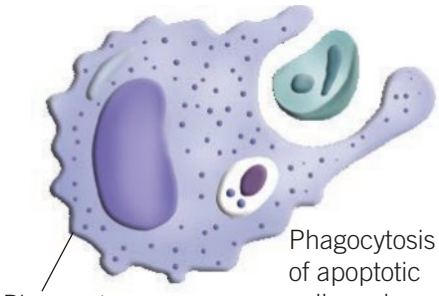
UNIT 3 LINK

**Phagocytic cell** a white blood cell of the immune system that engulfs and disposes of unwanted structures, such as dying cells

UNIT 4 LINK

ISBN 978-1-108-88711-3

**Table 3C–1** *Continued*

| Execution pathway step | Summary of event | Diagram |
|---|---|---|
| 5 | Bubble-like structures, known as **blebs**, form on the membrane of the cell. |  Membrane blebs |
| 6 | The cell cytoskeleton breaks up, resulting in the blebs forming membrane-bound vesicles known as **apoptotic bodies**.<br>These bodies contain the cell's cytoplasm and tightly packed organelles. |  Apoptotic body |
| 7 | Phagocytic immune cells are attracted to the area and act like a vacuum cleaner by 'engulfing' the apoptotic bodies.<br>*Note:* This step is not classified as part of the apoptosis pathway. Rather, it is the result of the release of the various signals throughout steps 1–6. |  Phagocyte Phagocytosis of apoptotic cells and fragments |

**Bleb**
a rounded structure that forms on the plasma membrane of a cell undergoing apoptosis

**Apoptotic bodies**
membrane-bound vesicles that contain the intracellular contents of an apoptotic cell

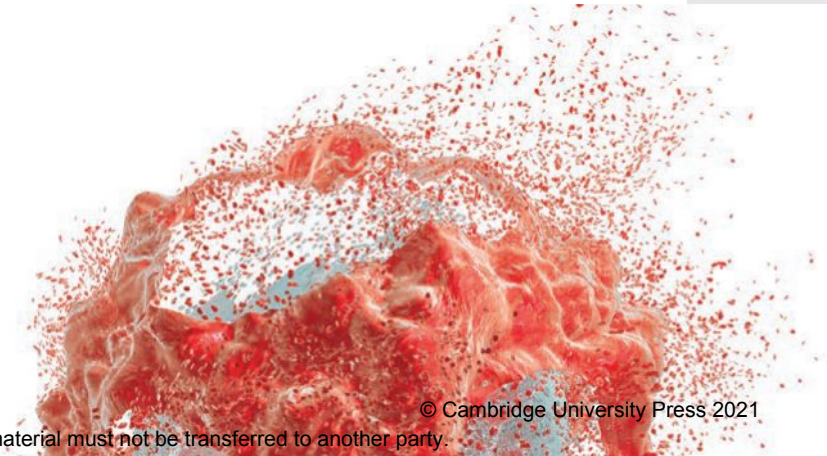
LINK **2A** THE NATURE OF SUBSTANCES AND THEIR MODES OF TRANSPORT

## Apoptosis pathways

There are two major types of apoptosis pathways. Which pathway a cell will follow is determined by the location of the signal that initiates apoptosis. An internal signal will result in the activation of the **intrinsic pathway**. On the other hand, an external signal will activate the **extrinsic pathway**. (*Think of intrinsic as 'interior' and extrinsic as 'exterior'.*) Regardless of where the signal comes from to initiate apoptosis, most of the two pathways and the end result are always the same: the systematic and complete destruction of the cell, and the recycling of its material.

**Intrinsic pathway**
the apoptosis pathway activated by an intracellular signal

**Extrinsic pathway**
the apoptosis pathway activated by an extracellular signal



ISBN 978-1-108-88711-3

### Intrinsic pathway

The intrinsic apoptosis pathway is activated when intracellular stress signals are received by the mitochondria. Stress signals may be the result of radiation or toxic chemicals damaging the cell's DNA or proteins. The absence of important growth factors can also initiate the release of stress signals.

In a healthy cell, the mitochondrial membrane contains a specific regulatory protein (Bcl-2) that inhibits apoptosis. Upon receipt of an intracellular stress signal, another type of protein (Bax) moves to the mitochondrial membrane, inserting itself into it and puncturing holes as a result. Cytochrome c leaks into the intracellular space, triggering the activation of caspase enzymes. The end result of the pathway is the formation of apoptotic bodies, the final step in the destruction of the cell.

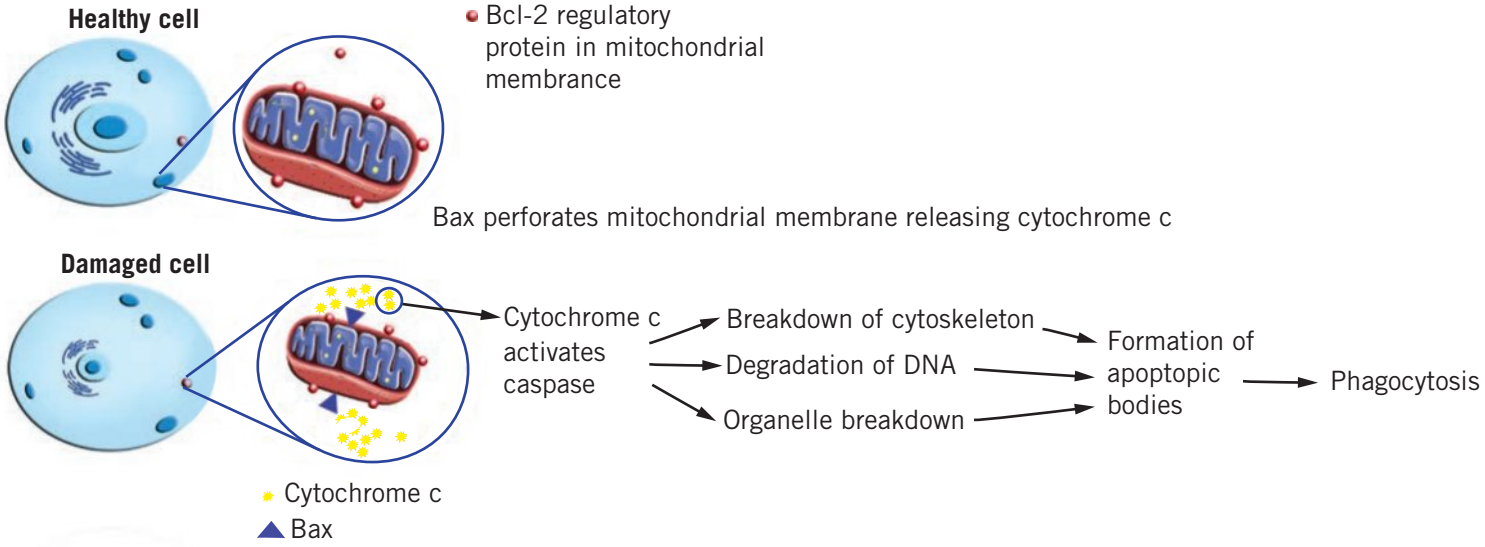



**Figure 3C–9** The intrinsic pathway of apoptosis

### Extrinsic pathway

UNIT 4 LINK

The extrinsic apoptosis pathway is activated in response to external signals that bind to 'death' receptors on the plasma membrane of the target cell that is to be destroyed. The death signal may be the result of extreme heat exposure but usually the cell is diseased and, for that reason, the extrinsic apoptosis pathway is an important aspect of our immune defence.

The binding of the external signal to the 'death' receptors on the surface of the cell's plasma membrane results in the transmission of the death signal through the cytoplasm. Once the signal is detected by the caspase enzymes, they control the cell through the rest of the apoptosis pathway. This occurs in the same manner as the intrinsic pathway, beginning with the release of cytochrome c from the mitochondria and ending with the formation of apoptotic bodies.

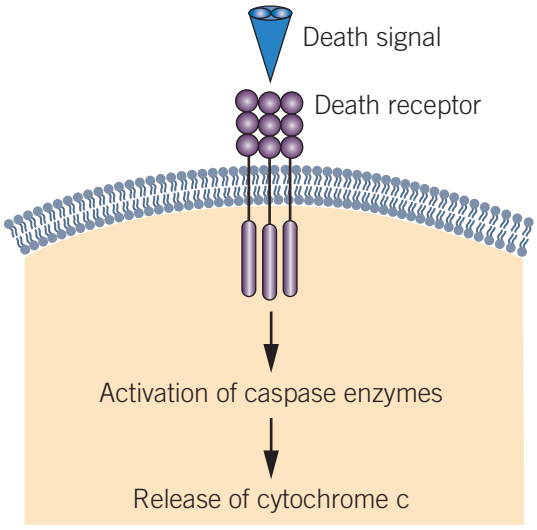



**Figure 3C–10** The extrinsic pathway of apoptosis is initiated by an external signal; after the release of the caspase enzymes, it is the same as the intrinsic pathway.

WORKSHEET 3C–1 APOPTOSIS: PROGRAMMED CELL DEATH

ISBN 978-1-108-88711-3

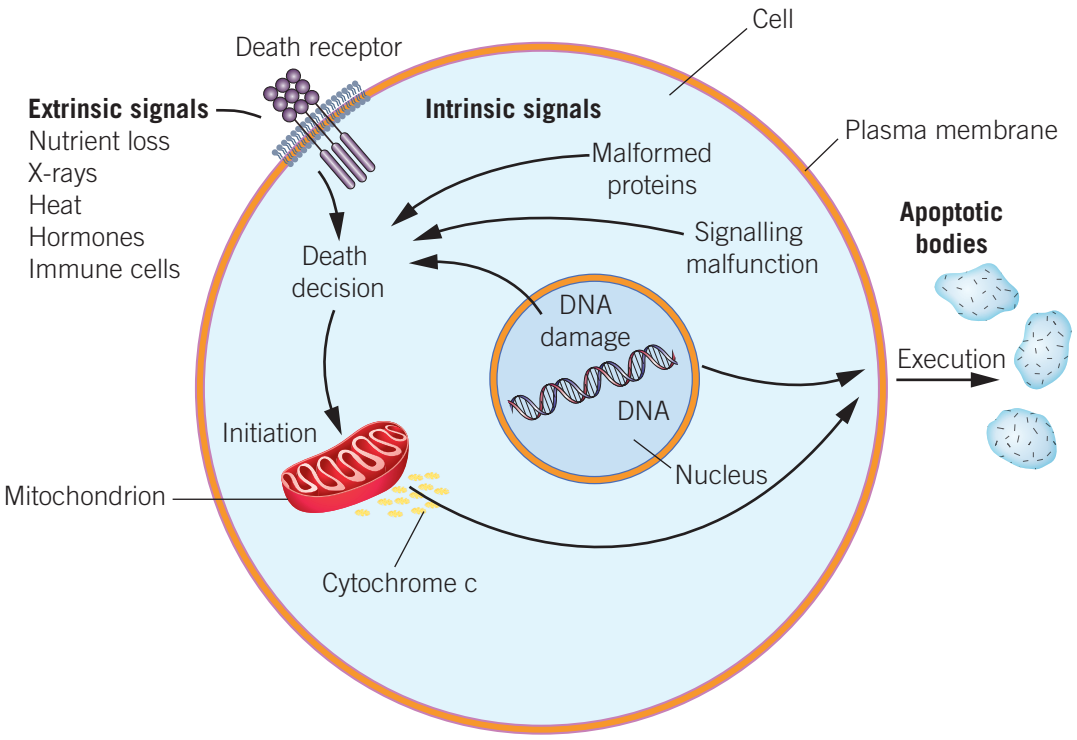



**Figure 3C–11** A summary of the signals that result in the pathways that lead to apoptosis. Initiation occurs when the mitochondria release cytochrome c, and execution is the packaging of cellular organelles and cytoplasm into apoptotic bodies engulfed by phagocytic cells.

## Necrosis: premature (unprogrammed) cell death

Apoptosis is not the only cause of cell death within an organism. **Necrosis** is the name given to cell death that occurs as a result of trauma or injury. Unlike apoptosis, necrosis is not controlled and results in the swelling of the cell before it bursts, causing a messy spillage of cellular contents into the surrounding extracellular space. This uncontrolled spillage causes inflammation, which is detrimental not only to cells in neighbouring tissue, but also to the health and wellbeing of the organism.

**Necrosis**
cell death as a result of trauma or injury

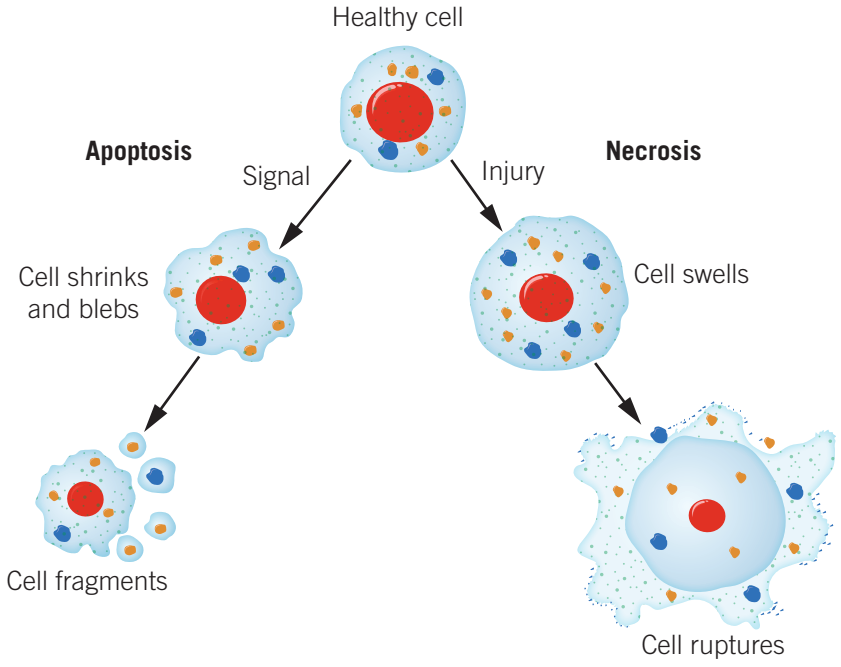



**Figure 3C–12** Simplified comparison of apoptosis and necrosis. If apoptosis is referred to as cell 'suicide', then necrosis would be known as cell 'homicide'.

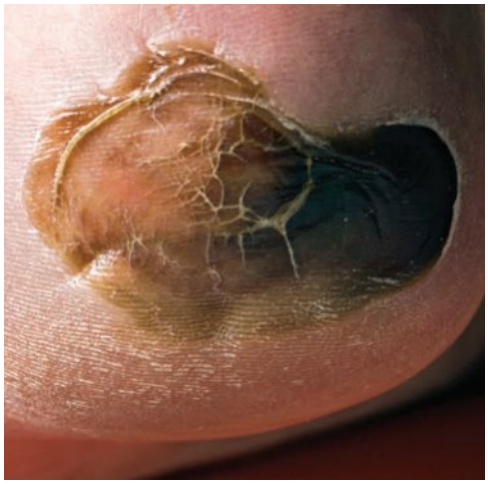


**Figure 3C–13** This gangrene on the heel of a foot is the result of necrosis.

ISBN 978-1-108-88711-3

## Check-in questions – Set 2

1 Define 'apoptosis'.
2 Identify the situation that would lead to the activation of the intrinsic pathway instead of the extrinsic pathway.
3 Why is necrosis referred to as 'messy' cell death?

## Cell cycle malfunction and apoptosis

Earlier in this chapter, you learned about the role of cell cycle checkpoints in preventing damaged or unhealthy cells from dividing and forming a generation of defective cells. At each of these checkpoints are regulatory proteins that respond to cellular signals, halting the cell cycle if errors are detected.

A regulatory protein is only able to detect errors and halt the cell cycle if it is structurally sound. If it is damaged, it will no longer be able to detect errors that should lead to the onset of apoptosis. This damage may result in the malfunction of the cell cycle, the division of defective cells and the possible onset of cancer.

### The p53 protein: a master regulatory protein

**p53 protein** a regulatory protein that is vital to the division of healthy cells

The **p53 protein** is a regulatory protein that operates at the G1 and G2 cell cycle checkpoints. Its role is to detect damaged DNA within a cell prior to the cell reaching mitosis and dividing. In healthy cells, p53 protein levels are low but in cells with damaged DNA, p53 protein levels increase, for three major purposes:

- halting of the cell cycle
- enzyme repair of DNA
- activation of apoptosis.

Damage to the p53 protein will result in an abnormal protein that can no longer perform the three purposes outlined above. This will result in the division of cells with damaged DNA and the rapid accumulation of mutated cells within the organism, which can lead to cancer (see Figure 3C–15). Many skin cancers are the result of UV radiation in sunlight affecting the correct expression of p53 proteins. The abnormal p53 proteins within the patient are unable to fix damaged DNA or trigger apoptosis, and this has results in cancer, as shown in Figure 3C–15. For the cancer to develop, it must shut down the activity of the p53 protein.

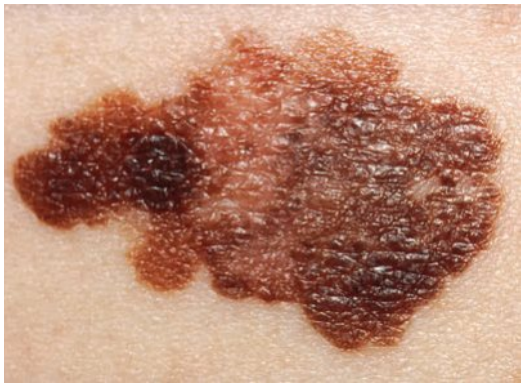


**Figure 3C–14** Top: Many factors can disrupt the cell cycle and its regulatory proteins. Environmental factors such as UV radiation can cause skin cancer. Bottom: When actor Angelina Jolie learned that she had a genetic predisposition to breast cancer, she chose to have a double mastectomy as a preventive measure.

#### Causes of regulatory protein malfunction

8B INTRODUCTION TO GENETICS LINK

UV radiation is not the only environmental factor that can result in the production of abnormal regulatory proteins. Cigarette smoke and prolonged exposure to pollution are both known to cause cancer as a direct result of regulatory protein dysfunction. Age and genetics also play a role in the effectiveness of these proteins throughout the cell cycle checkpoints.

ISBN 978-1-108-88711-3

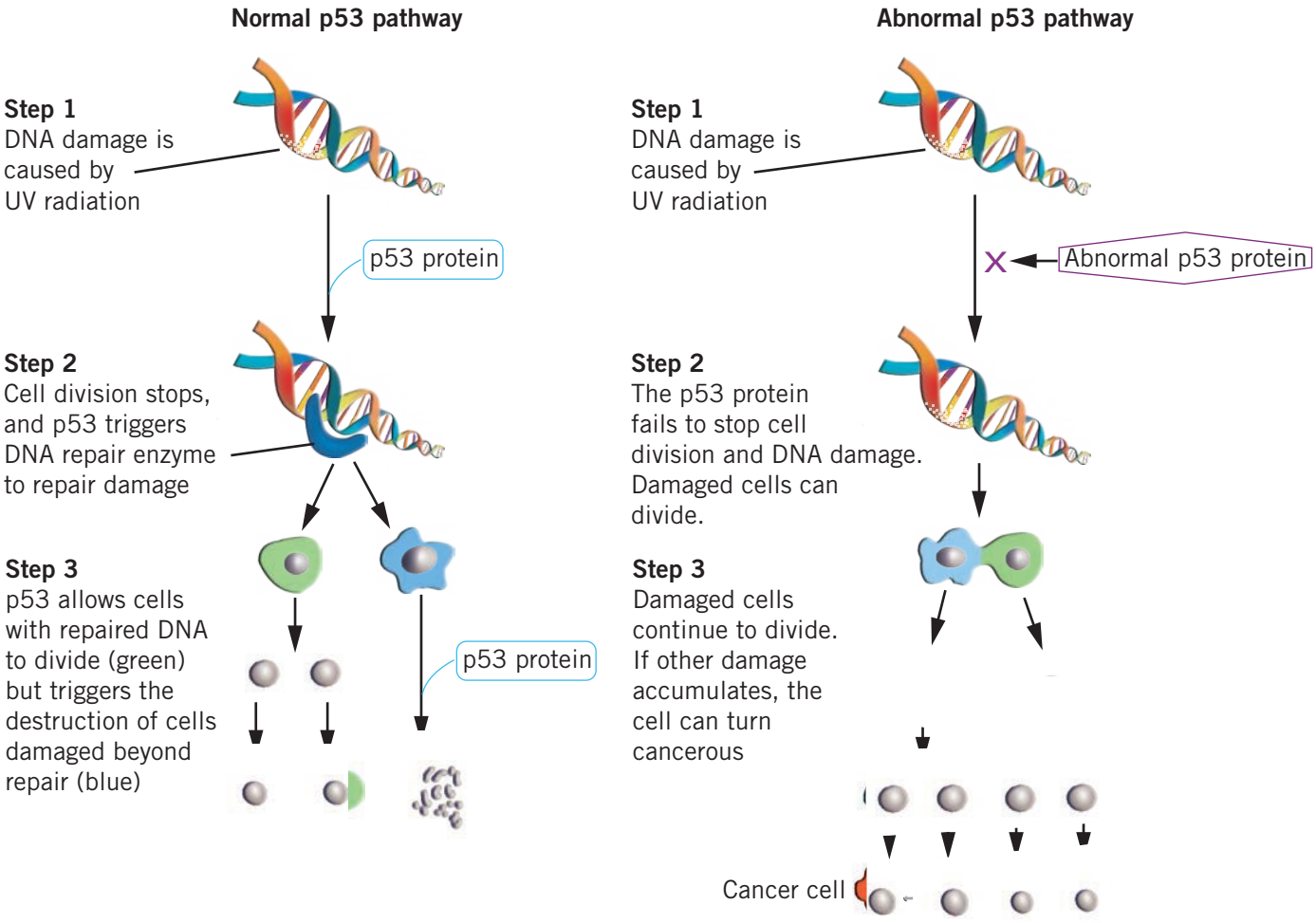



**Figure 3C–15** The action of the p53 master regulatory protein. This is one example of proteins that work to keep the cell cycle operating correctly.

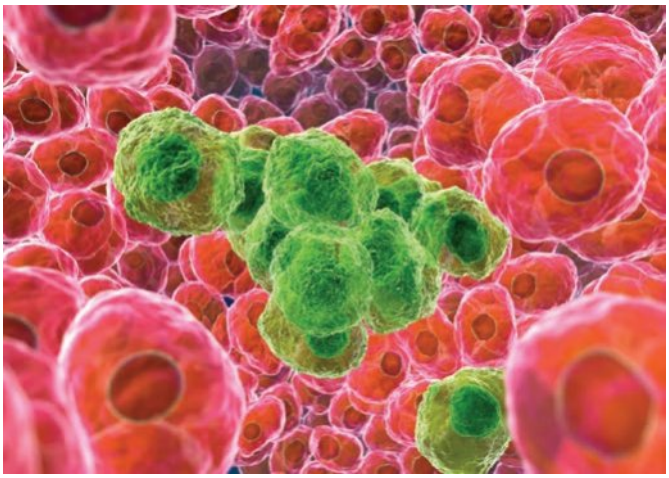


**Figure 3C–16** Cancer cells (green) surrounded by normal cells (pink). Cancer cells clump to form tumours that invade and destroy surrounding tissues. The first tissue they invade determines the type of cancer a patient will suffer from.

## Cancer and the cell cycle

**Cancer** is a disease that occurs as a result of uncontrolled cell division. In Australia, it is expected that around 150 000 new cases of cancer will be diagnosed each year. One in two Australians will be diagnosed with cancer by the age of 85, with prostate, breast, bowel, skin and lung cancers being the most common types, accounting for 60% of Australian cancer diagnoses.

**Cancer**
a disease that is the result of uncontrolled division of abnormal cells

**VIDEO 3C–1**
DEVIANT CELL BEHAVIOUR: CANCER

ISBN 978-1-108-88711-3

## Cancer development

Through the cell cycle, defective cells are given the opportunity to correct themselves but if this cannot be done, then regulatory proteins will initiate apoptosis, resulting in the destruction of the cell. For cancer to develop, regulatory proteins must be faulty or defective cells must acquire mechanisms that allow them to bypass the protective measures of regulatory proteins. For this reason, cancer is thought to develop through a series of progressive steps rather than in one immediate action.

UNIT 4 LINK

**Tumour**
an abnormal tissue mass that is the result of uncontrolled cell division

**Benign**
not cancerous; will not spread to surrounding tissue

**Malignant**
cancerous; can spread to surrounding tissue or elsewhere in the body

Cells can become cancerous through the development of a series of mutations that occur in DNA. These mutations allow a faulty cell to pass through checkpoints undetected. This leads to the increased division of subsequent generations of faulty cells and the potential for a **tumour** to form. Initially, this tumour may be classed as **benign** as it does not have the ability to invade neighbouring tissue, but further mutations in the DNA of tumour cells could further increase cell division, resulting in the formation of a **malignant** tumour. Cells that make up a malignant tumour have the capacity to invade neighbouring tissue and impair the function of organs throughout the body. It is at this point that the cells are classed as cancerous.

As a tumour progresses, the accumulation of DNA mutations becomes greater and occurs more quickly. Research suggests that cancer cells may possess as many as 60 different DNA mutations. Individuals who are in the late stages of cancer will have significant changes in their genomes, including the complete loss of some chromosomes.

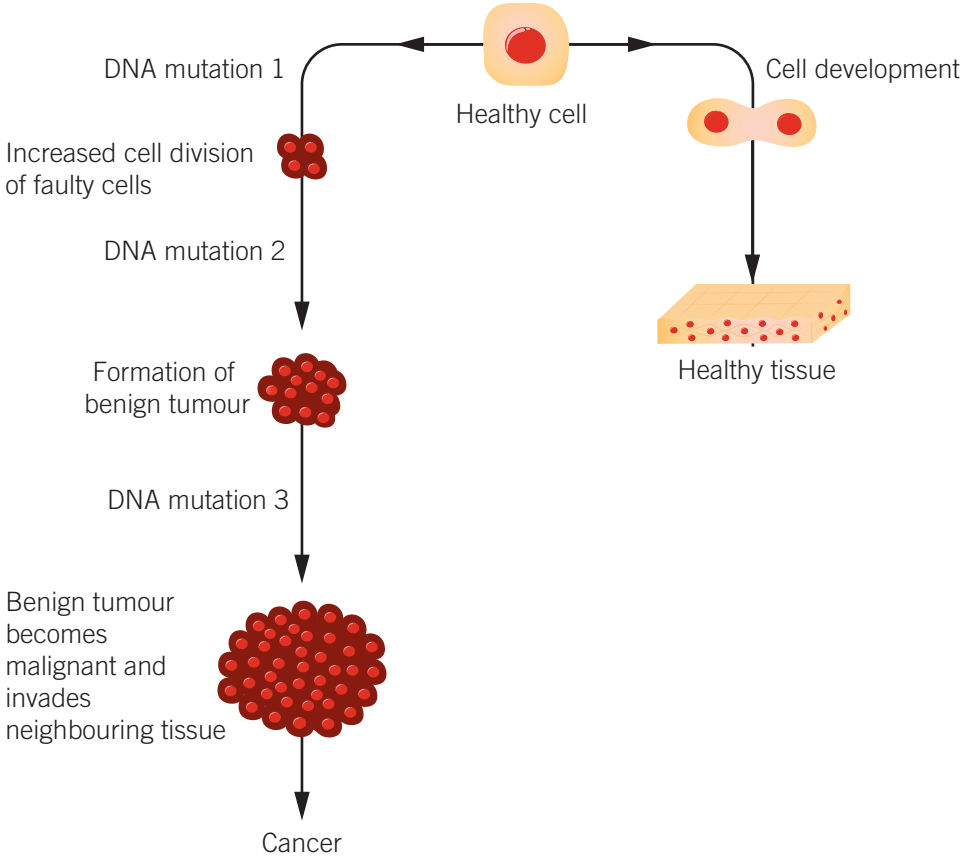



**Figure 3C–17** The development of cancer is the result of a series of DNA mutations.

ISBN 978-1-108-88711-3

## Characteristics of cancer cells

In order to be classified as cancerous, cells must possess a range of specific characteristics. These are outlined in Table 3C–2.

**Table 3C–2** Characteristics of cancer cells

| Characteristic | Explanation |
|---|---|
| Do not require growth factor signals | Cancer cells are capable of dividing rapidly outside the body in **culture**. This shows that the presence of growth factor signals is not needed for cancer cells to divide, unlike healthy cells, which do require growth factor signals. |
| Random arrangement of cell layers | Healthy cells form tissue through the uniform arrangement of cells. When normal cells become crowded, they stop dividing, but cancer cells do not stop; they continue dividing and form lumpy layers of cells (tumours). |
| Increased division | A healthy cell is thought to divide about 50 times before it is worn out. Cancer cells divide many more times and much more frequently than a typical healthy cell. |
| **Metastasis** | Cancer cells are able to enter the bloodstream or lymphatic fluid and travel to a new area in the body. This results in secondary tumours and furthers the spread of the cancer. |
| **Angiogenesis** | Cancer cells can trick the body into growing new blood vessels, which give them a direct supply of oxygen and nutrients. |

**Culture** the growth of cells in a nutrient medium, e.g. agar

**Metastasis** the spread of cancer cells from their point of origin to a new location in the body

**Angiogenesis** the formation of new blood vessels

There are also a range of structural features that are visible in cancer cells. These are shown in Figure 3C–18.

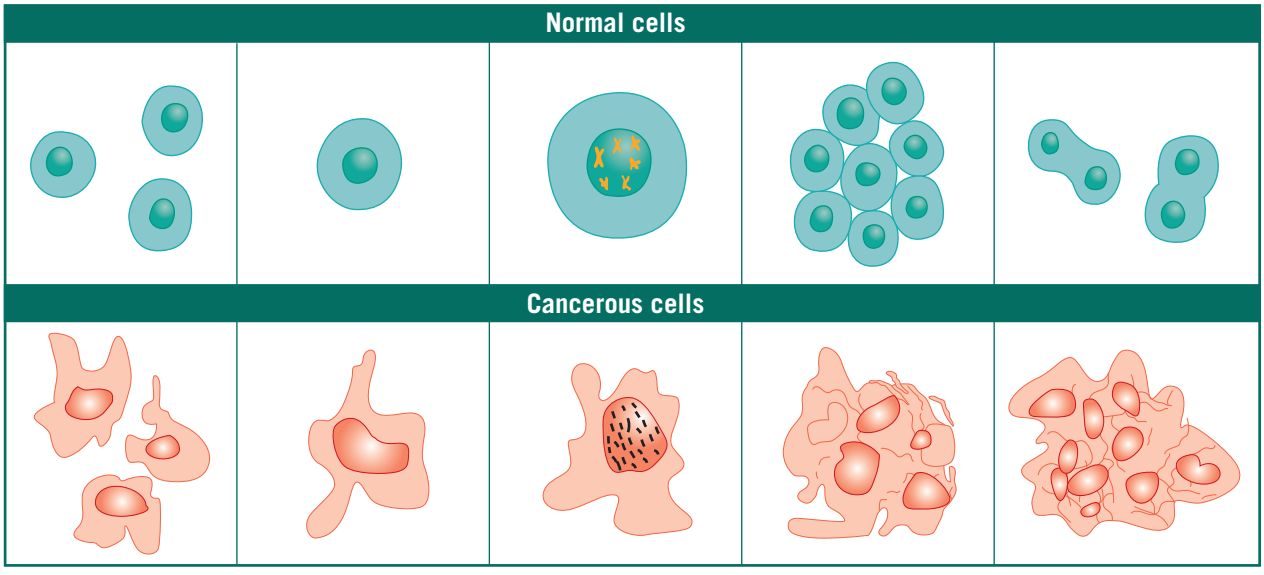



**Figure 3C–18** Structural characteristics of cancer cells

ISBN 978-1-108-88711-3

## Check-in questions – Set 3

1 Why is the p53 protein so important in the normal development of cells?
2 Identify three examples of factors that could limit the performance of a regulatory protein.
3 How do cancer cells differ structurally from normal cells?

## 3C SKILLS

**Diagrammatic representations of apoptosis stages**

Apoptosis is a highly complex process. It contains a series of complicated reactions, with many of these occurring simultaneously within the dying cell. For the purpose of VCE Biology, it is useful to simplify these reactions into a series of distinct stages. Rather than memorising chunks of complicated written information, it is also helpful to present each stage as a simple diagram organised into a flow chart, like the two examples shown on the next page.

*Suggested study tip:* Create a flashcard for each stage. Have a summary of the event on one side and the matching diagram on the other side of the card. Practise arranging the cards into the correct order. Alternate between using the written statements only, the diagrams only, and then a combination of both.

VIDEO 3C–2 SKILLS: INTRINSIC VS EXTRINSIC APOPTOSIS PATHWAYS

**Intrinsic vs extrinsic apoptosis pathways**

Another skill likely to be assessed is your ability to distinguish between the intrinsic and extrinsic pathways of apoptosis. When you are asked a question that relates to this topic, the first thing you should do is identify where the 'death' signal has originated from. If it began inside the cell, the intrinsic pathway will be in operation. If it started outside the cell, this would mean activation of the extrinsic pathway.

Extrinsic pathway tips:

- The extrinsic pathway is *always* activated by an external death signal. This signal binds to death receptors on the plasma membrane of the cell. From here, caspases are activated, which triggers a pathway that releases cytochrome c from mitochondria.
- Typically, the extrinsic pathway is activated by cells of the *immune system* acting to destroy:
  - viral infected cells
  - immune cells that are no longer needed (B plasma cells)
  - immune cells that may attack healthy cells needed by the organism (autoimmune disease).

UNIT 4 LINK

Intrinsic pathway tips:

- The intrinsic pathway is *always* activated by an internal signal. This signal triggers caspase activity, which releases cytochrome c from the mitochondria.
- The intrinsic pathway is activated when:
  - DNA is damaged
  - growth factor levels decrease or disappear completely.

Once the pathway has reached the mitochondria and released cytochrome c, the rest of the pathway, regardless of it being extrinsic or intrinsic, is *identical*.

ISBN 978-1-108-88711-3

Consider the following example:

*Question*: An external death signal is received by a cell. Describe two distinguishing features that make this pathway different from a signal that originates inside the cell.

*Answer:* The external signal was most likely from an immune cell that detected the presence of a viral infection. The death signal would interact with its corresponding death receptor on the plasma membrane of the diseased target cell. This would result in commencement of the apoptosis pathway.

The most important part of this response is the mention of the role of the plasma membrane receptor in receiving the signal. Mentioning the type of cell that released the signal and the reason that the signal was released takes the answer from being good to excellent.

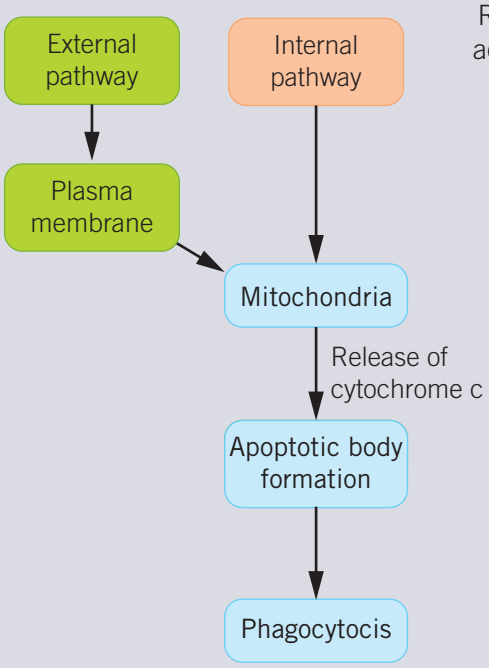



**Figure 3C–19** A simplified flow chart of apoptosis. Not all stages are shown.

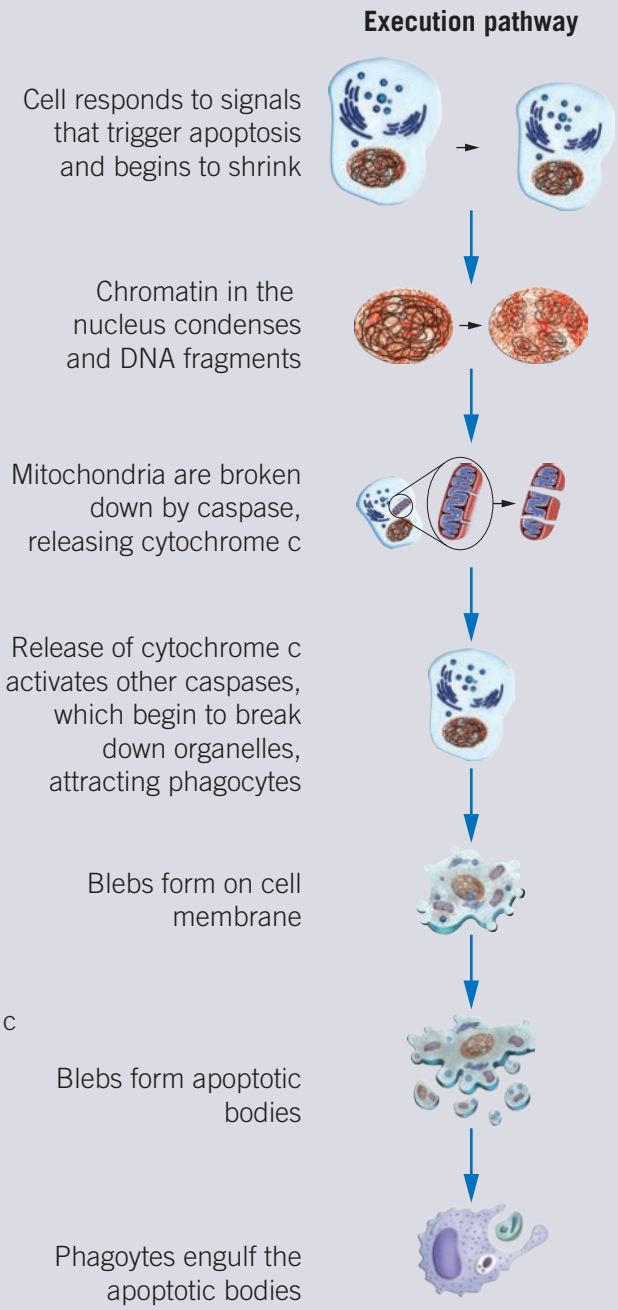



**Figure 3C–20** A flow chart, including diagrams, showing the stages of apoptosis

ISBN 978-1-108-88711-3

## Section 3C questions

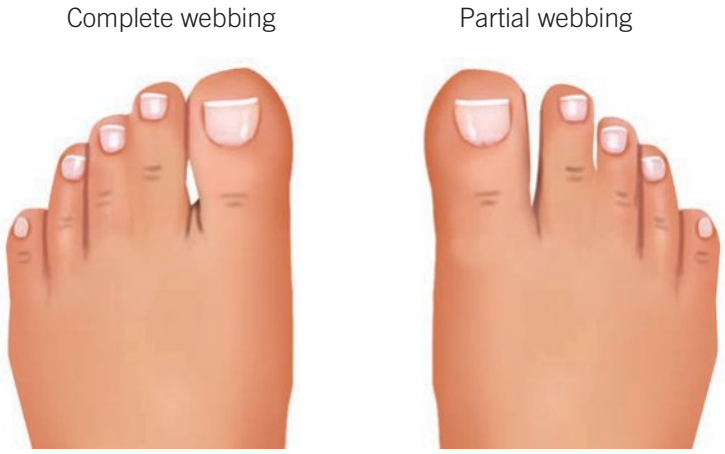
1 Identify the two ways in which a faulty cell could pass through cell cycle checkpoints undetected.

2 Why are caspases referred to as a 'cell's executioner'?

3 One of the main differences between apoptosis and necrosis is the lack of inflammation in the surrounding tissue of a cell that undergoes apoptosis. Explain why inflammation is a key feature of cell death via necrosis but is not present in cell death as a result of apoptosis.

4 Research has shown that the section of DNA (gene) responsible for the production of the p53 regulatory protein is the most highly mutated gene across all cancers. How does the mutation of this gene lead to the onset of cancer?

5 Syndactyly is a condition in which fingers or toes are fused. Individuals who have this condition may have complete or partial webbing between their digits.
Explain the biological malfunction that results in syndactyly.




6 Many types of drugs are used in treating cancer. Identify the phase of the cell cycle in which each of the following drugs would act. In your answer, explain how this action could help treat cancer.

a a drug that prevents DNA replication

b a drug that prevents the spindle microtubules from shortening

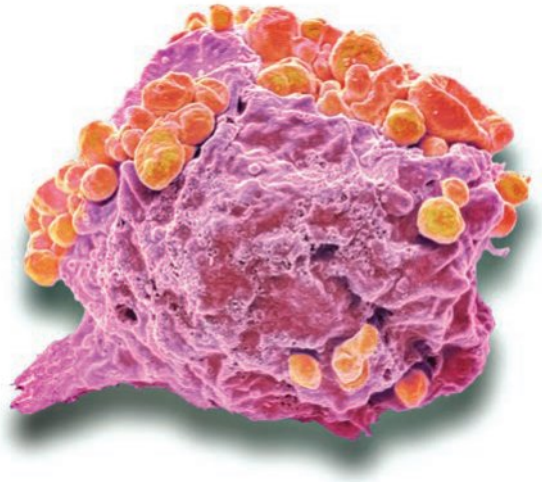
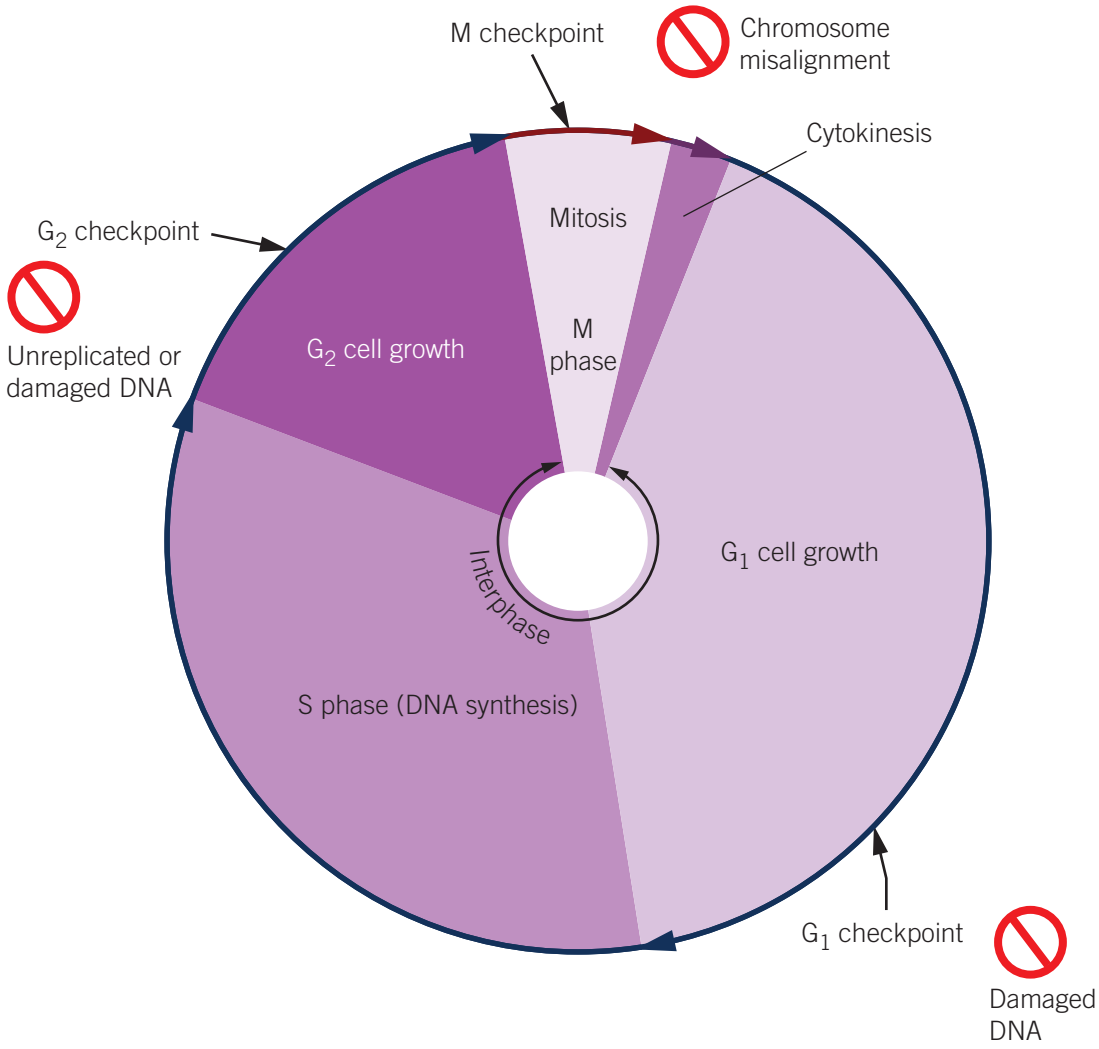


**Figure 3C–21** Coloured scanning electron micrograph (SEM) of a lymphoma cell showing early apoptotic changes.

ISBN 978-1-108-88711-3

**7** In the diagram of the cell cycle below, cell cycle checkpoints are identified with a prohibition sign. Which checkpoint in this diagram would be responsible for detecting a cell with genetic mutations prior to dividing? Explain your reasoning.




**8** Explain the importance of the plasma membrane in the activation of both the intrinsic and extrinsic apoptosis pathways. Use a diagram to help illustrate your answer.

ISBN 978-1-108-88711-3

# Chapter 3 review

## Summary

Create your own set of summary notes for this chapter, on paper or in a digital document. A model summary is provided in the Teacher Resources and can be used to compare with yours.

## Checklist

In the Interactive Textbook, the success criteria are linked to the review questions and will be automatically ticked when answers are correct. Alternatively, print or photocopy this page and tick the boxes when you have answered the corresponding questions correctly.

| Success criteria – I am now able to: | | Linked question |
|---|---|---|
| **3A.1** | Identify the key cellular stages of prenatal development from fertilisation to foetus (zygote, morula, blastocyst, gastrula, embryo and foetus) | 21☐ |
| **3A.2** | Define the key development terms: zygote, morula, blastocyst, gastrula, embryo and foetus | 21☐ |
| **3A.3** | Label the key features of a blastocyst and explain the significance of the inner cell mass in the development of an individual | 22b☐ |
| **3A.4** | Describe the role of stem cells in multicellular organisms | 22a☐ |
| **3A.5** | Explain the role of stem cells in the formation of the three primary germ layers | 22c☐, d☐ |
| **3A.6** | Identify the types of tissues that are generated by the endoderm, mesoderm and ectoderm within an organism | 3☐, 16a☐, c☐, d☐ |
| **3A.7** | Understand the concept of critical periods in the normal development of an embryo | 22e☐ |
| **3A.8** | Describe the properties of stem cells, including self-renewal and potency | 1☐, 15c☐ |
| **3A.9** | Distinguish between the different types of stem cells potencies (unipotent, pluripotent, multipotent and unipotent) | 2☐, 15b☐, 16b☐ |
| **3A.10** | Distinguish between embryonic, adult and induced pluripotent stem cells in terms of potency and the locations they can be sourced from | 15d☐ |
| **3A.11** | Describe the potential applications of each type of stem cell in regenerative medicine | 17☐ |
| **3A.12** | Describe the various ethical issues associated with the use of stem cells in medical and scientific research | 15e☐, 22f☐ |
| **3B.1** | Derive that all cells arise from pre-existing cells, through the cell cycle | 15a☐ |
| **3B.2** | Describe the role of mitosis in growth and repair | 12☐ |
| **3B.3** | Describe and diagrammatically represent the role of binary fission in prokaryotic asexual reproduction | 7☐, 13a☐, b☐, c☐ |
| **3B.4** | Recognise mitotic cell division as a prelude to cellular differentiation | 5☐, 22g☐ |
| **3B.5** | Identify and describe the key cell cycle events in eukaryotes, including reference to: growth (G1, G2), DNA replication (S), mitosis and cytokinesis | 11☐, 14a☐ |

ISBN 978-1-108-88711-3

| Success criteria – I am now able to: | | Linked question |
|---|---|---|
| **3B.6** | Recognise DNA replication (including via images of DNA structure) as a necessary precursor to cell division | 4☐ |
| **3B.7** | Describe and identify from diagrams, the stages in mitosis: prophase, metaphase, anaphase and telophase | 6☐, 14b☐ |
| **3B.8** | Describe and explain the similarities and differences in cytokinesis between plant and animal cells | 14c☐ |
| **3C.1** | Correctly identify key checkpoints on a diagram of the cell cycle and describe their purpose as regulatory mechanisms | 8☐ |
| **3C.2** | Explain the role of regulatory proteins at cell cycle checkpoints | 23a☐, b☐ |
| **3C.3** | Define apoptosis and its importance in normal biological development | 23e☐ |
| **3C.4** | Describe the key events of the apoptosis pathway | 18☐ |
| **3C.5** | Distinguish between the intrinsic and extrinsic apoptosis pathways including the circumstances that would lead to the activation of each pathway | 9☐ |
| **3C.6** | Distinguish between apoptosis and necrosis | 23f☐ |
| **3C.7** | Describe the significance of an abnormal regulatory protein (p53) in the onset of cancer | 23c☐ |
| **3C.8** | Give examples of factors that can contribute to the development of abnormal regulatory proteins | 23d☐ |
| **3C.9** | Explain how disruption to the regulation of the cell cycle can give rise to uncontrolled cell division and lead to the development of cancer | 20☐ |
| **3C.10** | Identify the key differences between cancer cells and normal cells, including in different cell types | 10☐, 19☐ |

## Multiple-choice questions

**1** Identify the process that results in the specialisation of stem cells.
- **A** self-renewal
- **B** multipotent specialisation
- **C** potency
- **D** differentiation

**2** Embryonic stem cells were removed from a blastocyst and grown in a laboratory. Further research showed that these cells were capable of producing only a few different types of cells. In terms of potency, these cells could be described as
- **A** unipotent.
- **B** totipotent.
- **C** pluripotent.
- **D** multipotent.

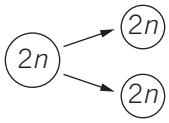
**3** Doctors can conclude that when a child is born with digestive system abnormalities, the child's condition is the result of problems occuring in the development of which primary germ layer?
- **A** ectoderm
- **B** mesoderm
- **C** endoderm
- **D** all three primary germ layers

**4** A common analogy used to describe the composition of chromatin is the visualisation of 'beads on a string'. The bead component of this analogy refers to
- **A** DNA.
- **B** centromere.
- **C** histone protein.
- **D** ribosome.

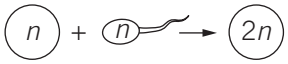
ISBN 978-1-108-88711-3

**5** Which diagram best represents cell division through the process of mitosis?

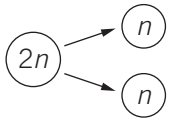
**A**



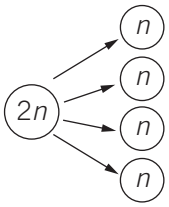

**B**




**C**

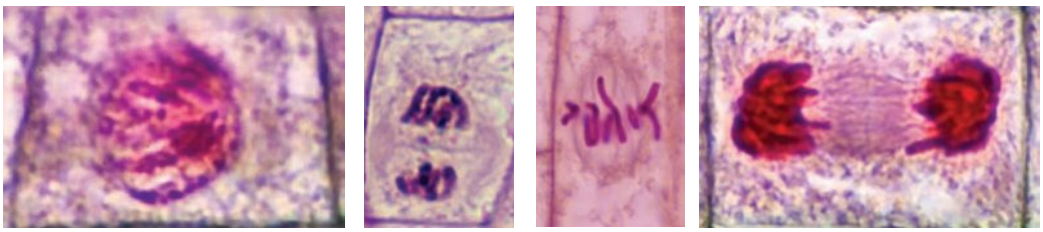



**D**




**6** Which of the following is the correct sequence of the events of mitosis, based on the images below?

**A** P, Q, R, S
**B** P, R, S, Q
**C** Q, R, S, P
**D** Q, P, S, R



**P** **Q** **R** **S**

**7** Which of the following statements about prokaryotic division versus eukaryotic division is *incorrect*?

**A** Prokaryotes divide by binary fission.
**B** Prokaryotic division is much faster than eukaryotic division.
**C** Prokaryotes divide for growth and repair.
**D** Prokaryotes divide only for reproduction.

**8** At which cell cycle checkpoint(s) is the cell cycle halted if the cell's DNA has not been replicated accurately?

**A** G1-S
**B** G2-S
**C** G2-M
**D** M

**9** The plasma membranes of multicellular organisms have receptors that detect the presence of an incoming 'death signal'. The death signal is important in the initiation of the apoptosis pathway in a faulty cell.
This death signal

**A** results in the spillage of cellular contents as it swells and bursts.
**B** increases the likelihood of cancer development.
**C** activates a pathway that results in the formation of apoptotic bodies.
**D** destroys all cells that are located in the area of the signal.

ISBN 978-1-108-88711-3

**10** Benign tumours are different from malignant tumours because
- **A** they are not metastatic.
- **B** they are invasive.
- **C** treatment includes chemotherapy.
- **D** they have a greater number of genetic mutations.

## Short-answer questions

**11** Complete the following table by matching each term with its correct description. Record the letter in the column on the left. (3 marks)

| | Term | Description |
|---|---|---|
| | **1.** mitotic spindle | **a.** the first stage of mitosis |
| | **2.** S phase | **b.** the period during which DNA is copied |
| | **3.** cleavage furrow | **c.** equally divides an animal cell into two daughter cells |
| | **4.** prophase | **d.** the time between cell divisions |
| | **5.** G1 phase | **e.** equally divides chromatids between daughter cells |
| | **6.** interphase | **f.** the first phase of interphase |

**12** 'Biology is the only subject where multiplication is the same as division.' Explain the reasoning behind this statement. (1 mark)

**13** **a** Draw a diagram that shows the key features of cell division in a bacterial cell. (2 marks)

**b** Cell division in a bacterial cell takes 20 minutes. How many cells will be present after this time? (1 mark)

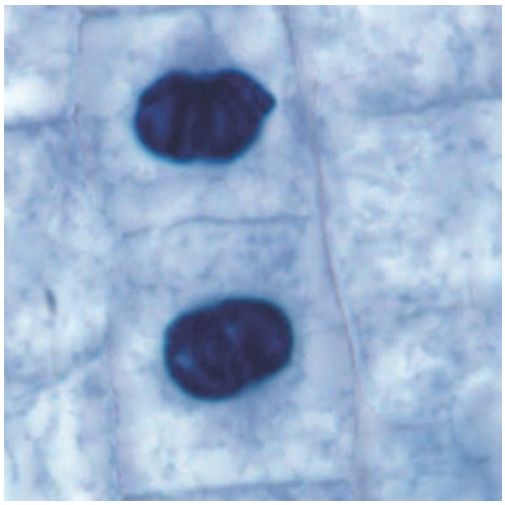
**c** How many cells will be produced after 3 hours? (1 mark)

**14** The cell cycle can be broken down into two major phases.

**a** Name the two phases. (1 mark)

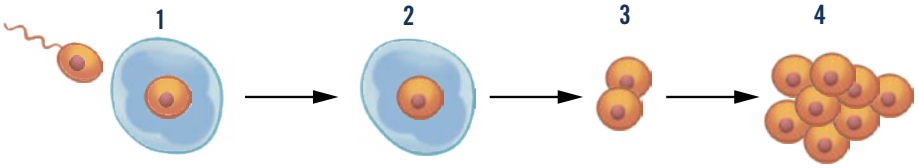
**b** In which of these two phases are chromosomes visible under a light microscope? Explain your answer. (1 mark)

**c** A student using a microscope saw the dividing cell shown below. She concluded that the organism the cell came from was a plant, not an animal. Is she correct? Justify your response. (1 mark)



ISBN 978-1-108-88711-3

**15** The diagram shows stages in early prenatal development.




**a** Name and describe the process that results in the increase of cell numbers throughout each stage of the diagram. (1 mark)

**b** What potency do the cells at step 3 have? How does this differ from the single cell in the first step? Explain. (2 marks)

**c** Researchers prefer to harvest embryonic stem cells at day 5. If they were to wait a few more days, they would have more cells to work with. Why do they choose to harvest at this developmental point with fewer cells? (2 marks)

Embryonic stem cells are associated with a number of ethical concerns, and so adult stem cells are often used in place of embryonic cells.

**d** Name one location that adult stem cells can be sourced from. (1 mark)

**e** Outline one advantage and one disadvantage of using adult stem cells over embryonic stem cells. (2 marks)

**16** When a blastocyst implants into the uterus, the process of gastrulation commences. In gastrulation, the inner cell mass of the blastocyst will give rise to three primary germ layers.

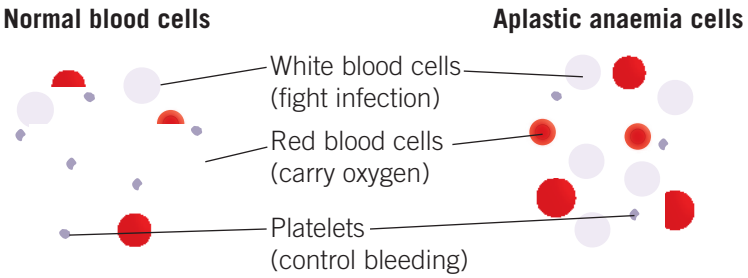
**a** Which of these is the outermost layer? (1 mark)

**b** What potency do the cells of each germ layer have after gastrulation? Explain. (1 mark)

**c** Which layer differentiates to form the supportive and connective tissue of an organism? (1 mark)

**d** Which layer gives rise to the nervous system? (1 mark)

**17** Aplastic anaemia is a rare condition in which the bone marrow is unable to produce all major types of blood cells – see the diagram below. It results in fatigue and a greater susceptibility to infections and uncontrolled bleeding.
Stem cell therapy offers hope for aplastic anaemia sufferers. Discuss how stem cells could be used to treat a patient with aplastic anaemia. (2 marks)



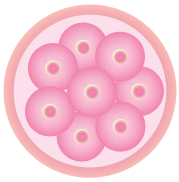
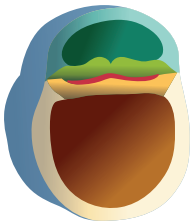
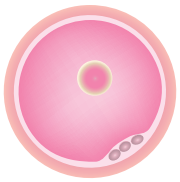
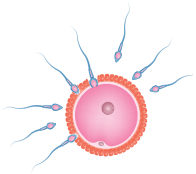
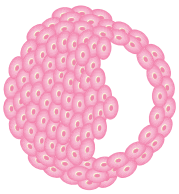

**18** Both the intrinsic and extrinsic pathways of apoptosis result in the release of mitochondrial cytochrome c, a component of the electron transport chain stage of aerobic cellular respiration. Use your knowledge of aerobic cellular respiration to explain why the release of cytochrome c is pivotal in the programmed destruction of a damaged cell. (2 marks)

**19** Do you think plants can get cancer? If so, how might the onset of cancer in plants differ from that in animals? (3 marks)

ISBN 978-1-108-88711-3

**20** In most situations, a mutated gene produces an abnormal protein, which results in a biological process being blocked. How, then, is it possible that a mutated gene product can cause cancer, which is a process of *active* cell division? (3 marks)

**21** Match the following terms (A–F) with their correct definition (I–VI) and diagram (1–6).

| Term | Definition | Diagram |
|---|---|---|
| **A.** Blastocyst | **I.** A ball of 16–32 cells resulting from the cleavage of a fertilised ovum | **1.**  |
| **B.** Embryo | **II.** Stage of embryonic development where some differentiation of cells occurs | **2.**  |
| **C.** Foetus | **III.** Early stage of development from 2 to 8 weeks of pregnancy | **3.**   |
| **D.** Gastrula | **IV.** Unborn offspring from more than 8 weeks | **4.**  |
| **E.** Morula | **V.** Diploid cell formed from the fusion of ovum and sperm during fertilisation | **5.**  |
| **F.** Zygote | **VI.** When the embryo has differentiated into 3 layers of cells | **6.**  |

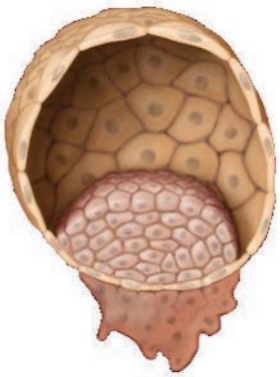
(6 marks)

ISBN 978-1-108-88711-3

**22** Stem cells can be defined as the 'unspecialised cells that have the ability to divide and differentiate into specialised'. The development of an embryo, and the subsequent foetus, relies on these stem cells.

**a** Using a specific example, describe the importance of stem cells in multicellular organisms. (2 marks)

**b** At day 4 in the development of an embryo, a blastocyst is formed. In the diagram shown below, label the inner cell mass and outline its importance in the development of the embryo into a foetus. (2 marks)



**c** The different types of cells that make up the inner cell mass are referred to as being multipotent. What does this means? (1 mark)

**d** Which type of stem cells are responsible for forming the inner cells mass, adult or embryonic? (1 mark)

**e** Identify three critical periods in the development of a foetus and outline why they are critical. (3 marks)

**f** Some individuals or groups perceive the use of stem cells for the purpose of medical and scientific research as unethical. Clearly describe two reasons that supports their concerns. (2 marks)

**g** Identify the stage of the cell cycle that occurs immediately before the division of the cytoplasm (cytokinesis). (1 mark)

**23** Much like the development of a foetus, which had critical periods, the cell cycle has critical checkpoints involving specific regulatory proteins.

**a** Explain the role that these regulatory proteins play during normal cell division compared to abnormal cell division. (2 marks)

**b** Provide an example of a regulatory protein involved in the process of apoptosis and explain the role of this regulatory protein. (2 marks)

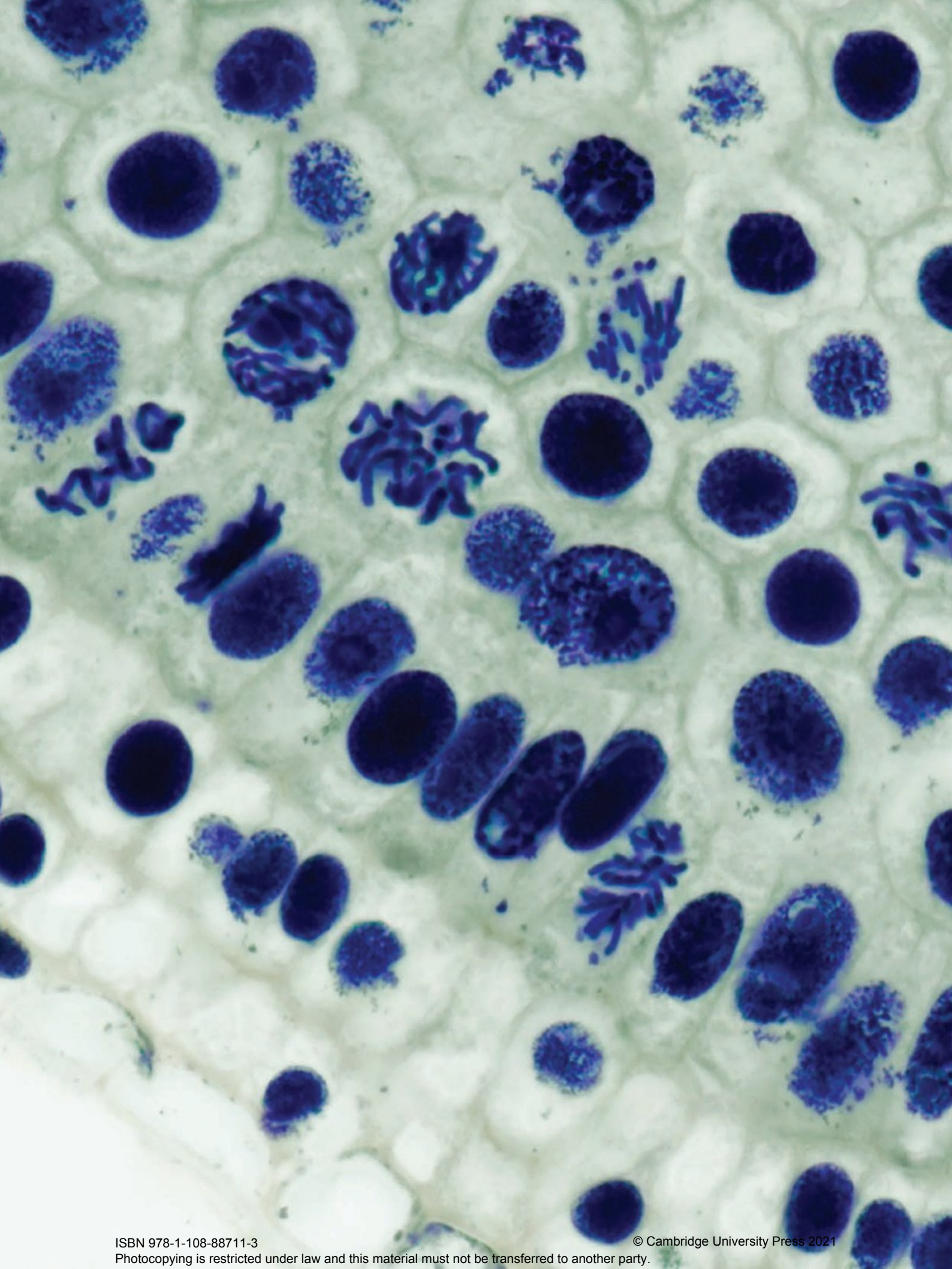
**c** For the regulatory protein you identified in part **b**, outline the significance of this protein in the development of cancer. (1 mark)

**d** List some factors that can influence the production of abnormal or defective regulatory proteins like that identified in part **b**. (2 marks)

**e** Define 'apoptosis' and provide two examples of the importance of this process to the survival or development of an organism. (3 marks)

**f** Identify three key differences between apoptosis and necrosis. (3 marks)

ISBN 978-1-108-88711-3



ISBN 978-1-108-88711-3

UNIT 1 HOW DO ORGANISMS REGULATE THEIR FUNCTIONS?

CHAPTER 4

# FUNCTIONING SYSTEMS

## Introduction

The previous chapters have examined the structure and function of organisms at a cellular level. In this chapter, you will investigate how specialised cells are organised into systems, forming complex multicellular organisms that rely on these sophisticated systems of cells for their survival. You will learn how the systems within mammals work together to obtain and transport nutrients as well as effectively manage the build-up of waste. More specifically, you will look at the role of the digestive system in obtaining nutrients and energy, the significance of the endocrine system in achieving stability, and the critical role of the excretory system in removing waste.

The healthy functioning of an organism depends on the coordinated action of all systems working together. When this fails, malfunctions are inevitable. In this chapter you will explore some of the malfunctions associated with each system and the consequences for the organism.

Plants also rely on the organisation of cells into systems. This chapter looks at the structure of vascular plants, specifically how specialised cells form organised systems responsible for the intake and transport of water throughout the plant.

## Curriculum

**Area of Study 2 Outcome 2**

| Study Design | Learning intentions – at the end of this chapter I will be able to: |
|---|---|
| **Functioning systems**<br>• Specialisation and organisation of animal cells into tissues, organs and systems with specific functions: digestive, endocrine and excretory | **4A From cells to systems**<br>**4A.1** Understand how the specific structure of a cell relates to its function and provide examples of specialised cells in the context of mammals, e.g. red blood cells and cardiac cells<br>**4A.2** Describe the relationship between cells, tissues, organs, organ systems and organisms in mammals<br>**4A.3** Explain the need for transport systems in multicellular animals in terms of size, level of activity and surface area to volume ratio |

ISBN 978-1-108-88711-3

| Study Design | Learning intentions – at the end of this chapter I will be able to: |
|---|---|
| • Specialisation and organisation of animal cells into tissues, organs and systems with specific functions: digestive, endocrine and excretory | **4B The digestive system: getting the nutrients we need**<br>**4B.1** Define the overall role of the digestive system within a mammal<br>**4B.2** Recognise the structures of the digestive system<br>**4B.3** Describe the key function(s) each structure performs to enable the digestive system to carry out its role successfully<br>**4B.4** Explain the processes that occur within the digestive system and the role of specialised cells in performing these<br>**4B.5** Describe the cause and consequences of digestive system malfunctions for the sufferer |
| | **4C The endocrine system: chemical control**<br>**4C.1** Define the overall role of the endocrine system within a mammal<br>**4C.2** Recognise the structures of the endocrine system<br>**4C.3** Describe the key function(s) each structure performs to enable the endocrine system to carry out its role successfully<br>**4C.4** Explain the processes that occur within the endocrine system and the role of specialised cells in performing these<br>**4C.5** Describe the cause and consequences of endocrine system malfunctions for the sufferer |
| | **4D The excretory system: eliminating waste**<br>**4D.1** Define the overall role of the excretory system within a mammal<br>**4D.2** Recognise the structures of the excretory system<br>**4D.3** Describe the key function/s each structure performs to enable the excretory system to carry out its role successfully<br>**4D.4** Explain the processes that occur within the excretory system and the role of specialised cells in performing these<br>**4D.5** Describe the cause and consequences of excretory system malfunctions for the sufferer |
| • Specialisation and organisation of plant cells into tissues for specific functions in vascular plants, including intake, movement and loss of water<br><br>**Regulation of systems**<br>• regulation of water balance in vascular plants | **4E Plant systems**<br>**4E.1** Understand how the specific structure of a cell relates to its function and provide examples of specialised cells in the context of plants, e.g. guard cells, root hair cells.<br>**4E.2** Describe the relationship between cells, tissues, organs, organ systems and organisms in plants<br>**4E.3** Define vascular plants<br>**4E.4** Explain how the structure of a root hair cell is specialised for the uptake of water<br>**4E.5** Explain the various methods of movement that are used for the distribution of water, ions and minerals throughout the plant<br>**4E.6** Describe the composition, arrangement and role of xylem tissue in vascular transport throughout plants<br>**4E.7** Explain the cause and role of transpiration in plants<br>**4E.8** Explain how transpiration rate is influenced by various environmental factors |



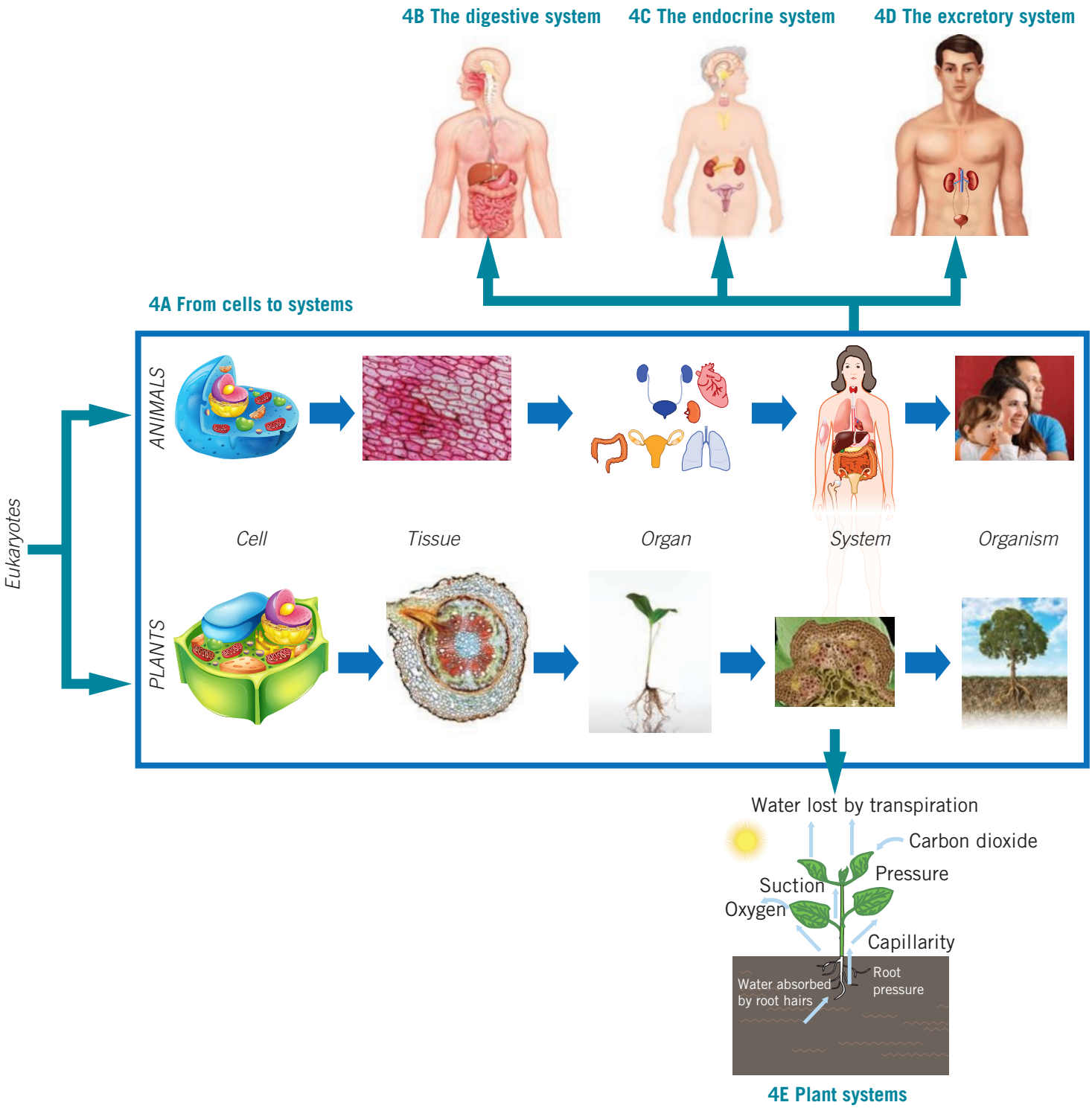
ISBN 978-1-108-88711-3

## Glossary

Absorption
Arteriole
Bile
Bolus
Cardiomyocytes
Chemical digestion
Chyme
Coeliac disease
Digestion
Diabetes
Egestion
Enzyme
Epithelial
Excretion
Filtration
Gastrointestinal tract
Gland (endocrine)
Glomerulus
Heartburn
Homeostasis
Hormone
Hyperthyroidism
Hypothyroidism
Ingestion
Lacteal
Lignin
Loop of Henle
Microvilli
Multicellular
Nephron
Non-vascular plant
Organ
Organism
Pathogen
Peristalsis
Peritubular capillaries
Phloem
Physical digestion
Reabsorption
Root hairs
Root system
Secretion
Shoot system
Specialised cell
Sphincter
Stomata
System (biological)
Target cell
Tissue
Tracheid
Transpiration
Transpiration stream
Tubule
Unicellular
Vascular plant
Vessel element
Villi
Xylem

ISBN 978-1-108-88711-3

## Concept map




*See the Interactive Textbook for an interactive version of this concept map interlinked with all concept maps for the course, and for a quiz of prior knowledge from Years 9 & 10 science.*

ISBN 978-1-108-88711-3

# 4A From cells to systems

**Study Design:**
Specialisation and organisation of animals cells into tissues, organs and systems with specific functions: digestive, endocrine and excretory

**Glossary:**
Cardiomyocytes
Multicellular
Organ
Organism
Specialised cell
System (biological)
Tissue
Unicellular

## ENGAGE

## Slime moulds

1A LIVING OR NON-LIVING LINK

Have you ever heard of slime moulds? Their slimy, jelly-like features make them one of the world's most interesting organisms. Slime moulds were thought to be a type of fungus because of their similar reproductive features, but now they are classified as protists, due to their gliding motion, which closely resembles that of an amoeba. Slime moulds can take many forms. Most of the time they exist freely as what appear to be single cells, but in other instances they have been shown to clump together, forming multicellular structures. A slime mould doesn't have a brain, but experiments have shown that it can learn the fastest route through a maze, and retain the memory of that path for over a year. Amazingly, scientists also found that when they placed oats (a food source) in the pattern of Japan's cities, the slime mould formed a multicellular nutrient-carrying network in almost exactly the same formation as the Japanese rail system!

So, what is a slime mould? Is it a cell? Is it an organism? Or is it somewhere in between? Read on and see if you can decide.

**Figure 4A–1** Different forms of slime moulds. Left: A caviar-like form, where individual cells appear to be present. Right: A different form, with no evidence of individual cells

ISBN 978-1-108-88711-3

EXPLAIN

## Types of cells

Can you remember from Chapter 1 how many cells there are in the human body? Of those cells, how many different types do you think there would be? 20? 100? 1000? In fact, the human body consists of approximately 210 types of **specialised cells**. The figure on the right shows some of the specialised cells in the human body. How many more can you list?

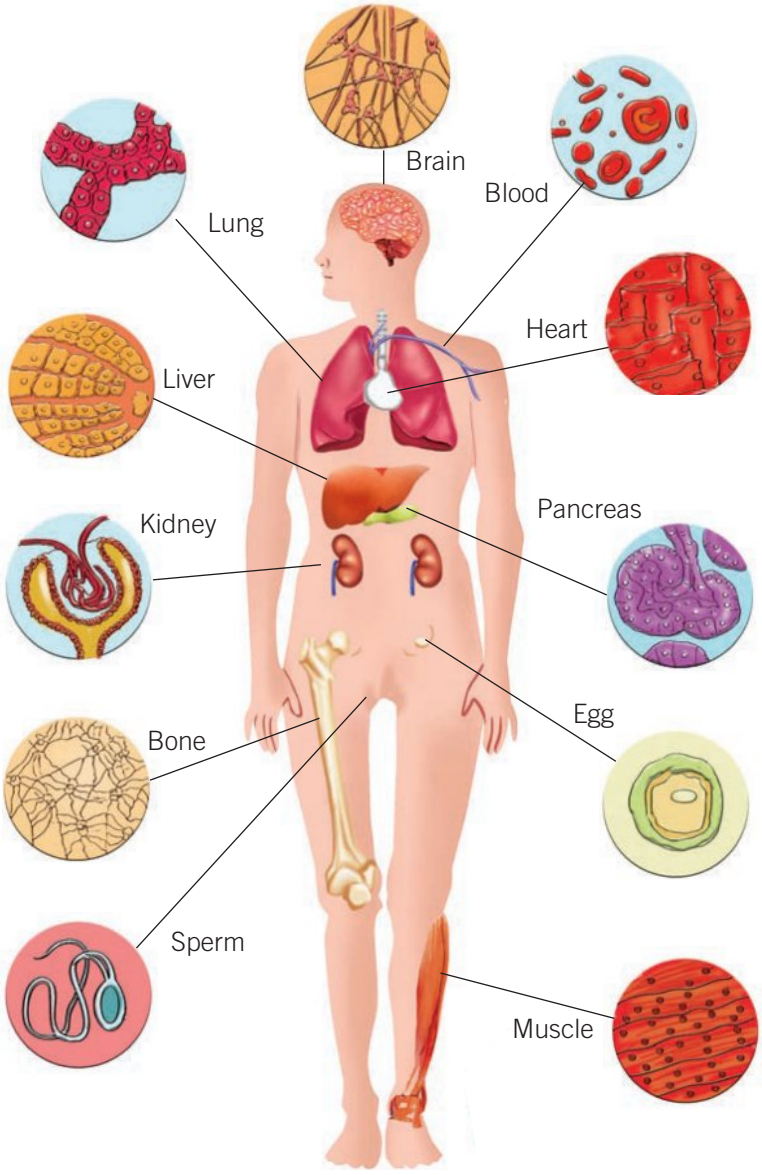



**Figure 4A–2** Some of the specialised cells in a human body. Note the different shapes and sizes that cells come in.

## Unicellular vs multicellular

For an **organism** to live successfully, it needs to have certain basic needs met. Energy and nutrients need to be readily accessible and waste removal needs to be effective. The organism also needs to have strong structural support and be capable of defending itself against danger. In a **unicellular** organism, one cell performs all these functions. In a **multicellular** organism, the load is shared among a variety of cells, each specialised to perform a specific function.

**Figure 4A–3** Which of these organisms are unicellular, and which are multicellular?

LINK 1A LIVING OR NON-LIVING

**Specialised cell** a cell with a specific function and structure within a multicellular organism

**Organism** an individual that is living (biotic)

**Unicellular** made up of only one cell

**Multicellular** made up of more than one cell

ISBN 978-1-108-88711-3

In energy terms, it is far more efficient to have different types of cells each perform one key specialised function than to have one cell do it all. This makes the multicellular organism our winner, but there is a drawback: size. Multicellular organisms are far larger than their unicellular counterparts, and to run as well-oiled machines they must be a highly organised framework of cells.

## Check-in questions – Set 1

1 Name five examples of specialised cells.
2 Summarise the major difference between a unicellular organism and a multicellular organism.
3 Describe one advantage and one disadvantage of being multicellular.

VIDEO 4A–1 LEVELS OF ORGANISATION

## Levels of organisation

You could say that organisation is the key to effectiveness. Do you play in a sporting team? Perhaps you play a musical instrument in a band. Maybe it's as simple as your position within your family. The role that you play, no matter how small, is vital to the overall success of your group. Complex multicellular organisms are no different. Each cell is arranged in a highly organised manner and performs a role that is essential to the overall function of the organism. The flow chart in Figure 4A–4 shows the hierarchy of cellular organisation in animals and plants, which can be applied in many ways, and Figure 4A–5 shows how this model can be applied to specific examples of animals and plants.


**Figure 4A–4** A general model of the cellular hierarchy of complex multicellular plants and animals

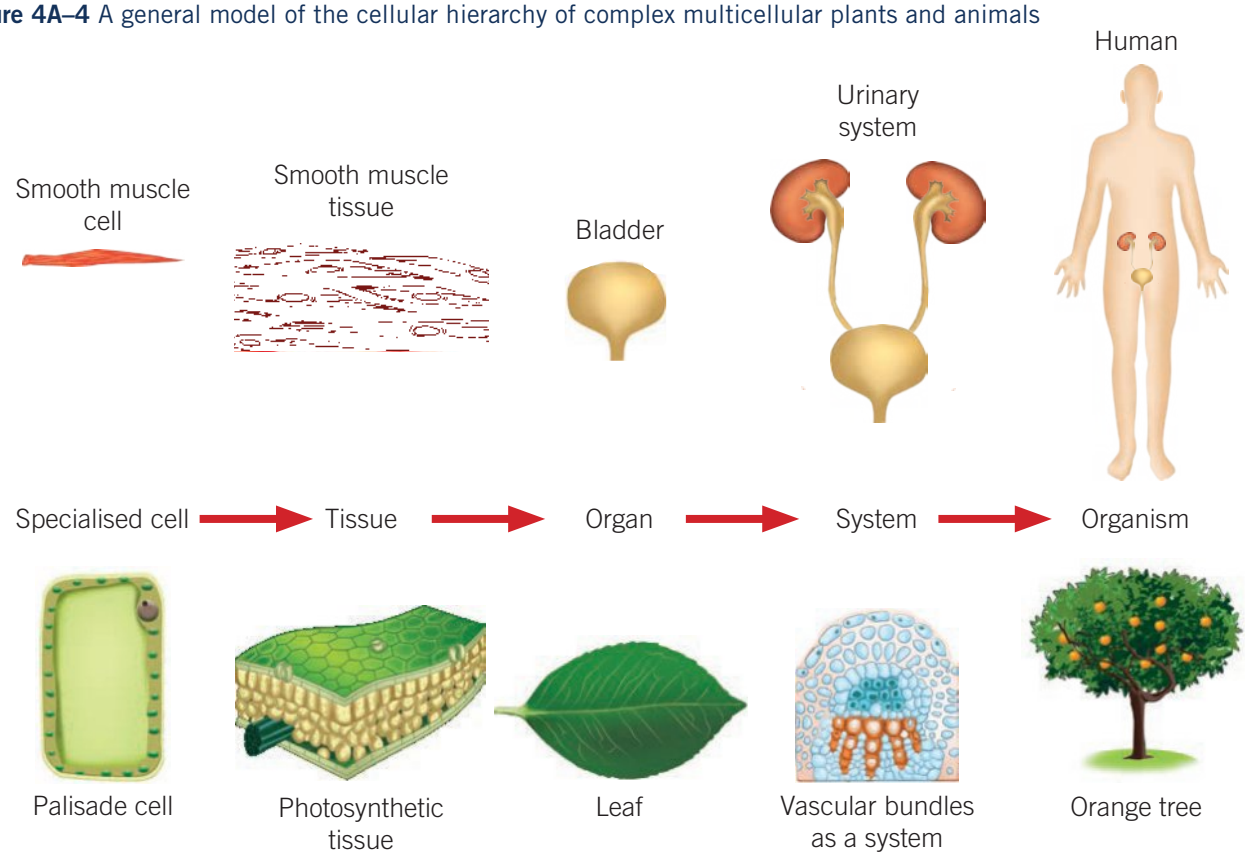



**Figure 4A–5** The levels of organisation that produce the urinary system in a human and the shoot system of an orange tree

ISBN 978-1-108-88711-3

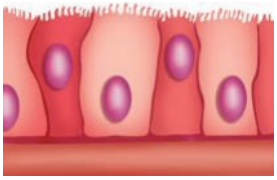
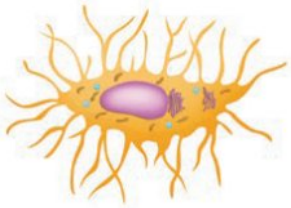
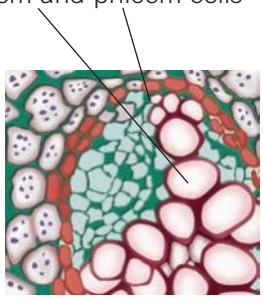
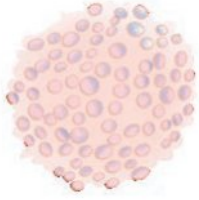
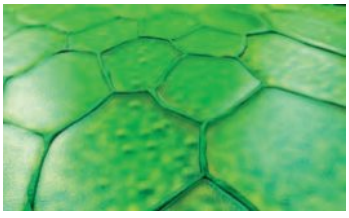
The remainder of this chapter explores the application of this flow chart in a variety of contexts, but first let's take a closer look at each of these levels.

LINK 3A WHERE DO NEW CELLS COME FROM?

## Specialised cells

Recall that there are approximately 210 different types of cells working hard to keep you alive. All cells within a multicellular organism carry out specific functions and are referred to as specialised cells. Not only do these specialised cells perform a specific role, they also have a highly adapted structure that allows them to carry out their function at an optimal level. Table 4A–1 shows a selection of the specialised cells in animals and plants. How does the structure of each of these cells contribute to the specialised function of the cell?

**Table 4A–1** Structure and function of specialised cells in animals and plants

| Specialised cells | | |
|---|---|---|
| **Animal structure** | **Function** | **Plant structure** |
| Intestinal cell with villi  | **Exchange**<br>Intestinal cells allow exchange of nutrients from the digestive tract into the bloodstream.<br>Root hair cells allow absorption of water from soil for plant survival. | Root hair cell  |
| Red blood cell  | **Transport**<br>Oxygen is carried by the protein haemoglobin in red blood cells to body cells and tissues so they can perform aerobic cellular respiration.<br>Tracheids transport water and mineral salts from the roots to the shoots of plants. | Tracheid in xylem  |
| Bone cell  | **Support/structure**<br>Bone cells are made mostly of the protein collagen, which forms a soft framework providing structure and support to an organism.<br>The xylem and phloem are vascular tissue networks that transport water and nutrients from roots to different parts of the plant and provide support to the leaves and stems. | Xylem and phloem cells  |
| White blood cell  | **Defence**<br>The many different types of white blood cells help the body defend itself against pathogens.<br>The layer of epidermal cells with thickened cell walls helps prevent pathogens from entering the leaves and stems. | Epidermal cells with thickened cell walls  |

ISBN 978-1-108-88711-3

2C SURFACE AREA TO VOLUME RATIO LINK

Note the red blood cell in Table 4A–1. One of its main functions is to transport oxygen around the body. Now look at its structure. The concave disc shape maximises the surface area to volume ratio of the cell. What does this mean? Maximising surface area means there is more plasma membrane available for oxygen to diffuse across, and this maximises the efficiency of oxygen transport throughout the organism.

**Tissue**
a group of similar cells that work together to carry out a specific function; organs are made up of different tissues

**Cardiomyocytes**
specialised cells making up the cardiac muscle tissue of the heart

## Tissue

A **tissue** is a group of specialised cells working together to perform a specific function. For example, the human heart consists of cardiac muscle tissue, which works to pump blood throughout the body. This cardiac muscle tissue consists of a group of highly specialised muscle cells, called **cardiomyocytes**. These cells are specialised to provide the strength and endurance needed for the heart to pump blood around our bodies every day for as long as we live.

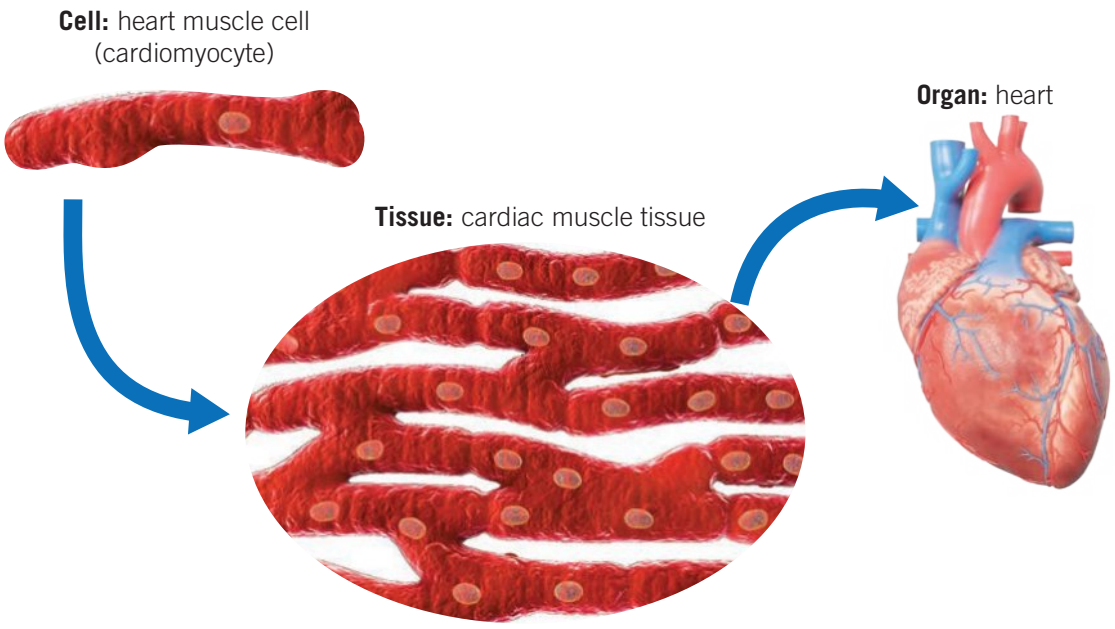



**Figure 4A–6** Many cardiac muscle cells work together to form one of the tissue types in the heart.

NOTE

Reflect on the organelles you read about in Chapter 1. What would you expect to find inside cardiomyocytes to provide the endurance needed by heart tissue?

### Tissue in mammals

**Epithelial**
belonging to epithelium, a connective tissue forming skin and protective surfaces of organs

All animals are made up of four types of tissue: muscle, nervous, **epithelial** and connective tissue. Each of these primary tissue types can be broken down further into subcategories, according to their role and position in the body. From here they can be further simplified into the specialised cells that make up each type of individual tissue. The organisation of tissue types can be seen in Figure 4A–7, and examples of these are shown in Figure 4A–8.

ISBN 978-1-108-88711-3

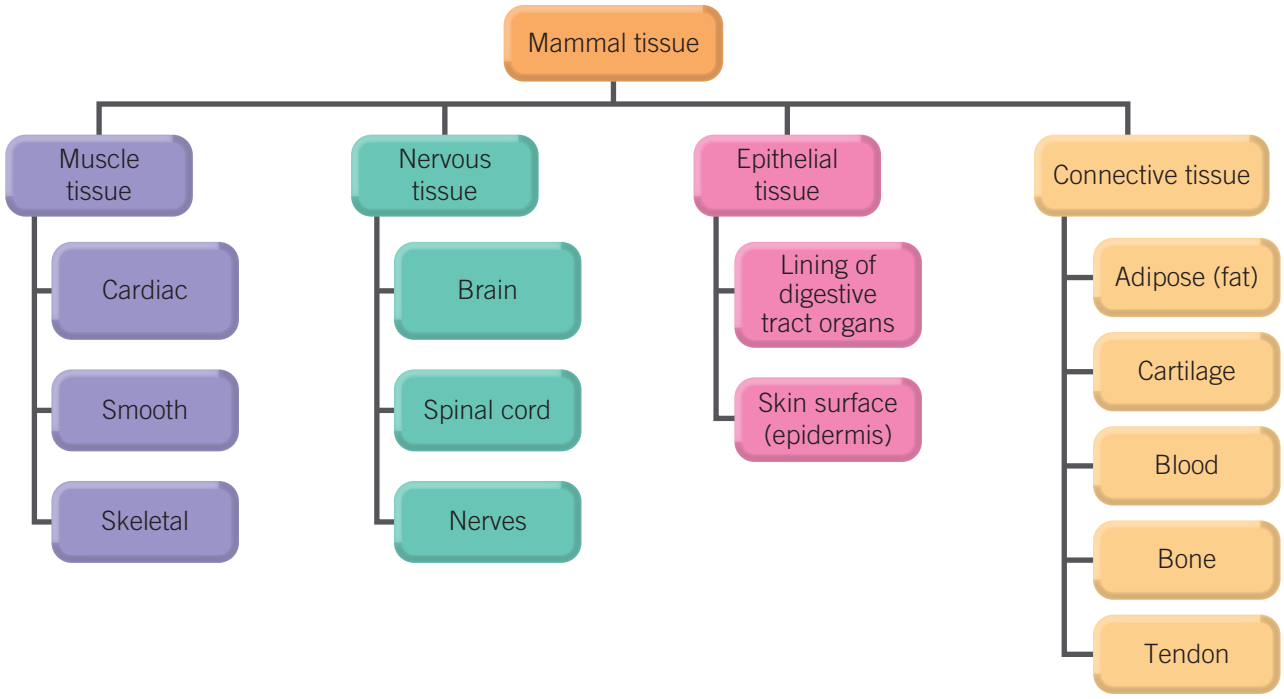



**Figure 4A–7** The organisation of mammalian tissue into its four main categories and subcategories. Each subcategory can be further divided into various types of specialised cells.


**Figure 4A–8** The locations of the four main types of tissue can be seen in the basketball player. What specialised cells would each of these tissues be made up of, in the area that they occur?

## Organ

When two or more types of tissues act together to perform one (or more) specific functions, an **organ** is formed. The heart consists of cardiac muscle tissue and works with connective, epithelial and nerve tissues. Together these tissues give rise to the heart and the properties that enable it to perform its role of pumping blood around the body.

**Organ**
two or more types of tissue acting together to perform a specific role

ISBN 978-1-108-88711-3

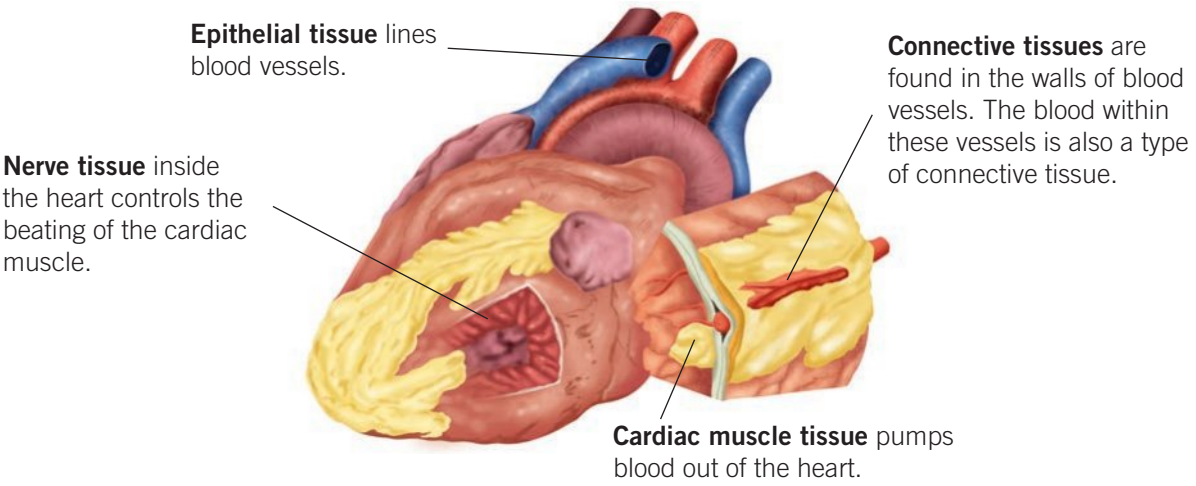



**Figure 4A–9** The human heart consists of many types of tissue that all work together so that the heart can pump oxygenated blood around the body.

If you were asked to name other organs in animals, no doubt you could make a comprehensive list: brain, lungs, stomach, liver and so on. But could you do the same for a plant? In fact, the leaves, stems, flowers and roots are the organs of a plant.

## System

**System (biological)** a group of organs working together to perform a task vital for survival

In complex multicellular organisms, organs do not function on their own. Instead, they work together with other organs, to form systems. A **system** is a group of organs working together to perform a complex task vital to an organism's survival. The bigger the organism, the greater the need for cooperation and coordination between cells, and thus the more complex the system. For example, the heart belongs to the circulatory system. It does not work in isolation to pump blood around the body. It is part of a large network of blood vessels that work with the lungs to provide the body with the oxygen and nutrients needed for survival.

## Organism

In complex multicellular organisms, such as mammals and vascular plants, many systems work together to ensure the organism has everything needed to thrive in its environment. Figure 4A–10 shows how our example of the heart comes together through each level.

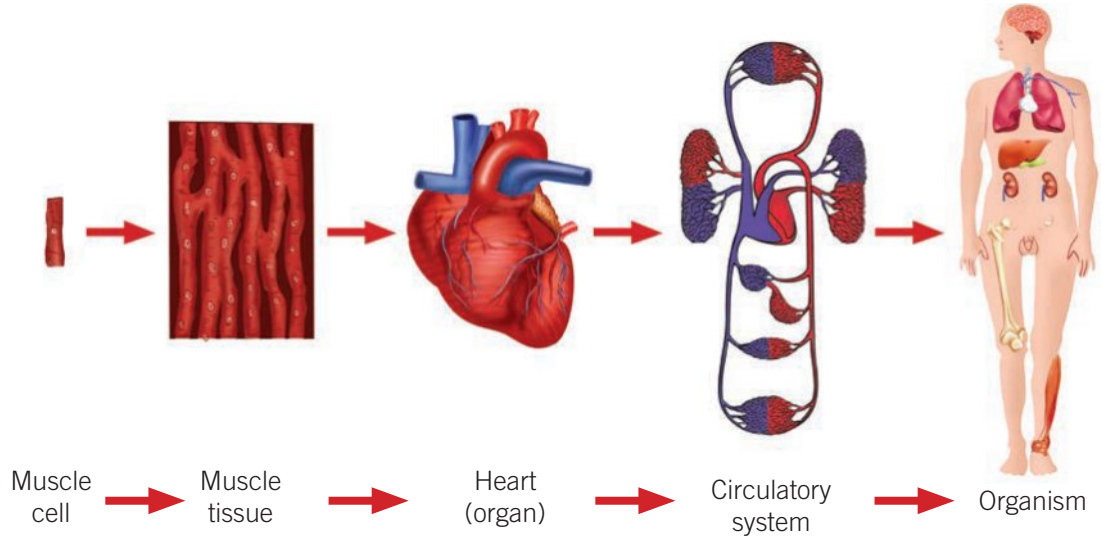



**Figure 4A–10** The levels of organisation that take a single heart cell to a fully functioning human with many interconnecting systems

ISBN 978-1-108-88711-3

## Check-in questions – Set 2

1 What is the relationship between cells and tissues?
2 How does tissue differ from an organ?
3 Define 'biological system'.

## Mammalian systems

Mammals, including humans, are complex multicellular organisms. We live in a variety of environments, but our requirements for survival are consistent regardless of whether we are Nepalese people living at high altitudes on Mount Everest, a scientist working in the –49°C conditions of an Antarctic research station or a NASA astronaut living in the microgravity environment of the International Space Station. In all cases, the specialised cells that make up the many interconnected systems of the human body are working hard to ensure that our survival needs are met.

There are ten systems that make up the human body. These systems do not work in isolation; many of their functions overlap, and our survival relies on cooperation between them to fulfil their roles and maintain balance.

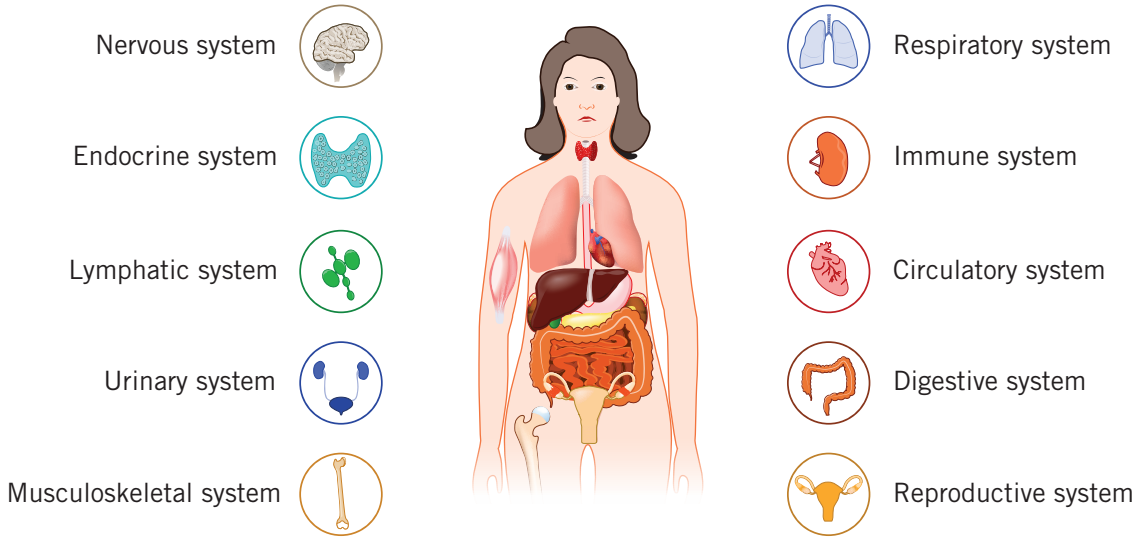



**Figure 4A–11** The ten systems of the human body

Now that you've read about all the levels of cellular organisation, think back to the slime mould you met at the start of this chapter. Where do you think it fits best in the overall structure that makes up an organism?

The following sections of this chapter take a closer look at the digestive, endocrine and excretory systems. You will explore the specialised cells that comprise the organs of each system and how malfunctions can occur, with varying consequences for the organism.

**Figure 4A–12** A slime mould: where does it fit in the heirarchy of cellular oganisation?

**WORKSHEET 4A–1**
SPECIALISED CELLS AND SYSTEMS

ISBN 978-1-108-88711-3

VIDEO 4A–2 SKILLS: CELLULAR SYSTEMS

## 4A SKILLS

### Cellular systems: arranging key terms into a sequence

The organisation of key terms in a way that shows their relationship with each other is a key skill in Biology. Being able to explain the hierarchical structure that leads to the formation of body systems from cells is the specific area of interest in this section.

Consider the following question:

> *Question*: Name a specialised cell and explain how it gives rise to a body system. (2 marks)
>
> *Answer*: A smooth muscle cell. When smooth muscle cells work together to perform a specific function, they form tissue. Different types of tissue working together form an organ, which in the case of smooth muscle tissue could be the bladder. The bladder then works with other organs to form the excretory system, which removes waste from the organism in urine.

Note that these examples include systems that are covered later in this chapter. You could also answer the question from a plant perspective. Here is another suitable answer.

> *Answer*: A palisade mesophyll cell. Palisade cells join other similar cells to form photosynthetic tissue. This tissue works with other tissue types and gives rise to a leaf. The leaf is a plant organ as it consists of multiple tissue types working together. Leaves work with the stems of plants to create the shoot system, which assists in the transport of key nutrients throughout the plant.

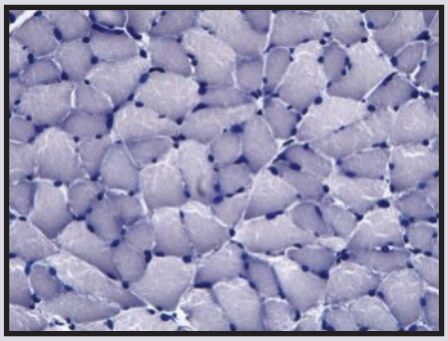
Although the content in the answer is different in the two examples, the basis of the answer is the same. In both cases, the following needs to be present to receive full marks:

- clear delivery of all relationship levels that result in cells forming systems cells → tissue → organ → system (with its function)
- links to the key components of the definitions of each term.

Correct application of both dot points would result in the award of 1 mark for each.

Other types of question styles can also test your knowledge of the relationship between key terms. Look at this more complex question style:

> *Question*: Aston and Harper are looking through a microscope at a group of cells that are similar in shape, size and function. However, the slide label has been damaged and they cannot read the name of the specimen. The image that they see with the microscope is shown here.



ISBN 978-1-108-88711-3

Aston tells Harper that they are looking at a random group of cells. Harper disagrees – she thinks they are looking at a section of tissue from an organism. Who is correct? Justify your answer.

*Answer*: Harper is correct. The image shows cells of the same type in close proximity, which indicates that they are working together. It is this close relationship between cells that gives rise to tissue. For Aston to be correct, the cells would be different in size and shape, and appear random in their arrangement.

Although there was more to work through in this question, the basis of the question is still the same. In order to gain the full 2 marks for this question, you need to:

- draw on the relationship between key terms to determine the difference between them (in this case, it was only cells → tissue)
- include key features of each term's definition as evidence to support your answer.

A useful way to consolidate your understanding of key terms is to create a concept map containing all the key terms listed at the beginning of each section of the chapter, after you have read each section.

## Section 4A questions

**1** Redraw the table, rearranging the terms in column 2 so they correctly match the examples in column 1.

| Example | Level of organisation |
|---|---|
| Human | Organ |
| Heart | System |
| Circulatory | Tissue |
| Cardiomyocyte | Organism |
| Cardiac muscle | Cell |

**2** Identify each of the following statements as true or false. Rewrite the false statements to make them true.

**a** Unicellular organisms contain tissue but not organs.
**b** Multicellular organisms contain organs but not tissue.
**c** Biological systems are the result of many organs working together.
**d** The correct order of cellular hierarchy is:
cell → organ → tissue → system → organism
**e** Multicellular organisms have different levels of cellular organisation.

**3** Classify each of the following as tissue, organ or system.

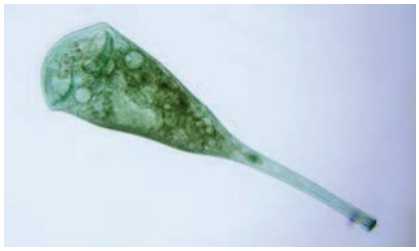
**a** brain
**b** blood
**c** larynx, trachea, bronchi and lungs
**d** layer of fat surrounding the kidney

**4** Explain how a specialised stomach cell is part of a body system.

**5** For each of the following examples, identify its highest level of cellular organisation.

**a** amoeba
**b** cardiac muscle
**c** the heart, blood vessels and blood working together
**d** the brain
**e** a dog

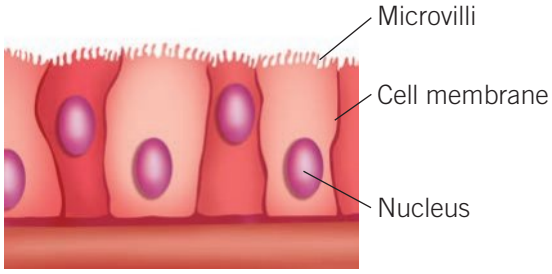
ISBN 978-1-108-88711-3



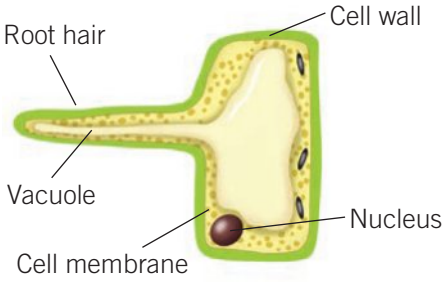
**6** Consider the image of a *Stentor* shown here. This organism is visible to the naked eye and lives in fresh water. Its external surface is covered in tiny hairlike projections called cilia. Is this organism unicellular or multicellular? Justify your answer.

**7** Plants and animals have certain cells that are specialised to absorb substances, which they do across their cell membranes. Microvilli on cells lining the inside surface of the small intestine increase the absorption of nutrients into the cell, from where it is passed on to the blood, just like root hair cells on plants increase the absorption of water from the soil. These cells are pictured below.

**Cells lining the small intestine**



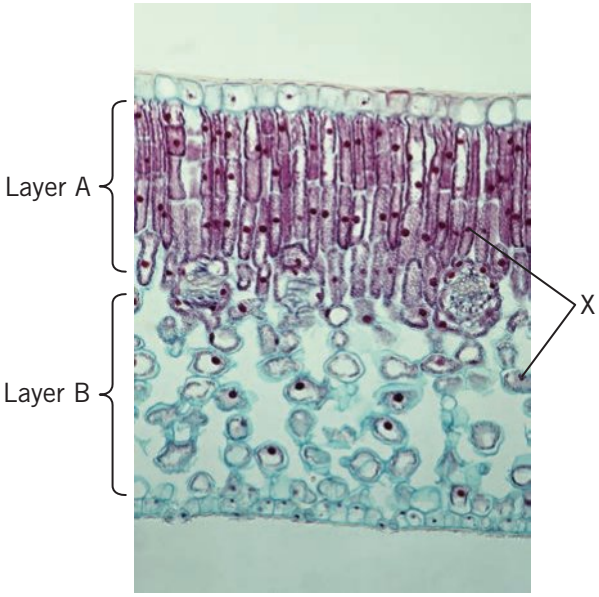

**Root hair cell**




**a** Describe the features of these cells that make them specialised for the exchange of substances across their membranes.

**b** What overall system do each of these cells belong to in their respective organisms?

**8** The following image shows a cross-section of leaf tissue, as seen at 400 × magnification.




**a** With reference to the image, explain how you can tell that cell layers A and B are not performing the same role in the plant, despite the individual cells all having the same basic features (labelled X).

**b** What level of cellular organisation are layers A and B? What is the level of cellular organisation above them? In other words, what do they form together – a tissue, organ, system or organism?

ISBN 978-1-108-88711-3

# 4B The digestive system: getting the nutrients we need

**Study Design:**
Specialisation and organisation of animal cells into tissues, organs and systems with specific functions: digestive, endocrine and excretory

**Glossary:**
Absorption
Bile
Bolus
Chemical digestion
Chyme
Coeliac disease
Digestion
Egestion
Enzyme
Gastrointestinal tract
Heartburn
Ingestion
Lacteal
Microvilli
Peristalsis
Physical digestion
Sphincter
Villi

## ENGAGE

### Diet and digestion

Figure 4B–1 shows the digestive systems of two very different animals, a lion and a deer. Both animals are multicellular, are mammals and they live in similar environments. But their digestive systems are very different. What do you think is the reason for this difference? If you said diet, you would be correct. Whether you're a carnivore or a herbivore makes a big difference to your overall digestive structure.

WORKSHEET 4B–1 CARNIVORES VS HERBIVORES

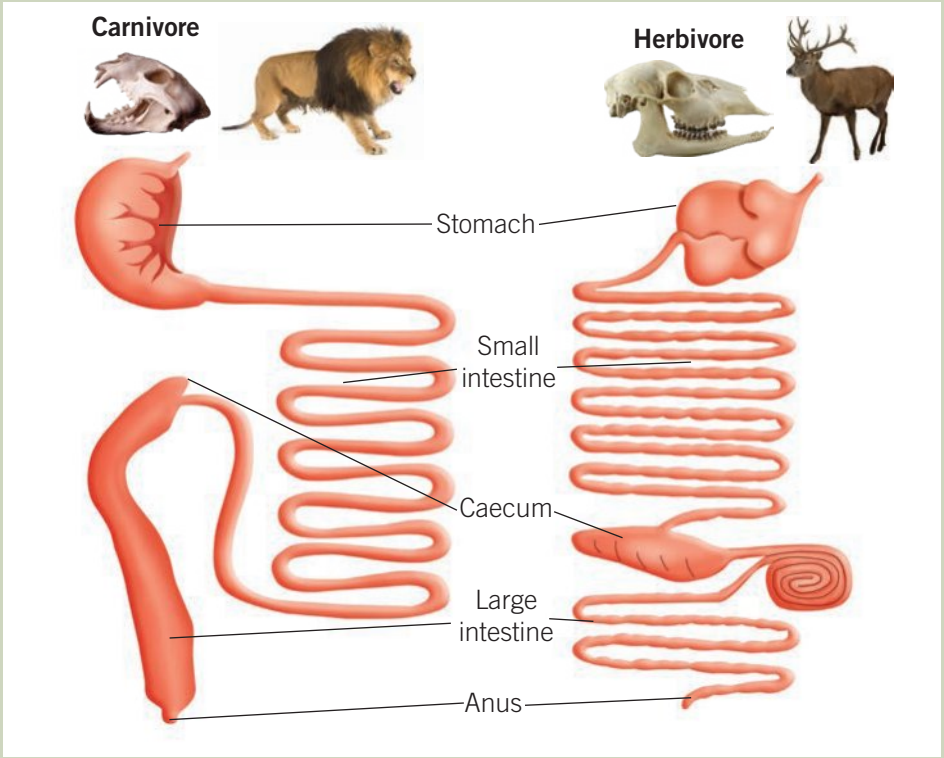



**Figure 4B–1** The digestive systems of two very different animals – a lion and a deer

Clearly, the mouths of a lion and a deer are very different. Where lions have sharp canine teeth capable of tearing and shredding meat, deer have wide, flat teeth to grind plant matter. What other differences do you notice in the two digestive tracts?

ISBN 978-1-108-88711-3

The lion's gut is much shorter than the deer's. Absorbing nutrients from plant matter takes longer, so herbivores have longer digestive tracts. A difference you can't see in the diagram is that the lion's large stomach contains ten times as much hydrochloric acid as the deer's, to assist in the breakdown of meat. The deer belongs to a group of herbivores known as ruminants, and its stomach has four chambers, the largest of which is called the rumen. No mammals produce enzymes capable of breaking down cellulose, and this is a problem for herbivores, given the high content of cellulose in the grasses that make up their diet. In the rumen of the deer are specialised bacteria that produce the enzyme *cellulase*, which breaks down the cellulose for them.

A final difference is in the caecum of the two animals. In the deer, the caecum is enlarged, because its function is similar to the rumen compartment of the stomach: cellulase-producing bacteria also live in the caecum and help in further breaking down cellulose so nutrients can be extracted. Because the lion does not eat plant material, its caecum is basically redundant, which explains its insignificant size in carnivores.

So where does this leave the human digestive system? Most humans are omnivores, and so our digestive system is somewhere between that of a carnivore and a herbivore. Read on to learn all about our digestive tract.

## EXPLAIN

# The human digestive system

**2D** ROLE OF CHLOROPLASTS AND MITOCHONDRIA LINK

**VIDEO 4B–1** HUMAN DIGESTIVE SYSTEM

To survive in our environment, we must provide our body with a wide range of nutrients. Autotrophs make their own food by converting inorganic substances into organic molecules, but as heterotrophs we are unable to do this, so we rely on our diet to obtain the nutrients we need. It is the role of our digestive system to break down our food and extract the vital nutrients needed for survival.

**Digestion** the process of breaking food down into smaller molecules that can then be absorbed into the bloodstream and transported to cells

**Gastrointestinal tract** a long hollow tube that connects the mouth to the anus

**Digestion** is the process of breaking food down into smaller molecules that can then be absorbed into the bloodstream and transported to cells. The digestive process occurs along the **gastrointestinal tract**, which is a long hollow tube that connects your mouth to your anus. This tube is open at both ends and includes the digestive organs (oesophagus, stomach, small intestine and large intestine). In addition, the accessory organs (liver, gall bladder and pancreas) also play an important role in the digestive process.

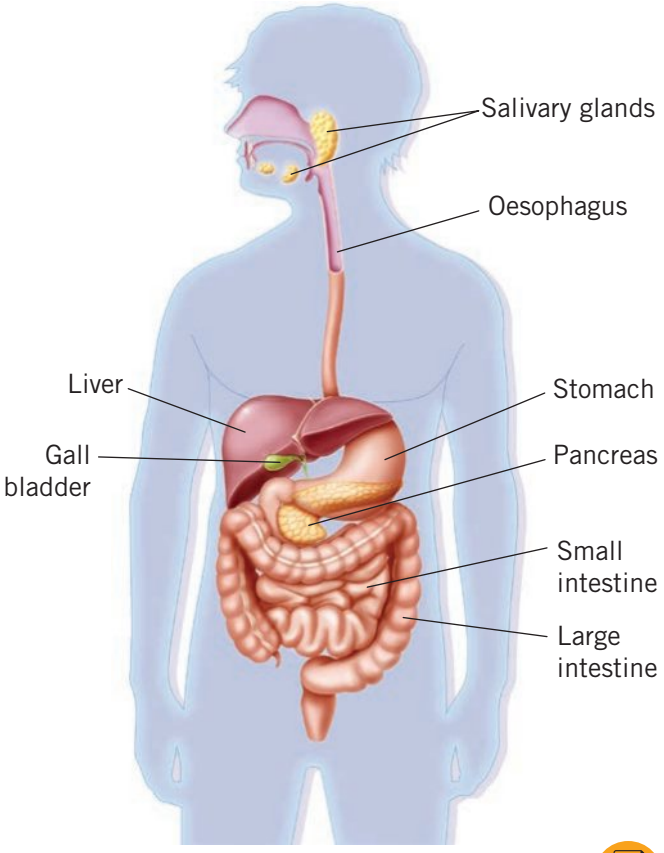



**Figure 4B–2** Organs of the human digestive system

Figure 4B–2 shows the human gastrointestinal tract and associated organs.

ISBN 978-1-108-88711-3

## Types of digestion

Digestion along the gastrointestinal tract occurs in two ways: physically and/or chemically. It is the combined effort of both forms of digestion that results in our cells receiving the nutrients needed for survival.

### Physical digestion

**Physical digestion** (also known as *mechanical digestion*) is the process of breaking large chunks of food into smaller pieces. This increases the total surface area of the food, which is important because the digestive **enzymes** in chemical digestion can only act on the surface of food. When the food is in smaller pieces and its surface area is therefore larger, the digestive enzymes are able to gain faster access to the nutrients stored in the food, and this speeds up the overall digestive process.

LINK 2C SURFACE AREA TO VOLUME RATIO

**Physical digestion**
the process of breaking large chunks of food into smaller pieces

**Enzyme**
a biological catalyst that speeds up a chemical reaction by lowering activation energy

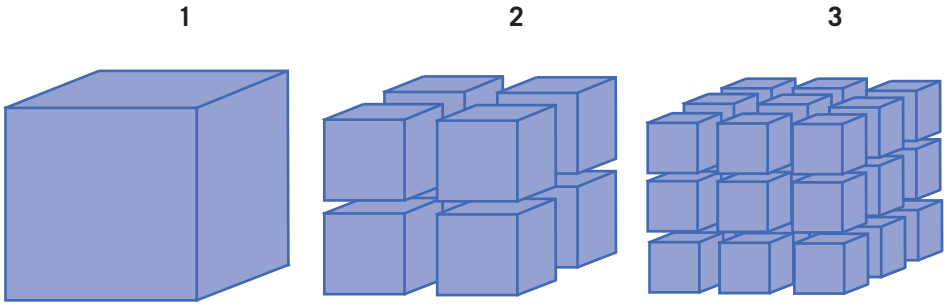



**Figure 4B–3** Box 1 represents a piece of food before mechanical digestion. In boxes 2 and 3, mechanical digestion has increased the surface area of the food.

Physical digestion takes place at various locations along the gastrointestinal tract:

- in the mouth, when teeth chew the food
- in the stomach, when the food is churned
- in the small intestine, when **bile** produced by the liver breaks down fats (lipids) in the food.

**Bile**
a substance produced by the liver that mechanically digests lipids

### Chemical digestion

**Chemical digestion** also occurs at several locations along the gastrointestinal tract. In chemical digestion, enzymes break down large complex substances into their simplest forms. In this simple form they can pass through cell membranes and be absorbed into the bloodstream, where they are transported to cells and used to maintain survival.

LINK UNIT 3

LINK 1B PLASMA MEMBRANE

Consider a sandwich that you have eaten for lunch. The bread contains a complex carbohydrate (polysaccharide) known as starch. As you chew the bread, your salivary glands release an enzyme, called amylase. Amylase breaks down starch into a simpler carbohydrate (a disaccharide) known as maltose. Later in the digestive process, maltose is further acted on by the enzyme maltase and converted into the simplest type of sugar, glucose (a monosaccharide). The glucose is then absorbed into the bloodstream, distributed to the cells and used for cellular respiration.

LINK 2D ROLE OF CHLOROPLASTS AND MITOCHONDRIA

Carbohydrates are not the only complex substance broken down through chemical digestion. Proteins are broken down into amino acids, and fats (lipids) are broken down into glycerol and fatty acid chains. All enzymes act on specific substances and operate within a narrow pH range. This pH range determines the location of each enzyme's action within the gastrointestinal tract.

**Chemical digestion**
the process of enzymes breaking down large complex substances into their simplest forms; occurs in several places along the digestive tract

ISBN 978-1-108-88711-3

Three main classes of digestive enzymes are involved in chemical digestion:
- proteases – break down proteins (e.g. pepsin and trypsin)
- amylases – break down large carbohydrates
- lipases – break down lipids.

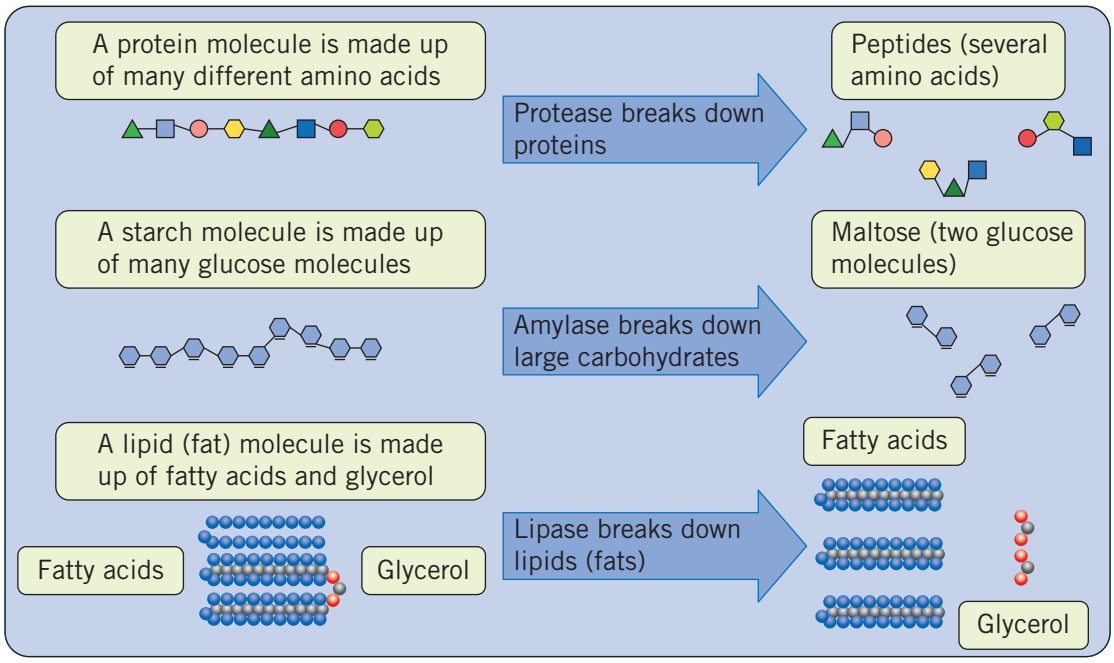



**Figure 4B–4** The major classes of digestive enzymes: proteases amylases and lipases

## Check-in questions – Set 1

1 Define 'digestion'.
2 What is the difference between physical digestion and chemical digestion?
3 Name the three complex substances broken down in the digestive system and what they are broken down into to allow for absorption.

**Ingestion** the entry of food into the gastrointestinal tract via the mouth

**Absorption** the movement of nutrients out of the digestive system and into the bloodstream for delivery to cells

**Egestion** the removal of undigested food (waste) material from the body

## The digestive pathway

The role of the digestive system can be broken down into four specific 'jobs', each of which contributes to the overall purpose of the system:
- **Ingestion** – food enters the gastrointestinal tract via the mouth.
- **Digestion** – food is broken down physically or chemically from its complex form into its simplest form (e.g. protein to amino acids).
- **Absorption** – nutrients move out of the digestive system and into the bloodstream for delivery to cells.
- **Egestion** – undigested food (waste) material is removed from the body.

Now let's follow the path that food takes through your digestive system.

ISBN 978-1-108-88711-3

## Mouth

*Role*: Ingestion/digestion
*Type of digestion:* Physical and chemical

The entry of food into the mouth is the beginning of the digestive process for most animals.

The steps below outline the sequence of events that occur within the mouth.

1 Food is physically broken down into smaller pieces by the action of the teeth. Incisors cut and tear the food, while molars crush and grind it.
2 Chewing stimulates the salivary grands to produce saliva, which is released into the mouth cavity.
3 Mucus within the saliva helps to lubricate the food and, together with the mashing action of the tongue, the food is mixed to form a **bolus**.
4 Chemical digestion begins when salivary amylase begins to break down the complex carbohydrate starch into maltose. *(The chemical digestion process in step 4 is sped up by the action of the teeth increasing the surface area that the enzyme has access to.)*
5 The tongue pushes the bolus to the back of the throat, ready to be swallowed into the oesophagus.

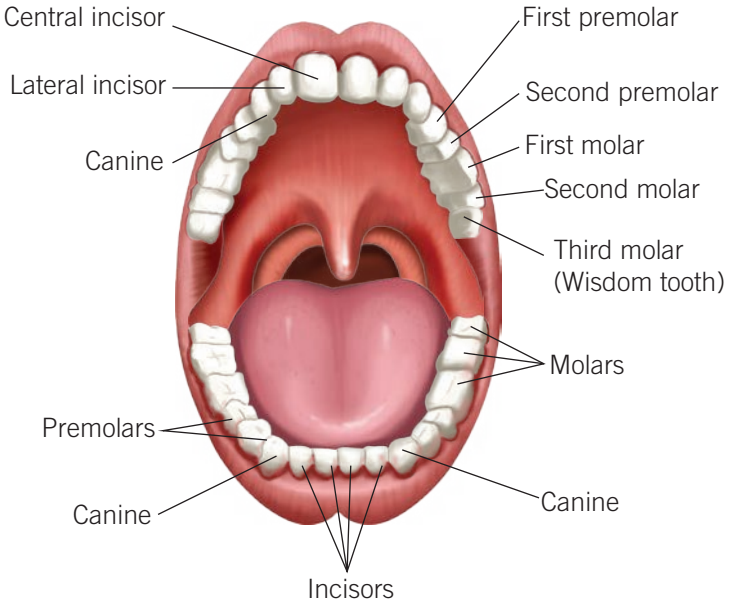



**Figure 4B–5** Teeth in the mouth

**Bolus**
a ball-like mixture of food and saliva that forms in the mouth

## Oesophagus

*Role:* Ingestion/digestion
*Type of digestion:* Chemical

In humans, the oesophagus is a narrow, muscular tube approximately 25 cm long that connects the mouth and the stomach. The bolus created in the mouth is pushed into the oesophageal opening, bypassing a flap of tissue known as the *epiglottis*. The epiglottis closes off the opening to the trachea, ensuring that no food enters the respiratory system. The bolus is pushed down the length of the oesophagus by muscular contractions in a process known as **peristalsis**.

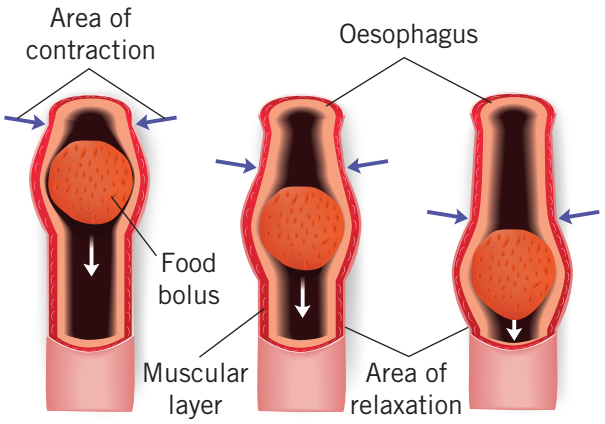



**Figure 4B–6** Circular muscles contract behind the bolus, and relax in front of the it, so it is moved forward. A 'wave' of muscular contraction travels down the oesophagus.

**Peristalsis**
involuntary contractions of muscles in the gastrointestinal tract that create a wavelike motion that pushes food through the tract

The chemical digestion of starch into maltose by amylase continues until the bolus reaches the stomach.

ISBN 978-1-108-88711-3

## Stomach

*Role:* Digestion
*Type of digestion:* Physical and chemical

The bolus enters the stomach through the *cardiac sphincter*. This muscle controls the entry of food into the stomach as well as preventing the acidic contents of the stomach from moving up into the oesophagus. The arrival of food here triggers the secretion of gastric juices, which are made up of pepsin (a type of enzyme that breaks down proteins), water, mucus and hydrochloric acid. At this point, the food pieces are still relatively large, so physical digestion occurs through the muscular contractions of the stomach wall churning the food, with the gastric juices creating a thick soupy substance known as **chyme**.

**Chyme**
a soupy mass of partly digested food and gastric juices

The secretion of hydrochloric acid into the stomach creates a highly acidic environment (pH approximately 2–3). Amylase cannot function in such conditions, so the chemical digestion of complex carbohydrates such as starch temporarily ceases here. Pepsin, however, is activated in an acidic environment and so the chemical digestion of large proteins into smaller peptides begins. The hydrochloric acid also acts as a protective mechanism for the organism, destroying any harmful bacteria or viruses ingested with food. While absorption of most nutrients into the bloodstream is yet to commence, it is possible for water (if the person is dehydrated) and alcohol to pass through the stomach wall into the blood.

**2A** THE NATURE OF SUBSTANCES AND THEIR MODES OF TRANSPORT LINK

**2B** OSMOSIS LINK

Food is stored in the stomach as chyme for approximately 5 hours until it moves into the small intestine for further processing.

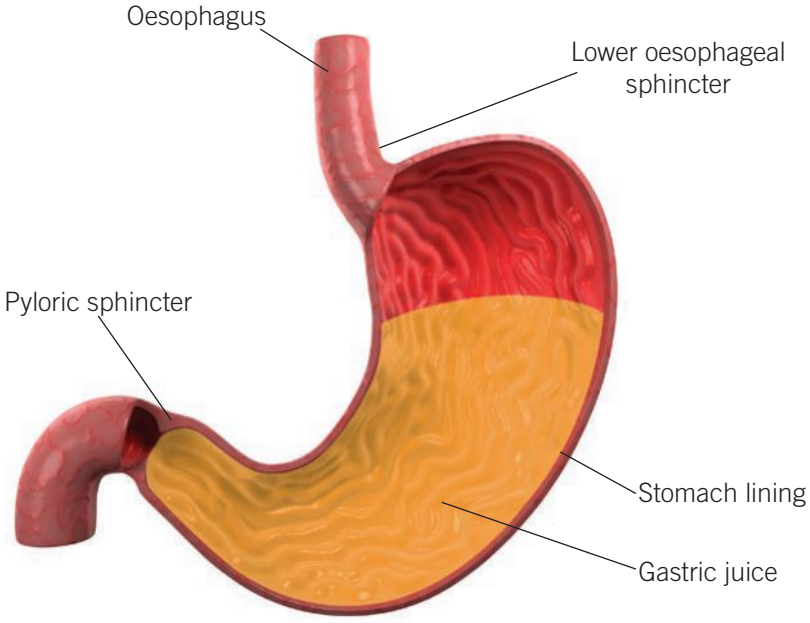



**Figure 4B–7** The stomach

## Check-in questions – Set 2

1 What types of digestion occur in the mouth?
2 Name and describe the action that moves material from the mouth to the stomach.
3 Explain the reason behind the stomach's acidic environment.

ISBN 978-1-108-88711-3

## Small intestine

*Role:* Digestion and absorption

*Type of digestion:* Physical and chemical

Through peristalsis, food in the form of chyme moves from the stomach into the first part of the small intestine, the *duodenum*, via the *pyloric sphincter* muscle. This **sphincter** muscle ensures that food does not enter the small intestine too quickly. Here, the accessory organs (liver, gall bladder and pancreas) perform their vital role in the digestion of food. Their digestive roles are summarised in Table 4B–1.

**Sphincter**
a ring of muscle surrounding a tube that tightens to close it or relaxes to allow it to open

**Table 4B–1** Accessory organs of the digestive system and their functions

| Organ | Role in digestion |
|---|---|
| Liver | Produces bile, which moves through the bile duct into the beginning of the small intestine (duodenum); bile digests lipids |
| Gall bladder | Stores bile if there is no food to break down in the duodenum |
| Pancreas | Secretes pancreatic juices into the start of the small intestine. Juices consist of the digestive enzymes amylase, trypsin and lipase as well as bicarbonate |

The small intestine is approximately 6 metres long in a fully grown human. It has a large network of blood vessels and consists of three sections: duodenum, jejunum and ileum.

### Duodenum

The duodenum is approximately 26 cm long and marks the beginning of the small intestine. It lies close to the pancreas and receives pancreatic juices from the small intestine and bile from the liver/gall bladder. Chyme passing from the stomach contains hydrochloric acid, which must be neutralised to prevent damage to the intestinal lining. The bicarbonate in pancreatic juice raises the pH to 6, which is not optimal for pepsin, so the pepsin ceases to act.

LINK 2C SURFACE AREA TO VOLUME RATIO

Bile secreted by the liver is involved in the mechanical breakdown of lipids. Lipids are broken down into tiny droplets in a process known as emulsification. This increases their surface area, allowing lipase to carry out the chemical digestion necessary to produce glycerol and fatty acids, which can then be absorbed into the blood via the lymphatic system.

The chemical breakdown of carbohydrates and proteins also continues through the action of amylase and trypsin respectively.

### Jejunum

LINK UNIT 3

The jejunum is the middle part of the small intestine and is approximately 2.5 m long. It is mostly responsible for the absorption of nutrients and therefore has a large surface area, enhanced by **villi** (see *Specialised cells of the small intestine* on pages 181–2). Amylase by now has broken down large carbohydrates into smaller disaccharides. These are then further digested by enzymes into simple subunits, such as glucose, which can then be absorbed into the bloodstream. Pepsin and trypsin have broken down proteins into smaller chains, known as peptides. Another class of enzymes, known as peptidases, break down these peptide chains into singular amino acids for absorption. Finally, bile and lipase have reduced the lipids into glycerol and fatty acid chains, which are also absorbed into the bloodstream.

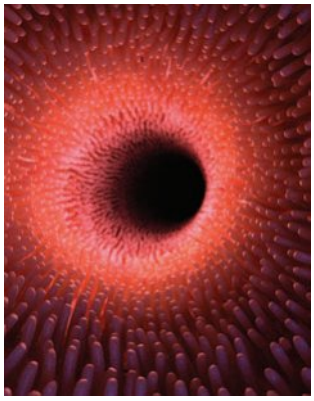


**Figure 4B–8** Villi in the jejunum

**Villi**
fingerlike projections that line the inner surface of the small intestine, increasing its surface area

ISBN 978-1-108-88711-3

**Table 4B–2** The digestive enzymes and their action

| | Enzymes | Site of production | Site of action | Starting substrate | End product |
|---|---|---|---|---|---|
| **Carbohydrates** | Salivary amylase | Salivary gland | Mouth/ oesophagus | Starch (polysaccharide) | Maltose (disaccharide) |
| | Pancreatic amylase | Pancreas | Small intestine | Starch (polysaccharide) | Maltose (disaccharide) |
| | Oligosaccharidases (e.g. maltase) | Lining of small intestine | Small intestine | Disaccharides (e.g. maltose) | Monosaccharides (e.g. glucose) |
| **Proteins** | Pepsin | Stomach | Stomach | Proteins | Peptides |
| | Trypsin | Pancreas | Small intestine | Proteins | Peptides |
| | Peptidases | Lining of small intestine | Small intestine | Peptides | Amino acids |
| **Lipids** | Lipase | Pancreas | Small intestine | Fats | Glycerol and fatty acid chains |

### Ileum

The final region of the small intestine is the ileum, which is approximately 3.5 m long and also plays a vital role in nutrient absorption. Here the chemical breakdown of peptides into amino acids and disaccharides into simple sugars such as glucose continues, for eventual absorption into the circulatory system. The ileum is also the site of absorption of vitamin $B_{12}$ and bile salts. Vitamin $B_{12}$ is essential for healthy brain and nervous system function, and bile salts have a vital role in the digestion of lipids, absorption of minerals and elimination of toxins from the body.

The end of the ileum, and the small intestine, is marked by the ileocaecal valve.

## Large intestine

*Role:* Absorption and egestion
*Type of digestion:* Does not occur

The large intestine gets its name because of its diameter relative to the small intestine, and it is the final part of the gastrointestinal tract. It is approximately 1.5 m long and consists of two main sections: the U-shaped colon and the rectum. Structures such as the caecum and the appendix are also associated with the large intestine.

The large intestine has two key roles:
- absorption of water and some salts back into the bloodstream.
- preparation of undigested waste material for excretion from the body.

The first part of the colon is where the absorption of water and some salts back into the body occurs. No digestive enzymes are at work here. Instead, bacteria act on the undigested material that has been passed on from the small intestine. The bacteria produce vitamins A and K, which are absorbed into the bloodstream through the membranes of cells that line the wall of the large intestine. Bacterial action also produces gas, which is expelled from the body.

ISBN 978-1-108-88711-3

At this point the material inside the colon is semi-solid as it is pushed into the rectum via peristaltic contractions. As the waste material is pushed into the thin walls of the rectum, stretching occurs, and this triggers defecation. A sphincter muscle around the external opening of the rectum, the anus, controls the removal of faeces. As the muscle relaxes, faecal matter, which consists of undigested food (mainly cellulose), water, bacteria and bile, can be pushed through the anus and removed from the body.

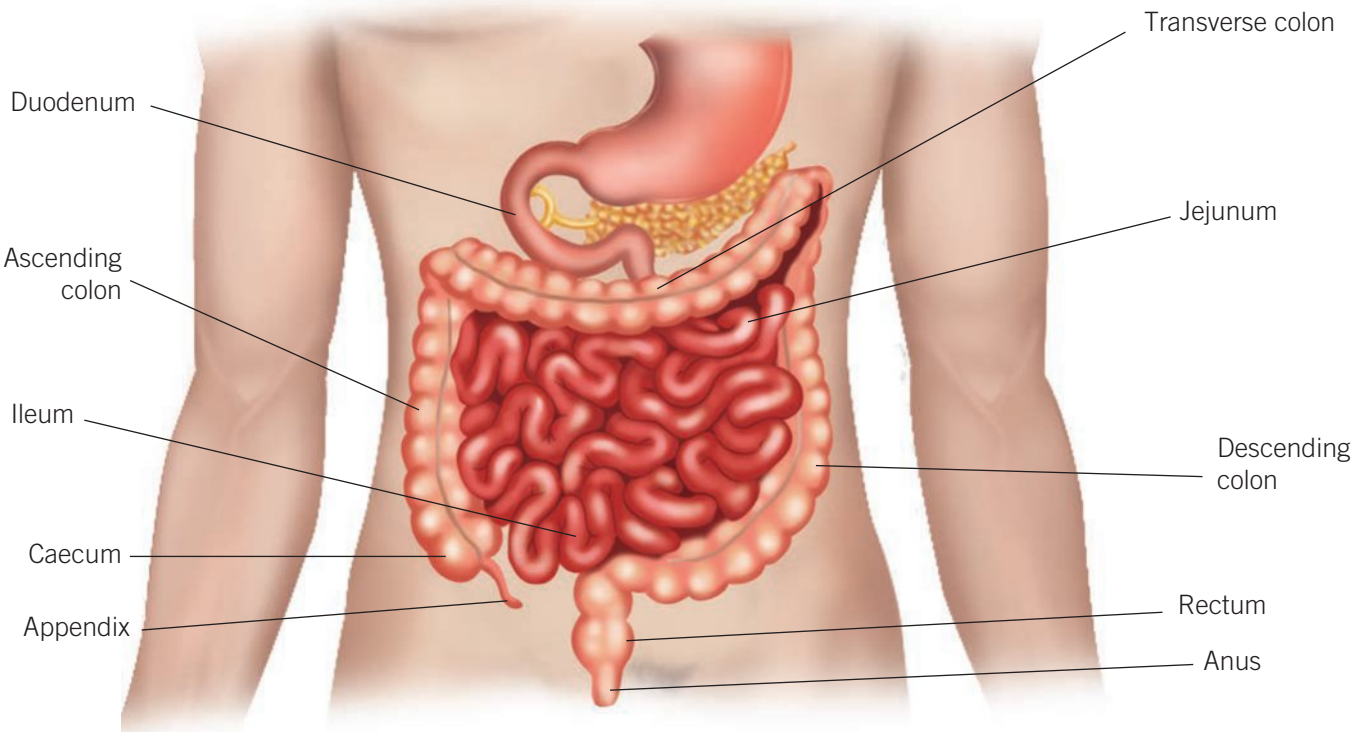



**Figure 4B–9** The U-shaped structure of the large intestine frames the small intestine.

## Check-in questions – Set 3

1 Name the three regions of the small intestine.
2 What is predominantly absorbed through the large intestine?
3 What does waste expelled from the body via the anus consist of?

## Specialised cells of the digestive system

As you read in Section 4A, it takes a variety of specialised cells (that form different tissues) to then form an organ that is suitably adapted to fulfil its role within a body system. The digestive organs consist of an array of complex specialised cells, particularly within the stomach and the small intestine.

LINK 4A FROM CELLS TO SYSTEMS

### Specialised cells of the stomach

As you read earlier, cells of the stomach secrete gastric juice, resulting in a highly acidic internal environment. Four types of specialised cells line the internal surface of the stomach and contribute to the production of gastric juice, as shown in Figure 4B–10.

ISBN 978-1-108-88711-3

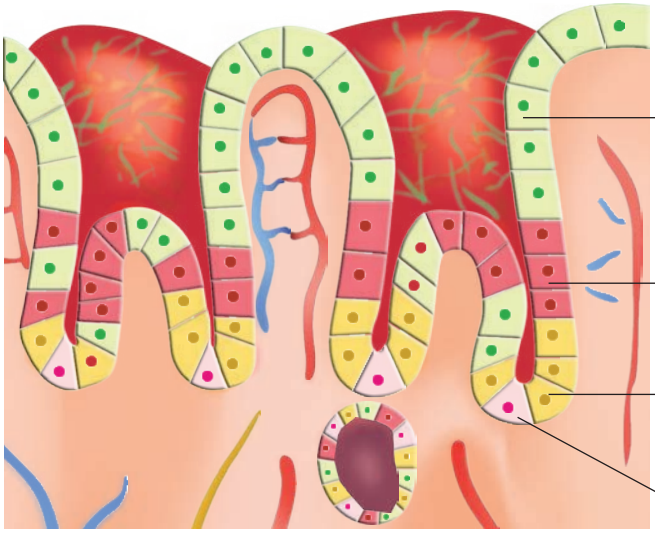



**Figure 4B–10** A cross-section of the inner lining of the stomach, showing the location of each specialised cell

2C SURFACE AREA TO VOLUME RATIO LINK

**Microvilli** minute projections that line the villi of the small intestine to further increase the surface area

## Specialised cells of the small intestine

Although digestion continues in the small intestine, its primary role involves the absorption of nutrients into the bloodstream. It is therefore essential that the surface area of the small intestine is increased so that maximum absorption can take place. The long, thin and highly folded nature of the small intestine provides a large surface area through which absorption can occur. It also has a thin, moist lining with an extensive network of blood vessels, which further assists in maximising absorption. The key factor in ensuring efficient absorption within the small intestine is the villi (singular: villus). These tiny fingerlike projections dramatically increase the surface area of the small intestine. Each villus (about 0.5–1.6 mm long) is lined with **microvilli** (about 1 μm), which increases the surface area even further.

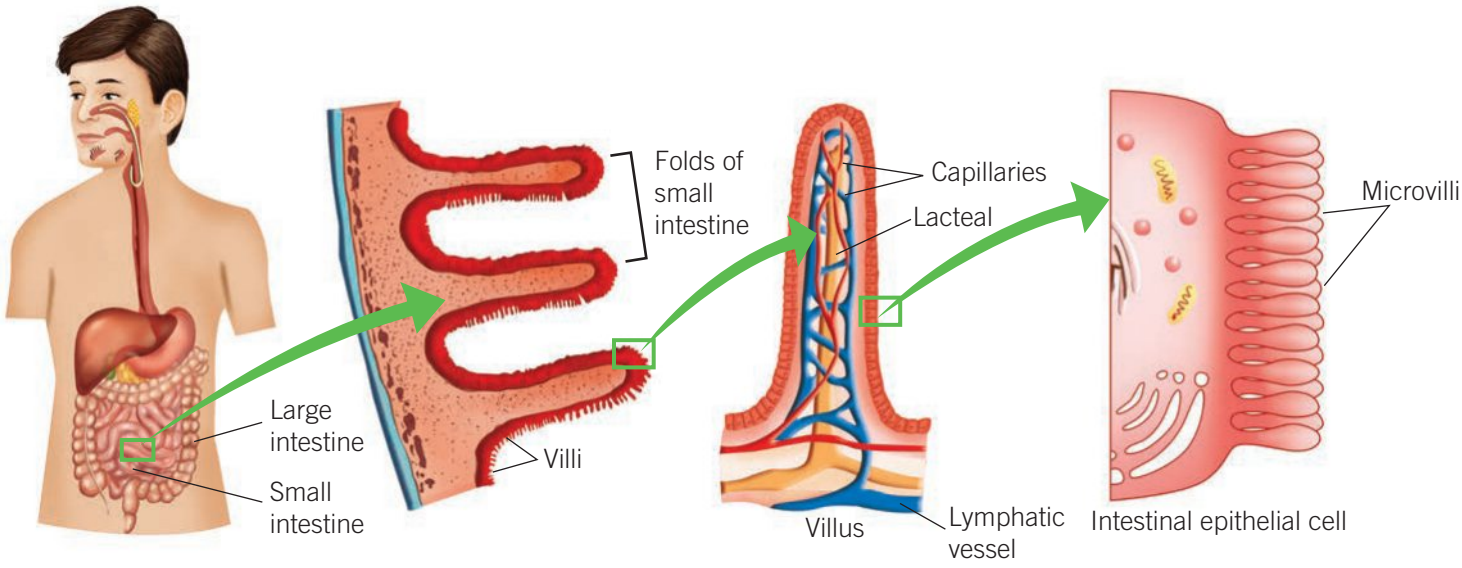



**Figure 4B–11** The inner lining of the small intestine contains tiny projections called villi and microvilli, which dramatically increase the surface area for absorption of nutrients into the bloodstream.

ISBN 978-1-108-88711-3

Within each villus is a complex network of capillaries that absorb glucose and amino acids from the digestive system into the circulatory system. Absorption of these substances occurs through facilitated diffusion and active transport. Within each villlus there is also a lymph vessel known as a **lacteal**. Here, glycerol and fatty acids are absorbed from the digestive system into the lymphatic system. Because glycerol and fatty acids are lipid soluble (hydrophobic/lipophilic), diffusion easily allows their fast absorption into the lacteals. Water is also absorbed (by osmosis) into the blood.

LINK 2A THE NATURE OF SUBSTANCES AND THEIR MODES OF TRANSPORT
LINK 2B OSMOSIS

**Lacteal**
a lymphatic vessel within the villi of the small intestine that absorbs glycerol and fatty acids

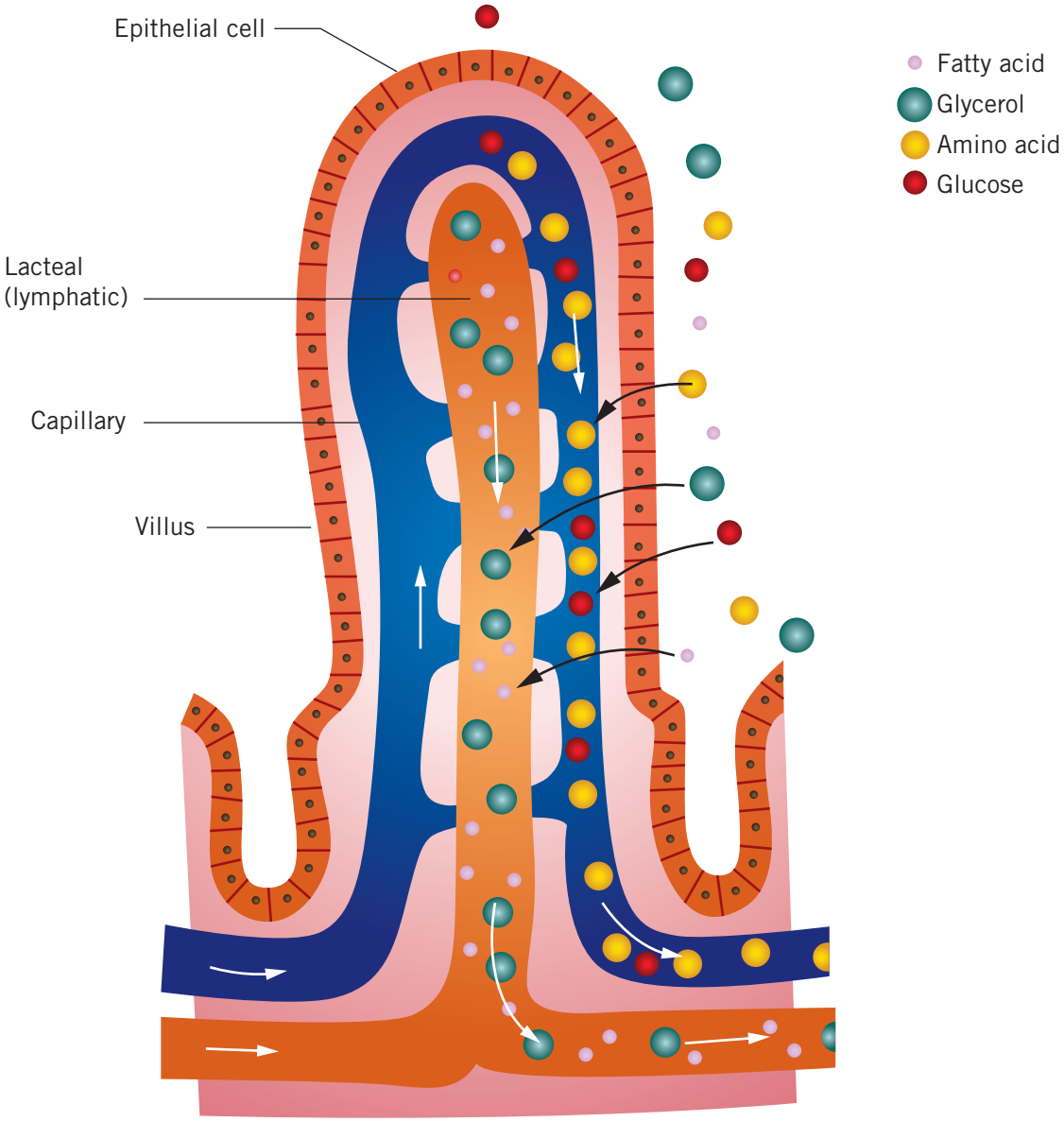



**Figure 4B–12** A villus, showing nutrient absorption. Nutrient absorption depends on chemical structure. Fatty acids and glycerol are absorbed into the villi's lacteals, and amino acids and glucose into the capillaries.

## Check-in questions – Set 4

1 Briefly explain the role of each specialised cell in the stomach.
2 Name the key features of the small intestine that give it such a large surface area.
3 How do amino acids and fatty acids differ in how they are absorbed into the bloodstream?
4 Where does the absorption of glucose occur? What method of membrane transport does it use?

WORKSHEET 4B–2 SUMMARISING THE DIGESTIVE SYSTEM

ISBN 978-1-108-88711-3

# Malfunctions of the digestive system

## Coeliac disease

**Coeliac disease** an autoimmune disease in which an individual's own immune system attacks the cells of the small intestine

**Coeliac disease** is an autoimmune disease that occurs when an individual's own immune system attacks the cells of the small intestine in response to gluten. Gluten is a protein found in wheat, rye, barley and oats. When foods containing gluten (such as bread made from wheat) are eaten, the cells of the small intestine become inflamed. If the condition is left untreated, the villi of the small intestine become inflamed and 'droopy'. This droopiness reduces the overall surface area of the small intestine, and consequently nutrient absorption also decreases, leading to deficiencies.

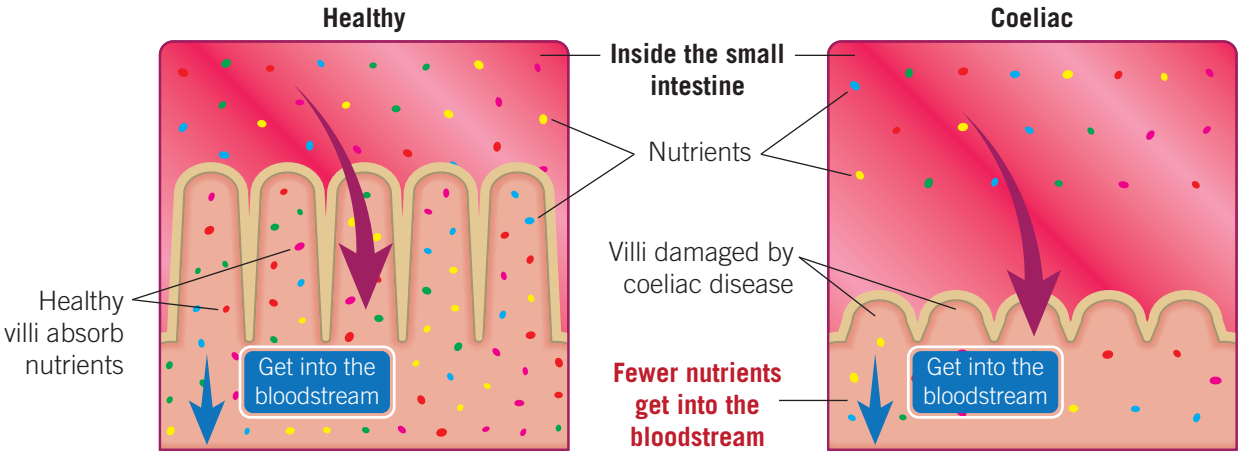



**Figure 4B–13** Comparison of nutrient absorption between a healthy individual and a coeliac sufferer

Coeliac disease affects approximately 1 in 70 Australians, but about 80% of these remain undiagnosed. Diagnosis is important because, if left untreated, coeliac disease can lead to a variety of poor health outcomes, including osteoporosis, depression, type 1 diabetes and some forms of cancer. Fortunately, treatment involving a lifetime of strict gluten avoidance allows the intestinal villi to heal and the sufferer to live a life of better health.

5C HOMEOSTASIS GONE WRONG LINK

## Heartburn

**Heartburn** a burning sensation in the chest caused by stomach acid rising into the oesophagus

**Heartburn** occurs when an uncomfortable burning sensation is felt in your chest, often accompanied by a bitter taste in your throat. It is the result of the contents of the stomach coming back up into the oesophagus. If the cardiac sphincter muscle between the oesophagus and stomach becomes weakened, gastric juices containing hydrochloric acid rise into the oesophagus, irritating it in a condition known as reflux.

Heartburn can be treated easily by taking antacid tablets, which neutralise stomach acid and consequently stop the burning sensation. Heartburn is generally no cause for alarm and can be caused by a variety of factors, such as eating spicy foods, too much chocolate, caffeine or alcohol, or lying down after eating. It is also a common condition in pregnancy, because increased production of the hormone progesterone can cause the cardiac sphincter to relax. Persistent episodes of heartburn should, however, be checked by a doctor as it could be symptomatic of a more serious condition, such as a gastric ulcer or a hernia.

ISBN 978-1-108-88711-3

## Check-in questions – Set 5

1 Define 'coeliac disease'.
2 What causes heartburn?
3 How do antacid tablets alleviate symptoms?

## 4B–D SKILLS

*This Skills section applies to Sections 4B-4D. Refer back to it when completing the end-of-section questions.*

VIDEO 4B–2 SKILLS: MAMMALIAN SYSTEMS

**Mammalian systems: making connections between topics**

In Biology, you are expected to be able to apply your knowledge by making connections between the different areas of the Study Design. The questions that test your knowledge in this way require higher-order thinking skills, and answering them correctly will be the difference between an average mark and a very good mark.

You will have noticed throughout each chapter that there are 'icons' in the margin that show a link between the content you are currently reading and concepts you have already read about in previous sections or will read about in later sections. These links are designed to help you make connections between key concepts and take your understanding to a higher level. Consider the following question.

> *Question*: After a person had digested lunch, the glucose concentration in their small intestine was measured to be 7.5 mmol/L, whereas in their bloodstream it was 4.0 mmol/L. Thirty minutes later, the concentration of glucose in the blood had increased to 5.3 mmol/L, and in the small intestine it had decreased to 6.2 mmol/L. Explain the process that led to this change in blood glucose. (2 marks)
>
> To answer, start by identifying the connections between topics.
> - Topic 1: The digestive system – specifically the absorption of glucose into the bloodstream that occurs in the small intestine (Section 4B)
> - Topic 2: Movement across membranes – specifically the facilitated diffusion of glucose across the intestinal wall into the bloodstream (Section 2A)

Hopefully, you will have noticed that the command term in this question is 'explain'. Let's step through the DER acronym from the Skills discussion in Section 2B before forming an answer.

- *Define:*
  - Facilitated diffusion is the net passive movement of a substance from a region of high concentration to a region of low concentration with the assistance of a protein until equilibrium is reached.
  - Absorption is the movement of nutrients out of the digestive system and into the bloodstream for delivery to cells.
- *Explain:* Glucose is the nutrient that moves out of the digestive system into the bloodstream for delivery to cells and is needed for cellular respiration.
- *Relate:* Blood glucose levels have increased from 20 mmol/L to 35 mmol/L – an increase of 15 mmol/L.

ISBN 978-1-108-88711-3

Therefore, to gain full marks, an answer to the question would be:

- Glucose moves passively by facilitated diffusion from an area of high concentration to an area of low concentration with the help of a protein.
- Initially there was a higher concentration of glucose in the small intestine (55 mmol/L) and a lower concentration in the blood (20 mmol/L).
- This resulted in the absorption of glucose from the small intestine into the bloodstream for its delivery to cells for use in cellular respiration.
- As a result, blood glucose concentration increased from 20 mmol/L to 35 mmol/L.

Let's try another question, this time with a focus on the excretory system.

*Question*: Diuretics are commonly referred to as 'water pills', as they increase the amount of water and salt excreted from the body as urine. The key to this is the role of the diuretic in reducing the amount of sodium ($Na^+$) reabsorbed in the loop of Henle. Explain how this leads to an increase in the excretion of urine. (2 marks)

- Topic 1: The excretory system – the reabsorption of $Na^+$ from the loop of Henle back into the blood (Section 4D)
- Topic 2: Movement across membranes – specifically the movement of water from the blood into the loop of Henle (Section 2B)

*Answer*:

- Using a diuretic results in a higher $Na^+$ concentration in the loop of Henle (hypertonic) than in the blood (hypotonic), which has a lower solute concentration.
- Water moves passively by osmosis from an area of high free water concentration to an area of low free water concentration across a semi-permeable membrane.
- So water moves from the bloodstream into the loop of Henle, resulting in the formation of more urine to be excreted.

Although the DER framework was not explicitly stated in this question, it still forms the basis of the answer. Practise applying DER by finding all the components of the answer.

Let's look at another example.

*Question*: Sufferers of coeliac disease have reduced numbers of villi or 'droopy' villi in the lining of their small intestine. Explain the consequences of reduced numbers of villi in coeliac patients. (2 marks)

- Topic 1: The digestive system – the role of villi in the absorption that occurs in the small intestine (Section 4B)
- Topic 2: Surface area – how SA:V ratio is used within an organism (Section 2C)

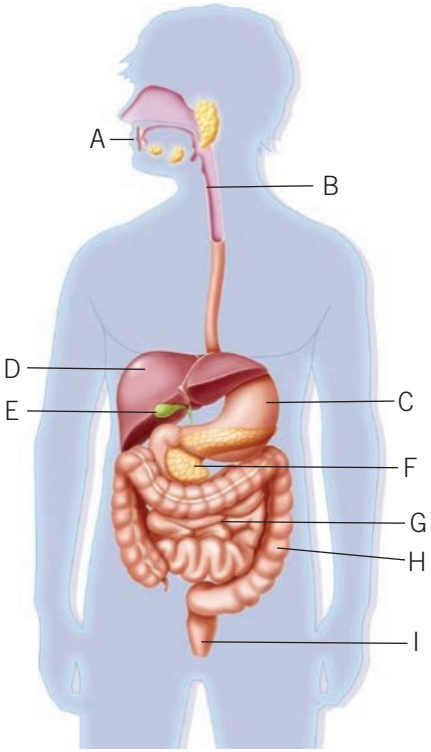
*Answer*: Villi in the small intestine allow greater absorption of nutrients into the bloodstream by increasing the surface area over which this exchange can occur. (1 mark) Reduced numbers of villi will reduce the surface area of the small intestine that this exchange can occur over, resulting in the decreased absorption of nutrients into the bloodstream for delivery to cells. (1 mark)

The end-of-section questions in this chapter will help you practise making connections between topics. As you work through these questions, remember to use the 'link icons' throughout the chapter to help you make relevant connections in your answers.

ISBN 978-1-108-88711-3

## Section 4B questions

1 Identify each of the labelled structures of the human digestive system shown at right.

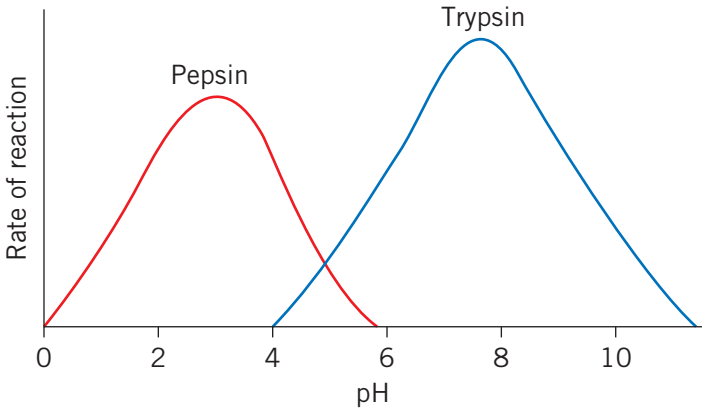



2 Food needs gravity to get to your stomach. Is this statement true or false? Justify your answer.

3 Why is it important that mechanical digestion occurs before chemical digestion in the digestive tract?

4 The surface area of the small intestine is approximately 250 square metres, or the size of a tennis court. This is because it has three features that are designed to maximise surface area. Identify and describe these features.

5 As proteins move along the digestive tract, they are digested by a class of enzymes known as proteases. All enzymes have optimal conditions that they work best under. The graph below shows the optimal pH of two digestive enzymes, pepsin and trypsin.




   a How does the optimal pH of the two digestive enzymes compare?
   b Based on your knowledge of the digestive system, where would you expect to find these two enzymes performing at their peak? Justify your answer.

6 Amylase is another enzyme of the digestive system. It is involved in the breakdown of complex carbohydrates, such as starch. It is most effective in the mouth and small intestine.
   a What does this suggest about the optimal pH of amylase compared to that of pepsin and trypsin?
   b Draw a graph that shows the action of amylase against the action of pepsin and trypsin.

7 Predict the effects on an individual if they did not have a large intestine and, instead, the small intestine connected directly to the anus.

8 Gallstones are small stone-like deposits that form from digestive fluid in the gall bladder. They can cause significant pain in sufferers , who may have to have their gall bladder removed. Many patients who have had their gall bladder removed have reported weight gain in the months after their surgery.
   a Use your knowledge of the digestive system to explain this trend.
   b What dietary advice would you give a patient who has had their gall bladder removed? Explain.

ISBN 978-1-108-88711-3

# 4C The endocrine system: chemical control

**Study Design:**
Specialisation and organisation of animal cells into tissues, organs and systems with specific functions: digestive, endocrine and excretory

**Glossary:**
Diabetes
Gland (endocrine)
Homeostasis
Hormone
Hyperthyroidism
Hypothyroidism
Pathogen
Target cell

## ENGAGE

### Hormones and height

Human height is the result of the interaction between genetics and environmental factors. The findings of the Human Genome Project have shown that it takes the interaction of approximately 697 genetic factors to determine our final height. Research has also shown a strong relationship between poor growth and illness or malnutrition as a child.

8B INTRODUCTION TO GENETICS LINK

Current data shows that the average global height of men is 171 cm and of women is 159 cm. Australians are above average: Australian men average 179 cm and women 166 cm.

According to the current Guinness World Records, the tallest living person is a Turkish farmer named Sultan Kosen, at a staggering 251 cm. The smallest living person ever documented and verified was Chandra Bahadur Dangi, from Nepal, who measured 54.64 cm.

Both these Guinness World Record holders are a long way from 'average'. How do we explain such extremes? The answer is growth hormone. Growth hormone is released from the pituitary gland, and it controls the development of cartilage, bone and muscle. Damage to the gland (e.g. from a tumour) can result in the overproduction or underproduction of growth hormone, which in turn results in the extreme heights seen in Sultan and Chandra.

**Figure 4C–1** Chandra Bahadur Dangi and Sultan Kosen together at a Guinness World Records day event.

ISBN 978-1-108-88711-3

EXPLAIN

## What is the endocrine system?

The endocrine system is a collection of **glands** that produce and secrete a variety of chemical messengers known as **hormones**. Hormones are released into the bloodstream, where they travel to a **target cell**/area and act to regulate various activities within the organism. Hormones control a wide range of bodily functions. They influence the growth and development of body parts, cellular metabolism, reproduction and behaviour. They also act to maintain **homeostasis**, a constant internal environment. Figure 4C–2 shows the location of the major endocrine glands in the body. Table 4C–1 on the next page lists the various hormones that they release and the bodily functions they control.

VIDEO 4C–1 THE HUMAN ENDOCRINE SYSTEM

LINK 5B HOMEOSTASIS

**Gland (endocrine)** an organ of the endocrine system that secretes hormones directly into the bloodstream

**Hormone** a chemical messenger that travels through the blood to a target cell to initiate a response

**Target cell** a cell with a complementary receptor for a signalling molecule/hormone

**Homeostasis** the maintenance of a constant internal environment despite changes in the external environment

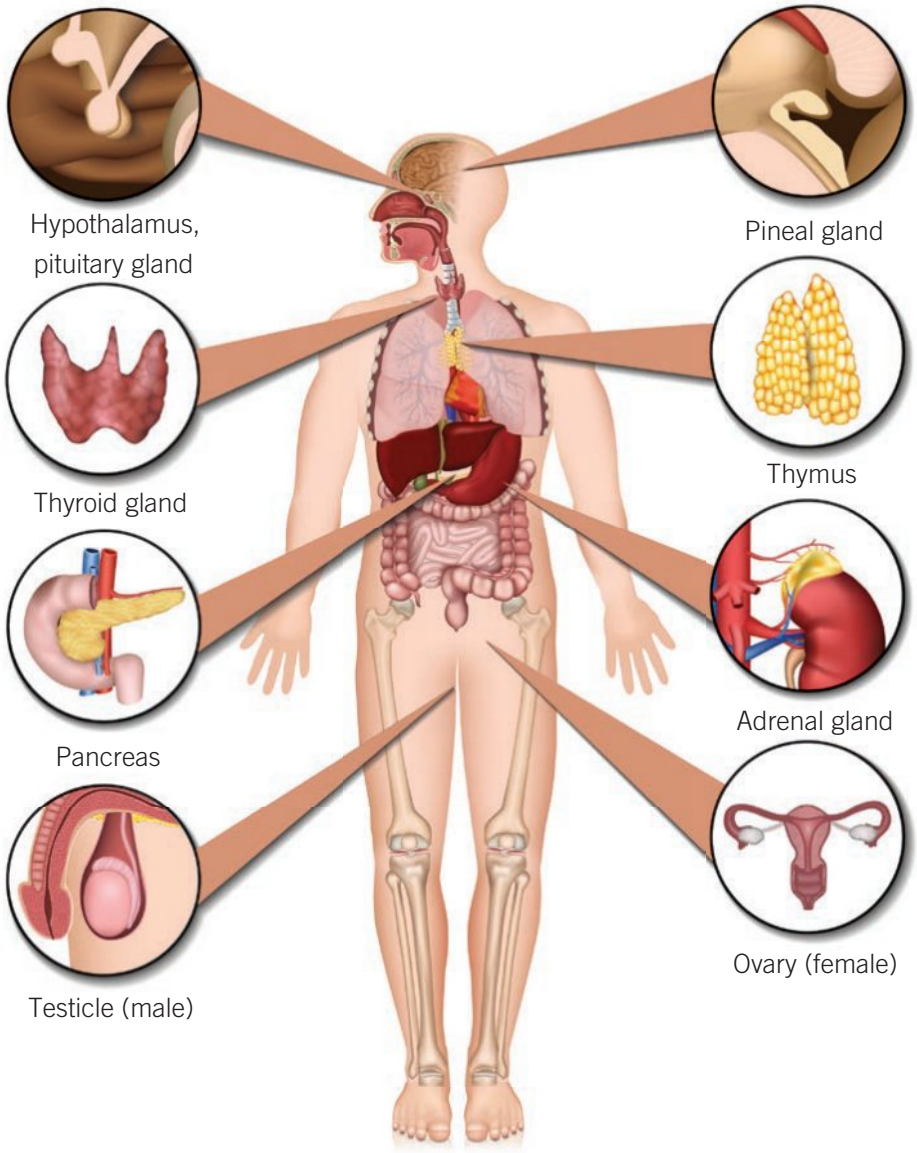



**Figure 4C–2** Endocrine glands of the human body

NOTE

The word 'hormone' comes from the Greek word *hormao* meaning 'I excite' and refers to the fact that each hormone excites or stimulates a specific target cell.

ISBN 978-1-108-88711-3

**Table 4C–1** Human endocrine glands, the hormones they secrete and the bodily functions they control

| Gland | Hormone | Target area | Function |
|---|---|---|---|
| Hypothalamus | Various types of releasing and inhibiting hormones | Pituitary gland | Regulates the release of anterior pituitary hormones |
| Pituitary gland: anterior (front of gland) | TSH (thyroid-stimulating hormone) | Thyroid | Stimulates production of thyroid hormones |
| | ACTH (adrenocorticotrophic hormone) | Adrenal gland | Stimulates production of adrenal hormones |
| | LH (luteinising hormone) | Gonads (testes in males and ovaries in females) | Stimulates sex hormone production and egg and sperm production |
| | FSH (follicle-stimulating hormone) | | |
| | PRL (prolactin) | Mammary glands | Stimulates milk production |
| | GH (growth hormone) | Tissue and bone | Stimulates cell division, protein production and bone growth |
| Pituitary gland: posterior (back section of gland) | ADH (antidiuretic hormone) | Kidneys | Increases reabsorption of water |
| | Oxytocin | Uterus and mammary glands | Increases uterine contractions and release of milk |
| Pineal gland | Melatonin | Brain | Regulates natural sleep–wake cycle |
| Thyroid | Thyroxine | All tissues | Increases metabolic rate, regulates growth |
| | Calcitonin | Bones, kidneys, intestines | Lowers blood calcium level |
| Parathyroid | PTH (parathyroid hormone) | Bones, kidneys, intestines | Raises blood calcium level |
| Thymus | Thymosin | T-lymphocytes (type of white blood cell) | Stimulates production of T lymphocytes |
| Adrenal | Cortisol | All tissue | Raises blood glucose levels and stimulates breakdown of protein |
| | Aldosterone | Kidneys | Reabsorbs sodium and excrete potassium |
| | Epinephrine (adrenalin) and norepinephrine (noradrenalin) | Cardiac and other muscle tissue | Activates the fight or flight response and raises blood glucose levels |
| Pancreas | Insulin | Liver, muscles and fatty tissue | Decreases blood glucose levels |
| | Glucagon | Liver, muscles and fatty tissue | Increases blood glucose levels |
| Gonads: testes | Testosterone | Gonads, skin, muscle, bone | Stimulates male sex features |
| Gonads: ovaries | Oestrogen | Gonads, skin, muscle, bone | Stimulates female sex features |
| | Progesterone | Gonads, skin, muscle, bone | Induces changes during pregnancy (e.g. placenta formation) |

ISBN 978-1-108-88711-3

## How do hormones exert control?

All hormones follow the same communication principles:

1 Specialised cells in the endocrine gland secrete the hormone.
2 The hormone travels in the bloodstream to target cells in a particular tissue.
3 The hormone binds to a specific receptor on the target cell (complementary in shape and charge), which initiates a response.

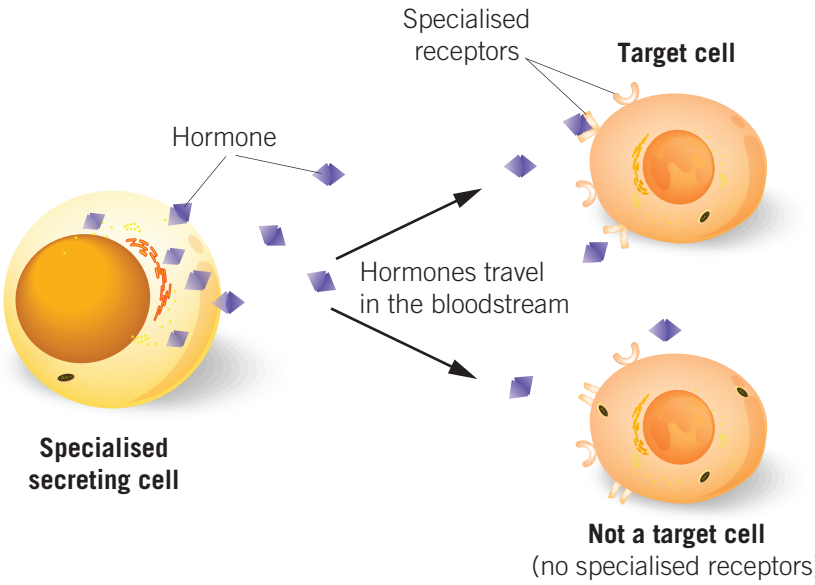



**Figure 4C–3** The interaction between hormones and their target cell receptors is highly specific. The complementary nature of the interaction is just like that of jigsaw puzzle pieces fitting together.

While endocrine responses tend to be slower than nervous system responses, they are longer lasting, making them better suited for the control of actions that require sustained balance, such as blood glucose levels. By travelling in the blood, hormones can have far-reaching effects within the organism, initiating responses in cells that are widely distributed around the body.

LINK 2A THE NATURE OF SUBSTANCES AND THEIR MODES OF TRANSPORT

All hormones can be classified into one of two categories, according to their chemical make-up:

- *protein (peptide) based* – hydrophilic in nature, unable to diffuse through the plasma membrane of their target cells; an example is insulin
- *lipid (steroid) based* – hydrophobic in nature, can diffuse through the plasma membrane of their target cells; an example is testosterone.

Whether a hormone is protein based or lipid based influences the position of the complementary receptor on the corresponding target cells. This is illustrated in Figure 4C–4.

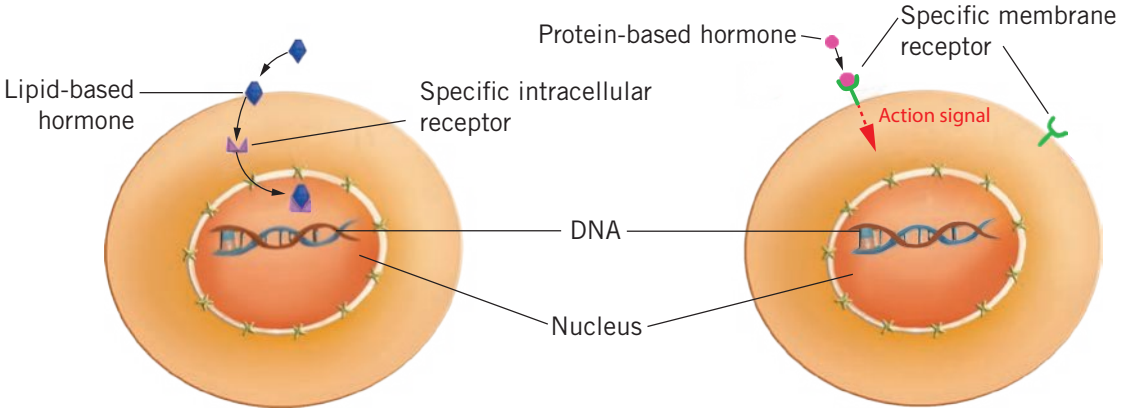



**Figure 4C–4** Lipid-based hormones are able to diffuse through the plasma membrane of their target cells, where they bind to specific intracellular receptors (as shown at left). Protein-based hormones are unable to pass through the plasma membrane of target cells, so they must bind to a specific complementary receptor on the surface of the membrane, which then sends a signal to carry out an action (as shown at right).

ISBN 978-1-108-88711-3

## Pituitary: the master gland

It is important that the nervous system and the endocrine system work closely together to maintain balance within an organism. This communication is achieved by the interaction between a small region at the base of the brain, known as the *hypothalamus*, and an even smaller gland nearby, about 1 cm in diameter, known as the *pituitary gland*. A stalk-like structure acts as a bridge connecting the two (Figure 4C–5).

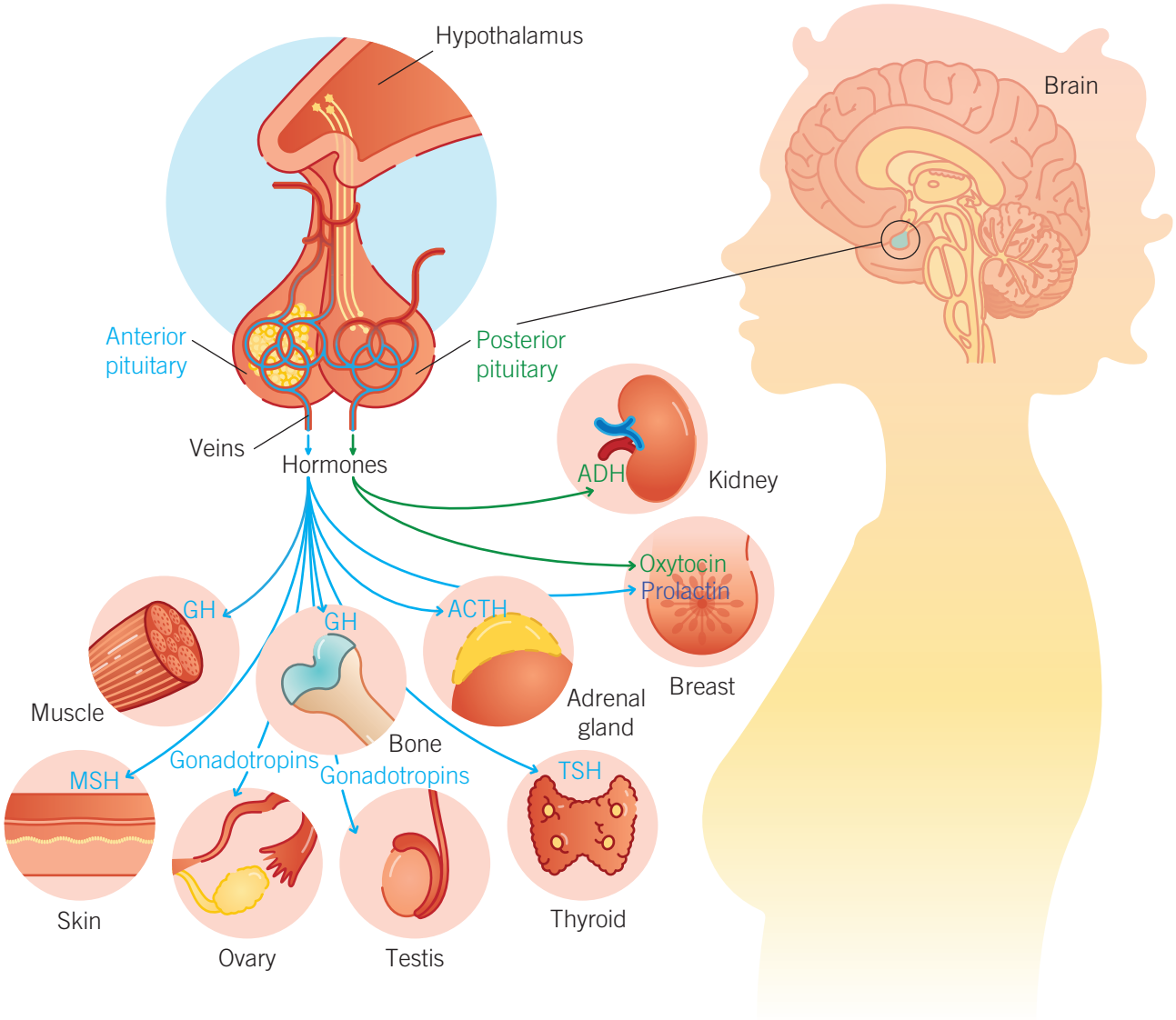



**Figure 4C–5** The wide-reaching effects of the pituitary gland. This is why it is known as the 'master gland'.

The hypothalamus is constantly surveying the conditions of an organism's internal environment. It helps to regulate heartbeat, body temperature and water balance. The pituitary gland is referred to as the 'master gland' as it responds to information from the hypothalamus by secreting a range of hormones that will act on other endocrine glands to restore balance if conditions change.

ISBN 978-1-108-88711-3

As you saw in Table 4C–1 (page 190), the pituitary gland has two parts: the anterior (front) and posterior (back). By regulating the release of hormones from the anterior section of the pituitary gland, the hypothalamus exerts control over other endocrine glands. Four of the hormones released by the anterior pituitary gland directly influence the release of hormones from other endocrine glands: ACTH on the adrenal gland, TSH on the thyroid, and FSH and LH on the ovaries and testes. By working together, the hypothalamus, pituitary gland and the other glands it controls act on feedback to maintain homeostasis – more details will be provided in Chapter 5.

LINK 5A HOMEOSTASIS

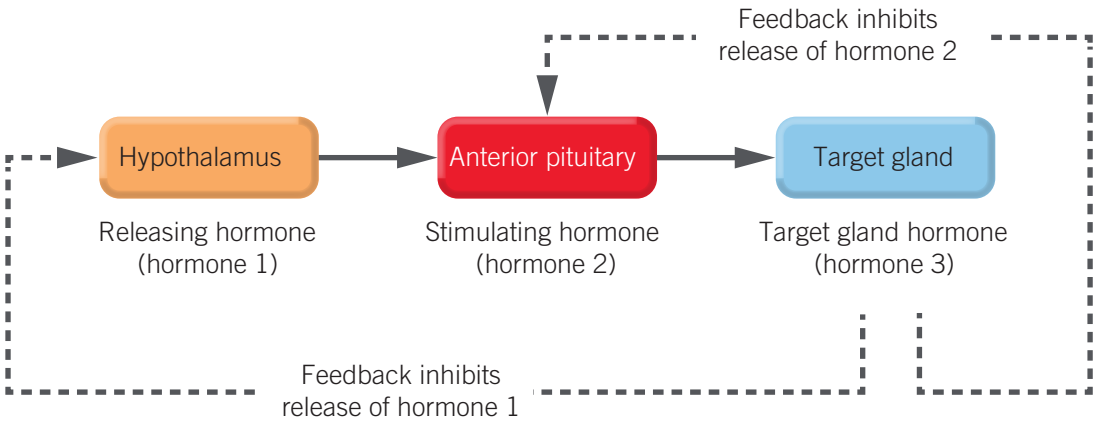



**Figure 4C–6** The feedback pathways by which the hypothalamus and the pituitary gland oversee other endocrine glands and maintain homeostasis. When the target gland has released enough hormone 3, feedback loops (negative in this case) stop the release of hormones 1 and 2.

## Check-in questions – Set 1

1 Define 'homeostasis'.
2 Which gland(s) are responsible for maintaining blood calcium levels?
3 Name the hormones responsible for stimulating the development of sex characteristics in males and females.
4 Describe the three steps involved in all hormonal communication.

## Specialised cells of the endocrine system

Each of the glands that make up the endocrine system contain specialised cells that produce and release a specific hormone into the bloodstream. Upon release, each hormone acts on its target cell(s) to bring about a response that is vital to the overall balance and development of the organism.

### Thyroid gland (thyroxine and calcitonin)

The thyroid gland, shown in Figure 4C–2, is a butterfly-shaped gland located at the base of the neck. It consists of two types of specialised cells that produce and release the protein-based hormones, thyroxine and calcitonin.

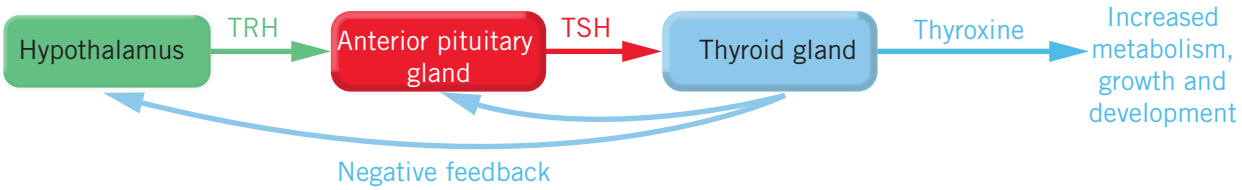
ISBN 978-1-108-88711-3

## Thyroxine

2D ROLE OF CHLOROPLASTS AND MITOCHONDRIA LINK

Thyroxine controls the metabolic rate of an organism. Rather than interacting with membrane receptors on a single organ, thyroxine acts to increase metabolic rate by stimulating all cells of the body to convert glucose into ATP more quickly.

The release of thyroxine from the thyroid follows a hierarchical pathway that is initiated by the hypothalamus. This release pathway is shown in Figure 4C–7.




TRH: Thyrotropin-releasing hormone
TSH: Thyroid-stimulating hormone

**Figure 4C–7** The feedback pathway that controls the release of thyroxine from the thyroid gland

## Calcitonin

The thyroid gland also releases the hormone calcitonin. Calcitonin works closely with PTH (parathyroid hormone) released from the parathyroid gland to maintain stable blood calcium limits. The regulation of blood calcium through the action of these antagonistic (opposing actions) hormones is shown in Figure 4C–8.

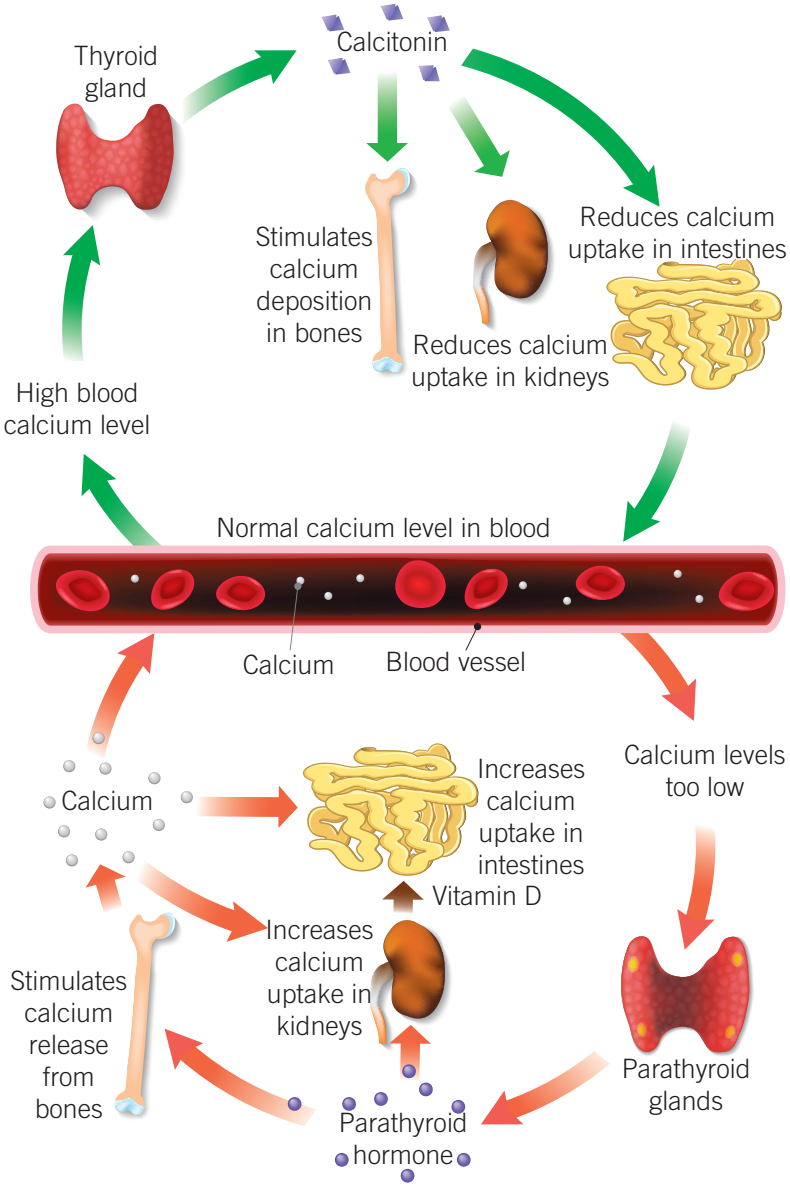



**Figure 4C–8** Hormonal regulation of blood calcium levels. Too much calcium could cause heart failure, while not enough calcium could cause loss of nervous system control.

ISBN 978-1-108-88711-3

## Thymus gland (thymosin)

The thymus is a pink, two-lobed structure that lies in front of the heart. While it is considered a component of the endocrine system, it is also a key structure of the lymphatic (immune) system.

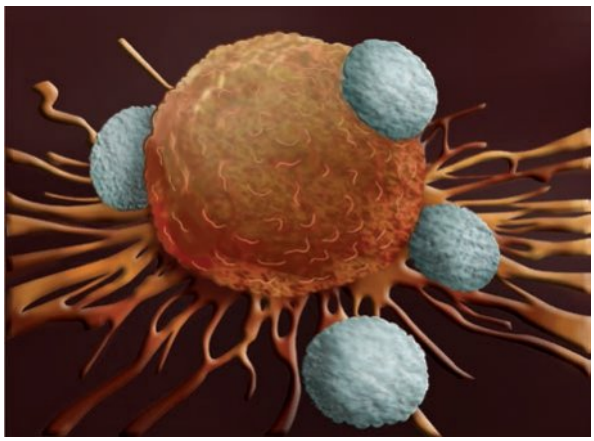


**Figure 4C–9** T-cells attacking a pathogen as part of an immune response that involves the hormone thymosin

LINK UNIT 4

**Pathogen**
a disease-causing agent

The function of the thymus is to receive a type of white blood cell known as a T-lymphocyte or T-cell. T-cells play a vital role in defending the body against harmful **pathogens**, such as viruses. As is the case with all types of blood cells, T-cells originate in the bone marrow. Unlike other blood cells, T-cells then migrate to the thymus for maturation, hence the name *T-cell* (t for thymus). The arrival of immature T-cells at the lobes of the thymus initiates the release of a protein-based hormone called *thymosin*. Specialised epithelial cells that line the thymus release thymosin, which acts on these immature T-cells (via a membrane receptor), causing them to mature. Once mature, they enter the bloodstream as highly specific immune cells, where they circulate throughout the body. The key role of T-lymphocytes in the immune system is discussed in detail as part of your Unit 4 Biology studies.

## Pancreas (insulin and glucagon)

The pancreas is a long organ (about 15 cm) that lies behind the stomach. The pancreas is made up of two types of tissue:

- exocrine tissue – responsible for the production and release of pancreatic juice into the duodenum via the pancreatic duct to aid digestion
- islets of Langerhans – endocrine tissue responsible for the production and release of the protein-based hormones insulin and glucagon into the bloodstream.

As you know, movement of substances into and out of cells relies on concentration gradients between the intracellular and extracellular environments. Glucose plays a key role in determining these gradients, so blood glucose levels must remain balanced for cells to function effectively. Two antagonistic hormones, insulin and glucagon, are responsible for maintaining blood glucose balance and overall homeostasis. Both hormones are produced and released from the islets of Langerhans in the pancreas, insulin from specialised 'beta' cells and glucagon from specialised 'alpha' cells (Figure 4C–10).

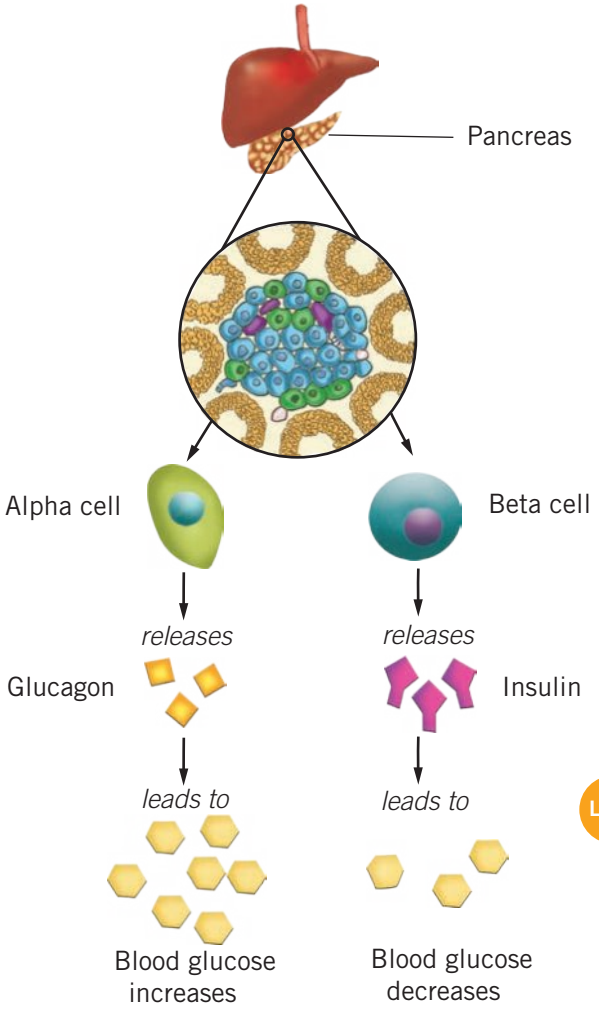



**Figure 4C–10** Islets of Langerhans in the pancreas contain specialised alpha and beta cells. These cells secrete the hormones responsible for keeping blood glucose concentration stable.

LINK 2A THE NATURE OF SUBSTANCES AND THEIR MODES OF TRANSPORT

ISBN 978-1-108-88711-3

5B HOMEOSTASIS IN ANIMALS LINK

The regulation of blood glucose through insulin and glucagon is an example of homeostasis through negative feedback and is described in detail in Section 5B.

## Gonads (testosterone/oestrogen)

2A THE NATURE OF SUBSTANCES AND THEIR MODES OF TRANSPORT LINK

The gonads (testes in males and ovaries in females) are responsible for the production of the sex hormones: testosterone, oestrogen and progesterone. Unlike the hormones of the thyroid, thymus and pancreas, sex hormones are lipid based and are therefore able to diffuse through the phospholipid bilayer portion of the plasma membrane of target cells and bind to complementary receptors in the cytosol.

The release of sex hormones from the gonads follows a hierarchical system, much like the release of thyroxine by the thymus gland. Hormones produced by the hypothalamus regulate the release of LH and FSH from the anterior pituitary gland, which in turn controls the secretion of testosterone, oestrogen and progesterone from the gonads. Traditionally, testosterone and oestrogen have been considered to be male and female sex hormones respectively. This, however, is not the case, as both hormones are actually produced in both sexes. Rather than the type of hormone produced being the difference between the sexes, it is the amount of each hormone. Males have approximately seven times more testosterone than females, and females produce significantly more oestrogen than males (Figure 4C–11).

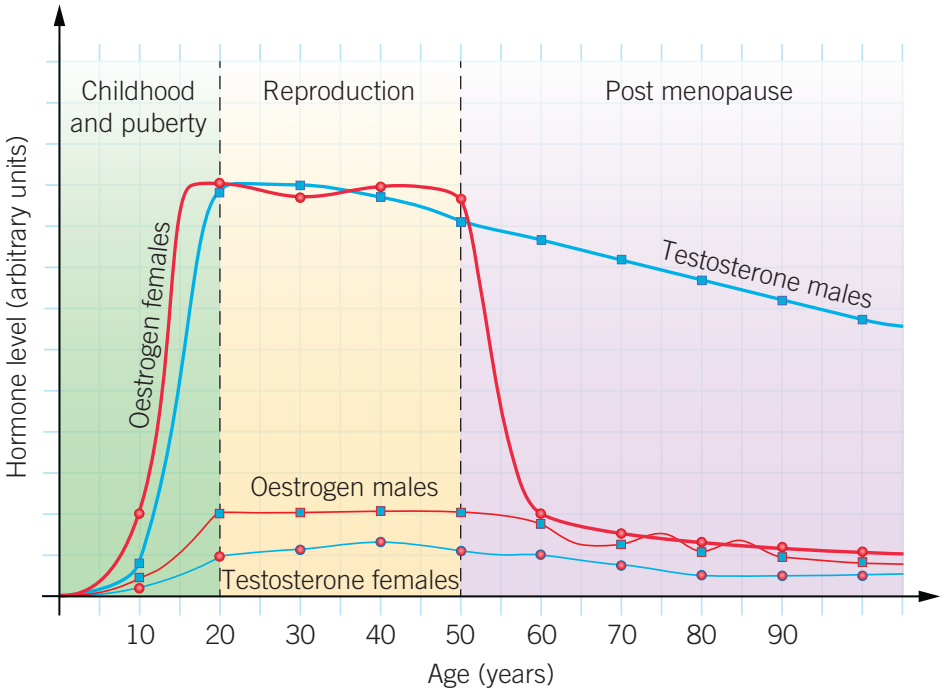



**Figure 4C–11** The levels of sex hormones in humans at different ages

### Testes

The testes contain specialised cells, known as *leydig cells*, that are stimulated by LH and FSH from the pituitary gland to produce and secrete testosterone. Testosterone is responsible for the development of typical male features such as the testes, prostate and sperm. Some testosterone is converted to oestrogen, which plays an important role in male fertility and sexual function.

ISBN 978-1-108-88711-3

The onset of puberty triggers an increase in the release of testosterone from the testes. This has the following effects:

- growth of penis and testes
- development of facial, underarm and pubic hair (secondary sex characteristics)
- enlargement of larynx and vocal cords (change in voice)
- increase in muscular strength
- stimulation of oil and sweat glands (contributing to acne and body odour).

### Ovaries

The ovaries contain specialised cells, known as *granulosa cells*, that contribute to oestrogen production, and *granulosa lutein cells*, which produce progesterone. As in the testes, the release of these hormones is stimulated by the action of FSH (oestrogen) and LH (progesterone) from the pituitary gland. Testosterone is also released from the ovaries in small amounts and contributes to the development of reproductive tissue and bone mass.

Oestrogen and progesterone play a role in many aspects of female development. While oestrogen is important in the development of female sex characteristics during puberty, progesterone is more active during pregnancy. Their roles are summarised in Table 4C–2.

**Table 4C–2** Functions of the female sex hormones

| Oestrogen | Progesterone |
|---|---|
| Regulates menstrual cycle through release of egg from ovaries | Regulates menstrual cycle through release of egg from ovaries |
| Stimulates vagina growth to adult size | Prepares lining of uterus for egg implantation |
| Stimulates development of pubic and armpit hair (secondary sex characteristics) | Plays an important role in foetal development through pregnancy |
| Causes growth of breasts during puberty | Stimulates breasts to produce milk |
| Makes bones of the pelvis broader | Strengthens pelvic wall muscles in preparation for labour |
| Keeps voicebox smaller and vocal cords shorter (higher-pitched voice) | |
| Increases fat storage around hips and thighs, giving rise to ‘curvy’ female shape | |
| Supresses glands that produce oil, reducing likelihood of acne | |
| Contributes to uterine contractions during labour | |

## Check-in questions – Set 2

1 Categorise the hormones produced by the thyroid gland, thymus gland, pancreas and gonads as protein based or lipid based.
2 Name the cells in the pancreas that secrete insulin and glucagon.
3 Why are insulin and glucagon described as ‘antagonistic’?


WORKSHEET 4C–1
THE ENDOCRINE SYSTEM

ISBN 978-1-108-88711-3

# Malfunctions of the endocrine system

## Diabetes

**Diabetes** is a condition that results from the body's inability to maintain healthy blood glucose levels. Glucose is unable to enter liver, fat and muscle target cells and instead remains in blood circulation. This elevated level of blood glucose is known as *hyperglycaemia*. Diabetes has become an epidemic of the 21st century and is currently the biggest challenge confronting the Australian health system. Currently 1.2 million Australians are diagnosed with diabetes and it is thought that another 500 000 are living undiagnosed with the condition. On average, 280 Australians are diagnosed with diabetes every day. That is one person every 5 minutes.

**Diabetes** a condition that results from an inability to maintain healthy blood glucose levels

There are two main types of diabetes and both arise from insulin not effectively carrying out its role in lowering blood glucose levels.

### Type 1 diabetes

UNIT 4 LINK

Type 1 diabetes occurs when immune cells attack and destroy the beta cells of the pancreas responsible for producing insulin. The cause of this autoimmune disease is currently unknown, and it cannot be cured or prevented. Sufferers of type 1 diabetes must have daily insulin injections to compensate for their body's inability to produce insulin. The diagnosis of type 1 diabetes represents approximately 10% of all diabetes cases.

### Type 2 diabetes

Type 2 diabetes currently represents approximately 90% of all diabetes cases and is increasing rapidly. It is a major consequence of Australia's obesity epidemic, with changes in diet and reduced physical activity being the main contributing factors.

Type 2 diabetes is the result of insulin resistance over a long period of time. Insulin slowly becomes ineffective at controlling blood glucose levels. To compensate, beta cells overproduce insulin, and over time become exhausted. Initially, exercise and a healthy diet can help in the management of type 2 diabetes. Ultimately, however, most sufferers will also require insulin, like type 1 sufferers.

Both types of diabetes are associated with the following symptoms: excessive thirst, increased urination, tiredness and lethargy, weight gain, dizziness/headaches, and constant hunger.

5B HOMEOSTASIS IN ANIMALS LINK

Early diagnosis and treatment plans are very effective in helping sufferers live a normal life. You can read more about the malfunction of insulin feedback pathways in Chapter 5.

## Graves' disease

**Hyperthyroidism** overproduction of thyroxine by the thyroid gland

Graves' disease is an autoimmune disease that affects the thyroid gland. It was discovered in 1835 when Robert J. Graves described it in a patient. It is the result of the thyroid gland producing too much thyroxine, a condition referred to as **hyperthyroidism**.

Graves' disease is the most common cause of hyperthyroidism. A properly functioning immune system involves white blood cells producing a special type of protein, known as an *antibody*. In a healthy individual, the role of antibodies is to destroy harmful invaders, but in Graves' sufferers, the immune system creates antibodies that mimic the action of pituitary TSH by binding to TSH receptors on the thyroid. This results in the thyroid being overstimulated, causing it to grow, overproduce thyroxine and speed up the person's metabolism. Common symptoms of Graves' disease are shown in Figure 4C–12.

ISBN 978-1-108-88711-3

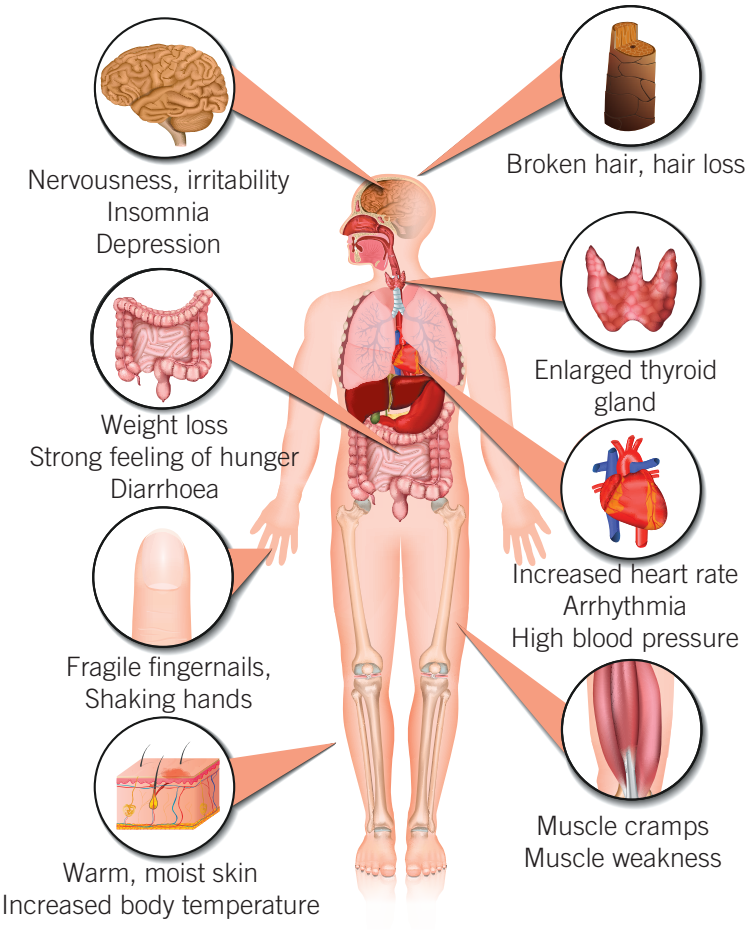



**Figure 4C–12** Graves' disease. Left: Symptoms of Graves' disease (hyperthyroidism). Right: Woman suffering from goitre (swelling of the neck) as a result of thyroid malfunction

The cause of Graves' disease is currently unknown but there is an element of genetic predisposition. Stress is also thought to play a role in the onset of the disease, and middle-aged females are eight times more likely than men to suffer from it. While there is no cure, there are treatment options:

- anti-thyroid drugs – interfere with the thyroid's ability to manufacture thyroxine from iodine
- radioiodine therapy – radioactive iodine is ingested and taken up by the overactive cells in the thyroid, killing them
- surgery – some or all of the thyroid gland is removed, depending on the severity of hyperthyroidism.

It is also possible to suffer from an underactive thyroid, where not enough thyroxine is released into the bloodstream. This is known as **hypothyroidism**. Symptoms include weight gain, fatigue, cold intolerance and goitres. Goitres result from the pituitary gland detecting low blood thyroxine levels and sending more TSH to the thyroid, causing it to enlarge. Hypothyroidism from infancy causes growth to be stunted. Treatment of hypothyroidism focuses on boosting thyroxine levels, either through hormone replacement tablets or by increasing the intake of iodised foods (seafood, dairy, bread made with iodised salt).

**Hypothyroidism** underproduction of thyroxine by the thyroid gland

Further information on the malfunction of thyroxine feedback pathways can be found in Chapter 5.

LINK **5B** HOMEOSTASIS IN ANIMALS

ISBN 978-1-108-88711-3

## Check-in questions – Set 3

1 Define 'hyperglycaemia'.
2 What component of the endocrine system is affected in the following disorders?
   a diabetes
   b Graves' disease
3 What is the difference between type 1 and type 2 diabetes?

VIDEO 4B–2 SKILLS: MAMMALIAN SYSTEMS

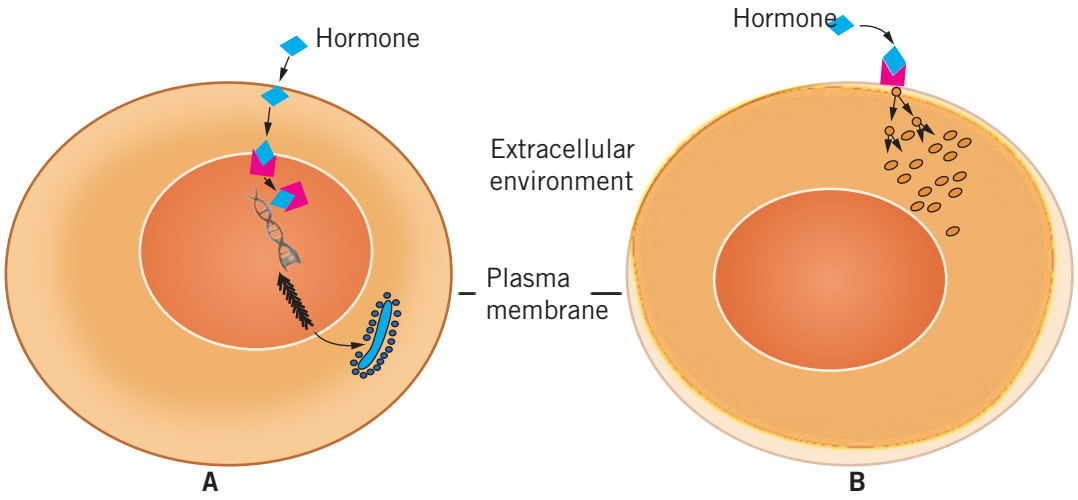
*Refer back to the 4B–D Skills section on pages 185–6.*

## Section 4C questions

1 Match the hormone to its gland and its function.

| Hormone | Gland | Function |
|---|---|---|
| Cortisol | Pineal | Decreases blood glucose |
| Testosterone | Parathyroid | Raises blood glucose and stimulates the breakdown of protein |
| Insulin | Adrenal | Stimulates male sex features |
| Melatonin | Testes | Regulates sleep–wake cycle |

2 Draw a simple diagram that shows the interaction between hormones and their receptors on target cells.
3 Complete each statement by selecting the correct term in the brackets.
   a A [target / receptor] cell is a specific cell on which a hormone acts.
   b A receptor is a [protein / enzyme] to which a molecule binds.
   c Amino acid based hormones are generally [protein / lipid] based.
   d The body makes steroid hormones from [lipids / proteins].
4 Thyroxine is a protein-based hormone produced in the thyroid gland. It plays an important role in metabolism regulation within an organism. The two diagrams shown below represent the interaction of thyroxine with its target cells.
   a Explain whether diagram A or B best represents the interaction of thyroxine with its target cells.
   b Describe why a cell might not respond to the action of thyroxine.




ISBN 978-1-108-88711-3

**5** Glucagon and insulin are referred to as 'antagonistic' hormones because they act to maintain stable blood glucose concentration from opposite extremes. Identify another example of antagonistic hormones from this chapter. Explain why they can be classified as antagonistic.

**6** A surgical procedure known as a 'hypophysectomy' is performed when the pituitary gland is removed as treatment for tumours. Patients who have undergone this operation often require hormone replacement therapy (HRT) as a consequence of the procedure.Why is HRT required in hypophysectomy patients? Use an example in your answer.

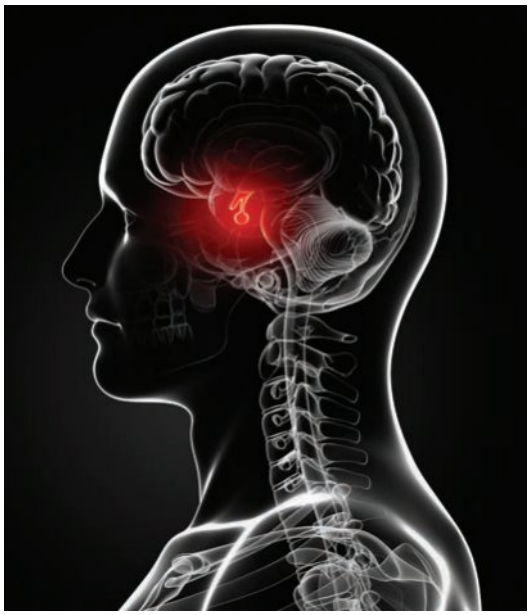


**Figure 4C–13** The location of the pituitary gland inside the brain

**7** A patient presents to their doctor complaining of fatigue and frequent urination. A urine test shows that the patient has abnormally high levels of glucose in their blood. These symptoms could indicate a problem with the patient's endocrine system.

**a** Name the hormone involved and explain how it may be causing the symptoms.

**b** What is causing the patient's symptoms of tiredness and frequent urination?

**8** Pheromones are a type of chemical signal that work in a similar way to hormones. Where hormones travel through the blood to target cells, pheromones are released into the environment by an organism, where they act to affect the behaviour of individuals of the same species.

Neuroscientists have conducted a study that investigated two potential pheromones found in humans. One of these pheromones (AND) mimics the action of testosterone and is found in male sweat, while the other (EST) mimics the action of oestrogen and is found in female urine.

The scientists used positron emission tomography (PET) scans on subjects to study the blood flow to various parts of the brain while the person breathed in either AND or EST. They found a clear pattern of results in the brain activity of participants. These are summarised below.

| Human pheromone | Effect on females after smelling pheromone | Effect on males after smelling pheromone |
|---|---|---|
| AND (mimics testosterone) | Increased blood flow to brain | None |
| EST (mimics oestrogen) | None | Increased blood flow to brain |

**a** What is the independent variable in this study?

**b** What is the dependent variable in this study?

**c** What two factors should the neuroscientists control for their results to be valid?

**d** At a cellular level, explain why AND had an effect on female blood flow to the brain but not male blood flow.

**e** AND and EST both increase blood flow to the brain in the opposite sex. What is the biological significance of this response to the pheromones?

ISBN 978-1-108-88711-3

# 4D The excretory system: eliminating waste

**Study Design:**
Specialisation and organisation of animal cells into tissues, organs and systems with specific functions: digestive, endocrine and excretory

**Glossary:**
Arteriole
Excretion
Filtration
Glomerulus
Loop of Henle
Nephron
Peritubular capillaries
Reabsorption
Secretion
Tubule

## ENGAGE

### Water intoxication

In 2007, a Californian radio station held a competition, called 'Hold your wee for a Wii'. Contestants were asked to drink as much water as they could without using the toilet. The person who held on for the longest would win a Nintendo Wii, which at the time was highly sought after and nearly impossible to find in the shops. The competition cost 28-year-old Jennifer Strange her life.

Initially, contestants were required to drink 240 mL of water every 15 minutes, but this escalated as the competition progressed. The competition lasted for about 3 hours and it is estimated that, in this time, Jennifer consumed 8 litres of water, which is four times the recommended daily intake. For all her efforts, Jennifer finished in second place and won two concert tickets.On her way home, Jennifer was reportedly crying and complaining of a very painful headache. Later that day, she was found dead in her home. How is it that water, a substance so vital to life, can also kill?

5B HOMEOSTASIS IN ANIMALS LINK

2B OSMOSIS LINK

The answer lies within our excretory system. Healthy kidneys are able to excrete 1–1.5 litres of water per hour. If too much water is drunk, the kidneys cannot excrete enough water to maintain homeostasis. Sodium concentrations in the blood drop, and this affects internal concentration gradients. Water intoxication ends with brain cells bursting as water rushes into them via osmosis. Sadly, this is what cost Jennifer Strange her life.

## EXPLAIN

### Removing toxic by-products

VIDEO 4D–1 THE EXCRETORY SYSTEM

**Excretion** the process of eliminating waste matter

2D ROLE OF CHLOROPLASTS AND MITOCHONDRIA LINK

The excretory system is primarily responsible for maintaining water balance within an organism. It also plays a major role in the **excretion** of waste. The chemical reactions that occur within an organism provide the vital ingredients for life. While these reactions produce necessary chemicals such as oxygen and ATP, they also generate toxic by-products that cannot be stored and must be eliminated quickly. For example, carbon dioxide generated by aerobic cellular respiration is transported through the bloodstream to the lungs, where it is breathed out. The other main form of waste is nitrogenous waste (N-waste) created from the breakdown of proteins. It is the role of the excretory system to remove this waste before it becomes toxic to cells.

ISBN 978-1-108-88711-3

## Nitrogenous waste

To remain healthy, all mammals must eat a balanced diet that includes proteins. Proteins are important because the amino acids they contain are used as the building blocks of new proteins within the body, such as muscle fibres. Excess amino acids cannot be stored, and if left to accumulate, they can quickly become toxic. A process called *deamination* breaks down amino acids, releasing energy. It also isolates the nitrogen-containing amine group, which is converted to ammonia. Ammonia is extremely toxic to cells.

The excretion of ammonia requires a large amount of water. For this reason, some organisms (mainly land-based animals) convert ammonia into either urea or uric acid for excretion. In humans, liver cells perform this function.

A summary of the various forms of nitrogenous waste is given in Table 4D–1.

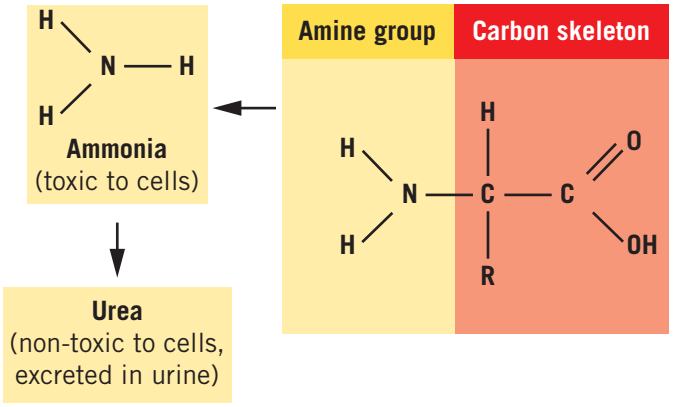



**Figure 4D–1** When amino acids are broken down, the nitrogen-containing amine group is converted to toxic ammonia.

**Table 4D–1** Forms of nitrogenous waste and their requirements for excretion

| Waste form | Advantages | Disadvantages | Habitat for excretion | Organisms |
|---|---|---|---|---|
| Ammonia | Requires very little energy to produce | Highly toxic to cells<br>Requires large amounts of water for excretion | Aquatic | Animals with a large amount of water available to them (e.g. fish) |
| Urea | Less toxic than ammonia<br>Less water needed for excretion | Requires more energy to produce it than ammonia | Land/sea | Animals with some water available to them, such as mammals (e.g. humans) and amphibians (e.g. turtles) |
| Uric acid | Relatively non-toxic<br>Requires little water for excretion | Requires a considerable amount of energy to produce it | Dry land | Egg-laying animals with little water available to them (e.g. birds, reptiles and insects) |

## Check-in questions – Set 1

1 Where does nitrogenous waste come from?
2 In what form do humans excrete nitrogenous waste?
3 Where is ammonia converted to urea?

## The mammalian excretory system – making urine

For simple unicellular organisms, such as an amoeba, the removal of waste is uncomplicated and occurs through simple diffusion. For more complex organisms, the process requires specialised organs working together to form the excretory system (see Figure 4D–2 on the following page).

LINK 1C CELL TYPES
LINK 2A THE NATURE OF SUBSTANCES AND THEIR MODES OF TRANSPORT

ISBN 978-1-108-88711-3

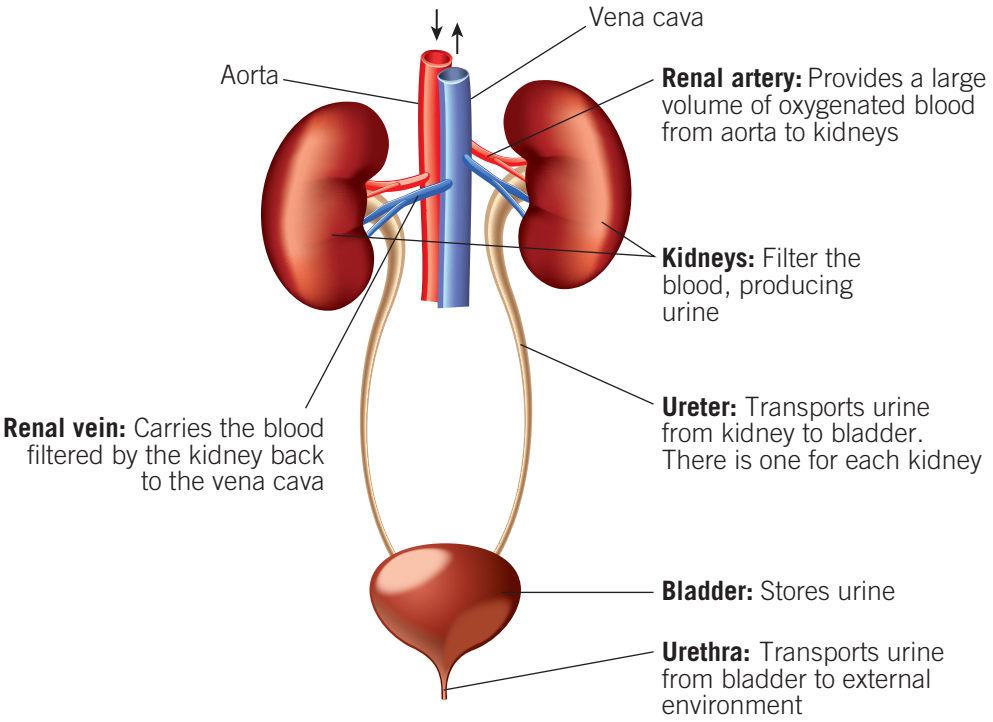



**Figure 4D–2** Key structures of the excretory system and their function

## Kidneys

The kidneys are the core structure of the excretory system. They are bean-shaped organs, each about the size of a large fist, and are located just below the rib cage. Most people have two kidneys, one on each side of their spine. In some cases, individuals can be born with only one kidney or have one removed due to damage. In these cases, it is still possible to lead a normal healthy life.

Kidneys are responsible for filtering the blood they receive through the renal artery. The total volume of the body's blood is filtered through the kidneys 12 times every hour, removing waste and excess fluid as well as maintaining the correct balance of water, salts and minerals to keep blood pH constant for the proper functioning of cells. Despite being only 0.5% of the body's overall mass, the kidneys receive 25% of all blood pumped through the heart. In comparison, brain tissue receives approximately 15%. This highlights the importance of the filtration function that kidneys perform.

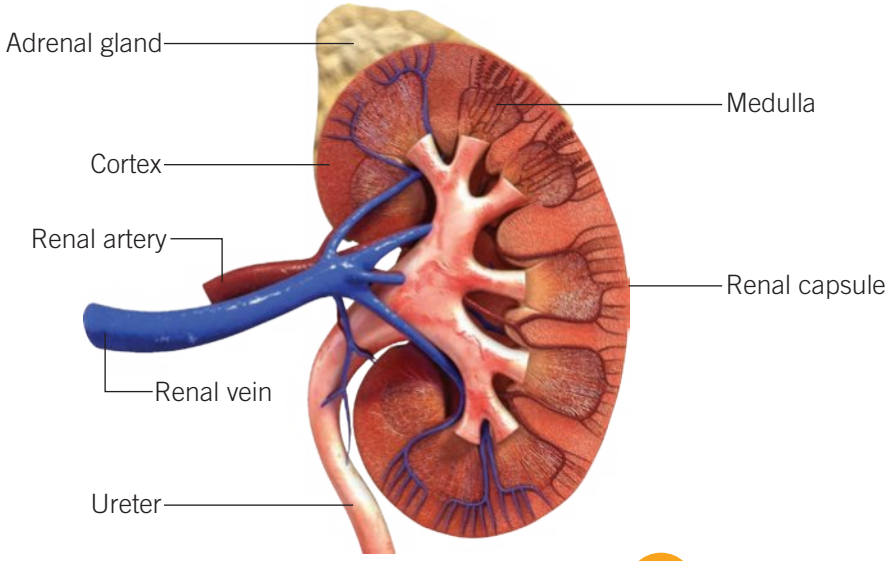



**Figure 4D–3** A cross-section of the mammalian kidney

Each kidney consists of three layers (Figure 4D–3):

- renal capsule – a thin layer of cells that covers the outer surface
- cortex – granular tissue that forms the outer portion (between capsule and medulla)
- medulla – the striated innermost portion of the kidney.

ISBN 978-1-108-88711-3

## The nephron

The functional unit of the kidney is the **nephron**. It is the nephron that is responsible for the filtration and reabsorption that allows blood and tissue fluid to remain balanced. The fluid generated by each nephron is referred to as *filtrate*. Most of the contents of the filtrate will be reabsorbed into the **peritubular capillaries** as it moves through the nephron, leaving only waste to be excreted as urine.

Each kidney contains, on average, 0.8 millon to 1.5 million nephrons. Each nephron has two main parts:

- **glomerulus** – responsible for filtering the blood
- **tubule** – consists of clearly defined regions that return important substances to the blood and keep waste for excretion.

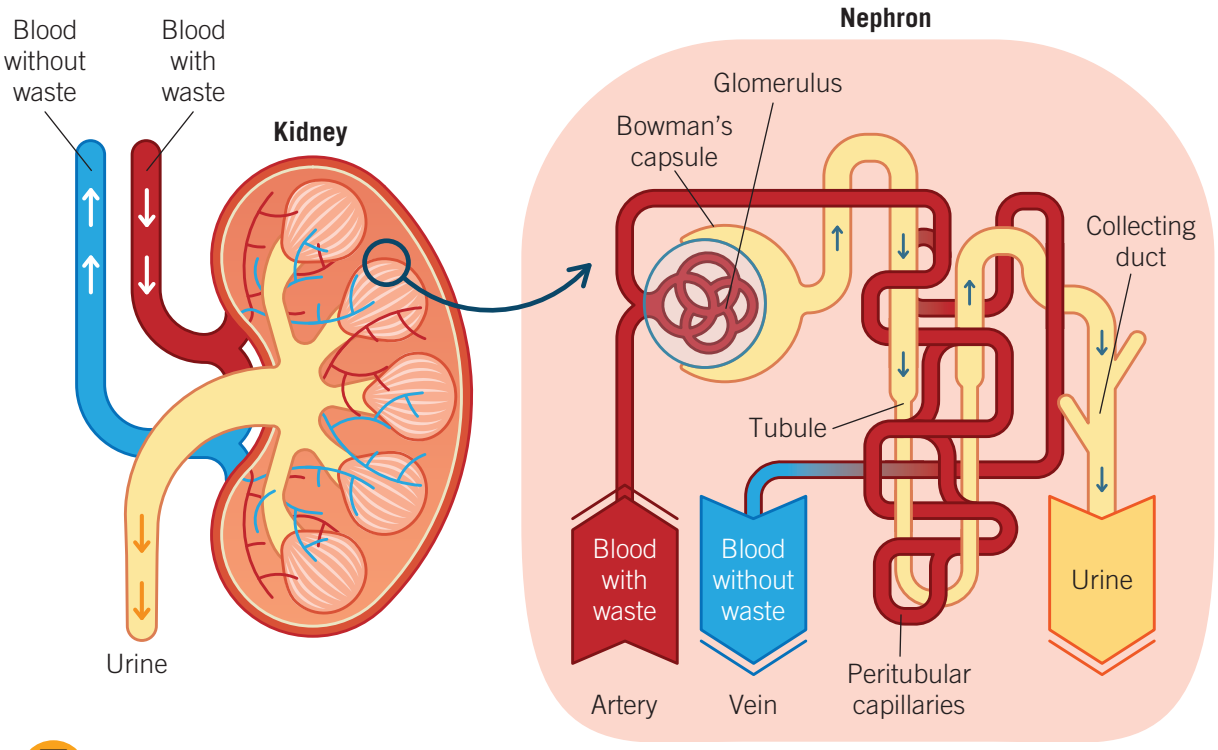



**Figure 4D–4** The anatomy of a nephron

Three key processes occur in the nephron to convert blood to urine:

- **filtration** – water and solutes are removed from the blood into the nephron tubule
- **reabsorption** – water and solutes move from the nephron tubule back into the blood
- **secretion** – solutes are actively transported from the peritubular capillaries into the nephron tubule.

Filtration occurs in the glomerulus, and the rest of the process takes place in the tubule.

## The glomerulus

The glomerulus is a ball-shaped network of capillaries that receives its rich blood supply from the renal artery. Blood pressure within each glomerulus pushes water and all solutes (except proteins) out of the blood plasma and into the beginning of the tubule, known as the Bowman's capsule (Figure 4D–5 on the following page).

**Nephron** the functional unit of the kidney

**Peritubular capillaries** a capillary network that wraps around the tubule and allows reabsorption and secretion between the bloodstream and the nephron

**Glomerulus** a network of capillaries that is the site of blood filtration in the nephron

**Tubule** the tubular portion of the nephron that the filtrate passes through to become urine

**Filtration** removal of water and solutes from the blood into the nephron tubule

LINK 2A THE NATURE OF SUBSTANCES AND THEIR MODES OF TRANSPORT

**Reabsorption** movement of water and solutes from the nephron tubule back into the blood

**Secretion** active transport of solutes from the peritubular capillaries into the nephron tubule

ISBN 978-1-108-88711-3

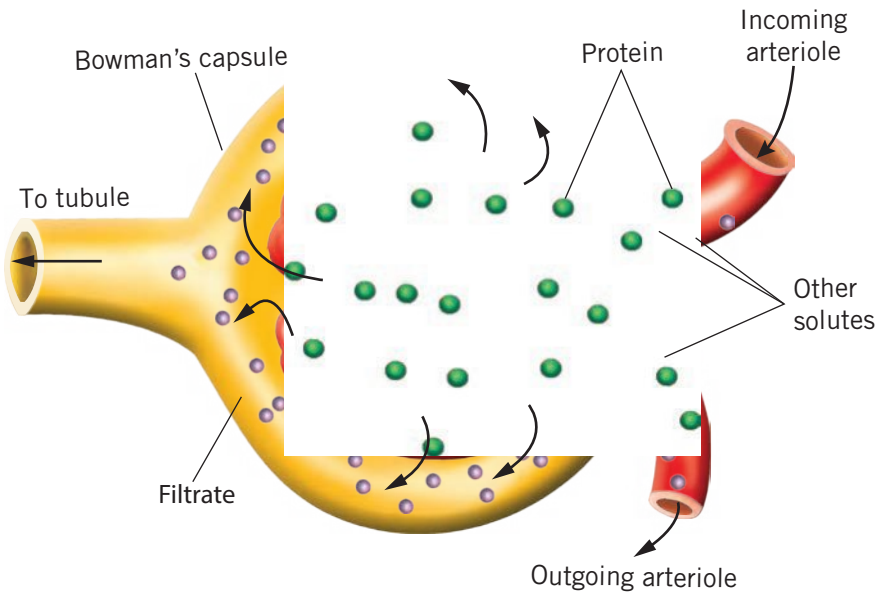



**Figure 4D–5** Filtration allows all water and solutes (except proteins) to move into Bowman's capsule from the glomerulus. This marks the beginning of the passage of filtrate through the nephron.

This passive movement creates the initial filtrate that moves through the tubule. An average human can have their total body plasma filtrated up to 60 times a day.

The glomerulus of each nephron lies in the outer portion of the kidney and gives the cortex its granular appearance.

## The tubule

The tubule consists of several clearly defined regions, beginning with the Bowman's capsule and ending with the collecting duct. As filtrate moves through the tubule, useful substances such as water and nutrients are passed back into the blood. What is left behind is waste, such as urea and excess water, for excretion as urine.

**Arteriole**
a small branch of an artery leading into capillaries

The tubule also has a close relationship with a network of capillaries connected to the outgoing **arteriole** of the glomerulus. This network is known as the peritubular capillaries and it contains the blood that was filtered in the glomerulus. The capillaries wrap around the tubule and are the site of reabsorption of water and useful substances from the tubule filtrate. Some substances may move from the blood into the tubule here as well.

Figure 4D–6 shows the path of filtrate through each region of the nephron and Table 4D–2 gives the functions of each part.

**2A** THE NATURE OF SUBSTANCES AND THEIR MODES OF TRANSPORT LINK

**2B** OSMOSIS LINK

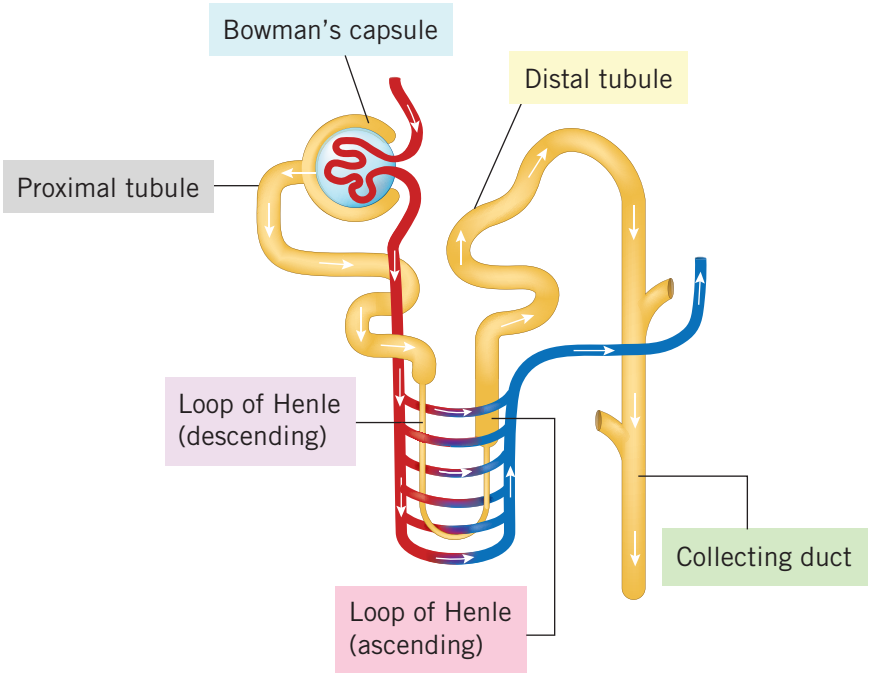



**Figure 4D–6** Parts of the nephron, colour-coded to the functions given in Table 4D–2.

ISBN 978-1-108-88711-3

**Table 4D–2** Parts of the nephron and their functions

| Name | Location | Structure | Function |
|---|---|---|---|
| Bowman's capsule | Cortex | A thin-walled, cup-like structure that encloses the glomerulus | **Filtration**<br>Filtrate received from the blood in the glomerulus passively enters the tubule here.<br>Contains 100% of filtrate absorbed from the glomerulus. |
| Proximal tubule | Cortex | Section of tubule between the Bowman's capsule and the beginning of the loop of Henle | **Reabsorption**<br>65% of all filtrate water is absorbed via osmosis back into the blood through the peritubular capillaries.<br>Reabsorption of 65% of ions and 100% of all amino acids and glucose via active transport from filtrate back into the blood via the peritubular capillaries.<br>20% of original filtrate is present by the end of the proximal tubule. |
| **Loop of Henle** (descending) | Medulla | The straight part of the U-shaped bend on the proximal tubule side | **Reabsorption**<br>Water flows out of the tube and into the blood via the peritubular capillaries by osmosis.<br>Walls are permeable to water.<br>14% of original filtrate left by the end of the loop of Henle. |
| Loop of Henle (ascending) | Medulla | The straight part of the U-shaped bend on the distal tubule side | **Reabsorption**<br>Chloride and sodium ions are actively transported into the peritubular capillaries.<br>Walls are impermeable to water. |
| Distal tubule | Cortex | Section of tubule between ascending loop of Henle and collecting duct | **Reabsorption**<br>Final adjustment of water occurs.<br>ADH can increase water permeability of tubule in case of dehydration, allowing for more water to move osmotically into the peritubular capillaries.<br>**Secretion**<br>Active transport moves ions from the peritubular capillaries into the tubule, e.g. $H^+$ movement helps maintain blood pH.<br>Drugs such as morphine are also removed from the body in this way.<br>5% of original filtrate left by the end of the distal tubule. |
| Collecting duct | Cortex, extending into the medulla | A network of tubes that collect urine | **Reabsorption**<br>Usually impermeable to water but becomes more permeable in the presence of ADH for water reabsorption back into the blood.<br>Filtrate is now urine and will pass into the ureter for storage in the bladder.<br>1% of original filtrate left by the end of the collecting duct. |

**Loop of Henle** the part of a kidney tubule that forms a long loop, from where water and salts are resorbed into the blood

ISBN 978-1-108-88711-3

### Making urine

Approximately 200 litres of blood pass through your kidneys each day. If all this was excreted, you would have to drink 4 litres of water every hour to keep your body hydrated. Luckily, only 1% of this filtrate becomes urine and is excreted from the body.

When the filtrate reaches the collecting duct as urine, the composition of that urine depends on many variables. For example, a person taking medication or vitamin supplements will pass some of them in their urine. Generally, 95% of urine is water, with urea and other substances making up the remaining 5%.

The kidneys work closely with the endocrine system to maintain water balance. For example, if an individual is dehydrated as a result of exercise, ADH will be released from the adrenal gland, and will act on target cells in the nephron, increasing the reabsorption of water from the tubule into the blood. On the other hand, if a person has drunk a lot of water, there is little need for ADH, so less water is reabsorbed and urine forms more quickly, increasing the need to urinate. This all contributes to the body's *osmoregulation,* maintaining the balance of water, which is an important homeostatic mechanism. You can read more about this in Section 5B.

5B HOMEOSTASIS LINK

WORKSHEET 4D–1 THE EXCRETORY SYSTEM

## Check-in questions – Set 2

1 What is a nephron?
2 Define the three key processes that occur in a nephron.
3 In which part of the nephron tubule does most filtrate reabsorption occur?

## Malfunctions of the excretory system

### Urinary tract infections

Urinary tract infections (UTIs) are the result of a bacterial infection in the urethra, bladder or kidneys. The urinary system protects the kidneys from serious infection by preventing the backflow of urine from the bladder to the kidneys. This results in most urinary infections being restricted to the bladder.

Symptoms of a UTI include:

- the urge to urinate more frequently but only releasing a few drops
- a burning pain when urinating
- cloudy, smelly urine with traces of blood
- feeling as though the bladder is full, even just after urinating.

Bacteria responsible for UTIs (mainly *E. coli*) usually enter the urinary tract through the urethra. This is the tube that is connected to your bladder for the excretion of urine. The female urethra is 4 cm long, while the male urethra is much longer, 20 cm. The short, straight female urethra makes it easier for bacteria to make their way to the bladder, which explains why women are 14 times more likely than men to experience a UTI.

While UTIs can be uncomfortable, they are not life threatening. The symptoms can be eased by drinking plenty of water and taking an alkaliniser, which will help neutralise the urine and ease the burning sensation when passing urine, until the prescribed antibiotics clear the infection.

UNIT 4 LINK

ISBN 978-1-108-88711-3

## Kidney disease

Kidney disease is often referred to as a silent disease because there are no early signs associated with it. It occurs when the kidneys are no longer able to filter waste out of the blood or maintain body fluid levels. It is possible to lose up to 90% of kidney function before any symptoms appear. These symptoms include:

- high blood pressure
- changes in frequency and amount of urine passed
- blood in the urine
- puffiness in the legs and ankles
- tiredness/loss of appetite.

Kidney failure can occur suddenly (e.g. due to an accident) or progress over a number of years. A sudden drop in kidney function is referred to as acute kidney failure, while a gradual loss of function is known as chronic kidney failure.

Several risk factors increase the likelihood of chronic kidney disease:

- high blood pressure
- having diabetes
- family history of kidney disease
- age (60+)
- poor lifestyle habits (obesity, smoking).

While medication and a diet aimed at reducing the load on the kidneys can help slow the progress of kidney disease, eventually the only way to survive is through dialysis (mentioned in Section 2B) or a kidney transplant.

LINK 2B OSMOSIS

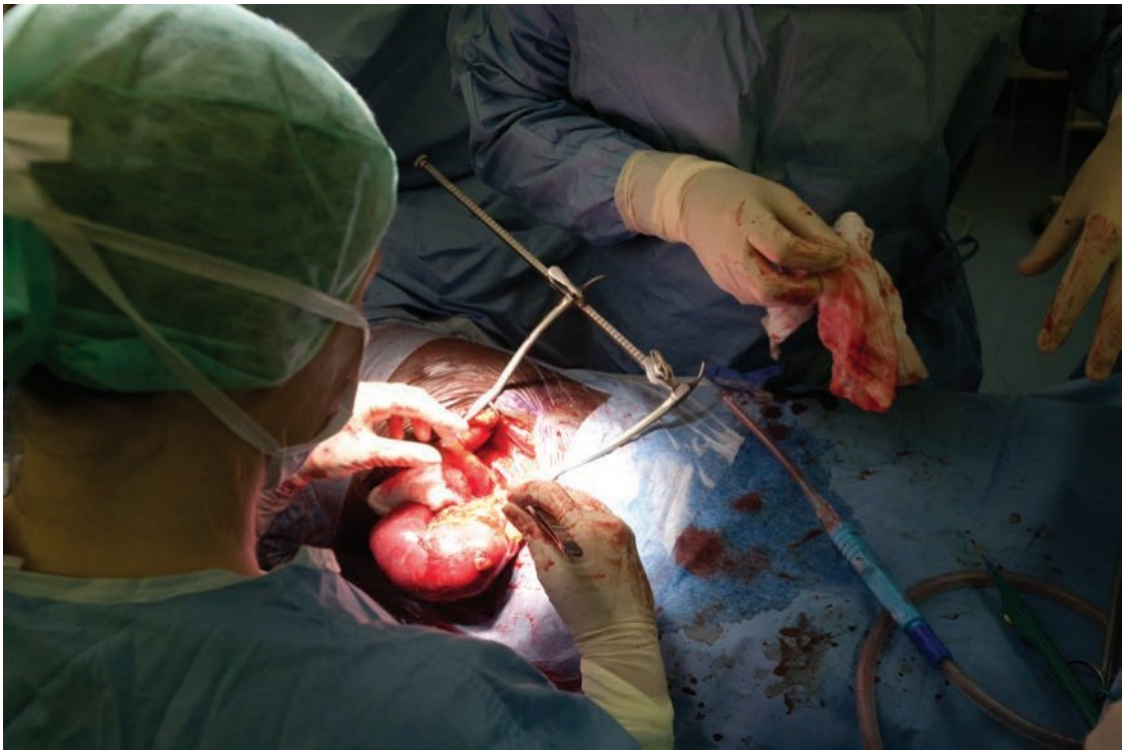


**Figure 4D–7** Surgeons performing a kidney transplant. The operation takes 2–3 hours.

ISBN 978-1-108-88711-3

To improve their quality of life, many sufferers opt for a kidney transplant. Even if both kidneys fail, only one healthy kidney is needed, which makes living donor transplants an option. Research has shown that receiving a kidney from a living donor who is a relative offers the best chance of long-term success, giving up to 35 years of healthy function. Unrelated donor kidneys have a higher chance of rejection despite anti-rejection medication, but can still last for 20 years if successful. The average waiting time for a deceased donor kidney in Australia is 3 years. Deceased donor kidneys offer the least longevity but can still provide up to 10 years of effective function.

UNIT 4 LINK

The idea of 'self' versus 'non-self' and why the immune system attacks non-self cells is explored in Unit 4.

3A WHERE DO NEW CELLS COME FROM? LINK

With advances in technology, it is likely that, in the near future, it will be possible to 3D print kidneys using the patient's own stem cells. This is a very exciting frontier in medicine!

## Check-in questions – Set 3

1 Why are most UTIs restricted to the bladder?
2 Why are men less likely to experience UTIs than women?
3 Receiving a kidney from which type of kidney donor is likely to be most successful? Rank the success rate from most successful to least successful, based on the type of kidney donor.

VIDEO 4B–2 SKILLS: MAMMALIAN SYSTEMS

*Refer back to the 4B–D Skills section on pages 185–6.*

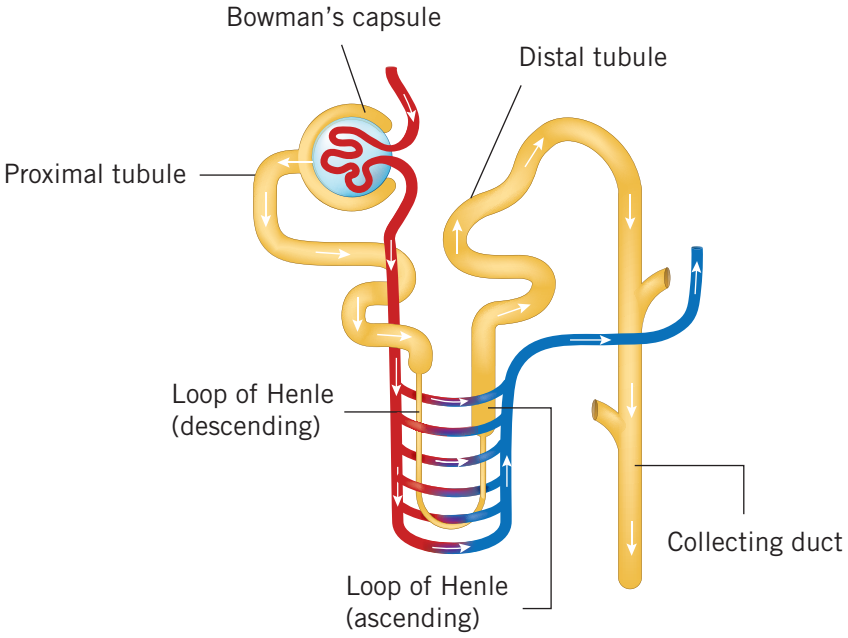
## Section 4D questions

1 Fill in the blanks.
   a The basic functional unit of the kidney is the _____.
   b Each kidney is connected to the bladder by a _____.
   c The innermost region of the kidney is the _____.
   d The most toxic from of nitrogenous waste is _____.
   e Urine is a mixture of urea and _____.
   f If a person is dehydrated, then their urine will be more _____.
2 Create a flow chart to show the passage of blood through the excretory system.
3 Why are there no proteins in glomerular filtrate?
4 Explain the passage of each of the following substances through a kidney nephron, beginning with the glomerulus and ending with the collecting duct. Identify the method of movement that each substance uses (diffusion, osmosis, etc).
   a water
   b urea
   c sodium ions
   d glucose
5 Kidney stones (shown here) are hard deposits of minerals and salts that form inside the kidneys. They can move to the ureter and bladder and are very painful for the sufferer. Explain the consequences of stones forming in the following locations.
   a kidney medulla
   b ureter
   c bladder

ISBN 978-1-108-88711-3

6 Most mammals excrete nitrogenous waste in the form of urea. Despite being a mammal, the egg-laying echidna excretes its nitrogenous waste in the form of uric acid. Explain why this is an advantage.

7 The loop of Henle consists of a descending loop and an ascending loop. The ascending part of the loop has a longer thick section than the descending loop, due to the increased presence of mitochondria. Why would this part of the loop of Henle require more mitochondria than anywhere else?




8 Mammalian systems do not operate independently of one another. Explain the relationship between the excretory system and the endocrine system.

ISBN 978-1-108-88711-3

# 4E Plant systems

**Study Design:**

- Specialisation and organisation of plant cells into tissues for specific functions in vascular plants, including intake, movement and loss of water
- Regulation of water balance in vascular plants

**Glossary:**

Lignin
Non-vascular plant
Phloem
Root hairs
Root system
Shoot system
Stomata
Tracheid
Transpiration
Transpiration stream
Vascular plant
Vessel element
Xylem

## ENGAGE

## How do plants transport substances?

In previous sections, you learned about the complex nature of mammalian systems. Cellular organisation into systems is not exclusive to the animal kingdom. Plants are also highly organised in their structure and have a variety of systems in operation to ensure their survival. This section takes a closer look at plant transport systems.

The tallest trees in the world are California redwoods (*Sequoia sempervirens*), which grow on the west coast of the United States. They reach an average height of 90 metres, with trunks up to 7 metres in diameter. The tallest of them all, named Hyperion, was discovered in 2006 and boasts a height of 115.7 metres! Sadly, its location must be kept a closely guarded secret, to protect it from vandalism. On average, redwood trees live for 500–700 years, although some have been documented to be more than 2000 years old. The California State Park service has attributed the tremendous growth of these trees to the heavy annual rainfall and mild year-round temperatures. This makes for the perfect tree-growing climate.

**Figure 4E–1** Left: The extreme heights of the California redwood canopies. Right: Their trunks are so wide that tunnels can be carved in them for visitors to comfortably pass through.

In Australia, there is the magnificent mountain ash (*Eucalyptus regnans*). It is the second-tallest tree species in the world but has the title of 'world's tallest flowering plant'. Mountain ash are found only in forests of Victoria and Tasmania, and can reach heights of up to 140 metres, with a trunk diameter of more than 15 metres. Currently, the tallest mountain ash, named Centurion, stands at 99.6 metres tall and is in Tasmania.

**2D** ROLE OF CHLOROPLASTS AND MITOCHONDRIA LINK

As you learned in Section 2D, plants convert carbon dioxide and water into glucose and oxygen through photosynthesis. Oxygen is released into the atmosphere, and used by all

ISBN 978-1-108-88711-3

living organisms, including humans. In aerobic cellular respiration, oxygen is consumed and glucose is broken down. Both photosynthesis and cellular respiration require various substances to be transported throughout the plant. In the tallest plant species, like the California redwood and the mountain ash, these substances must travel over 90 metres. But without a heart to act as a pump, how do plants achieve this? The answer depends on the type of plant in question.

**Figure 4E–2** Mountain ash in Sherbrooke Forest, 40 minutes from Melbourne in the Dandenong Ranges

## EXPLAIN

# Plant classification

When you think of the word 'plant', you probably picture something with green leaves, roots, branches and maybe some flowers. These types of plants make up approximately 90% of the Earth's vegetation and are known as **vascular plants**. The other 10% are **non-vascular plants**. The classification of plants as vascular or non-vascular is the broadest level of classification in terrestrial (land) plants.

**Figure 4E–3** There are many types of vascular plants, making up most of Earth's plant life.

**Vascular plant**
a plant that has tissue for conducting water and minerals throughout the plant

**Non-vascular plant**
a plant that has no conducting tissue so cannot retain water or deliver it to other parts of the plant

## Non-vascular plants

As their name suggests, non-vascular plants lack vascular (transport) tissue. This means that they do not have any internal structures capable of transporting water and nutrients. They simply use osmosis to transfer substances from cell to cell, and diffusion for the movement of minerals between cells. For this reason, non-vascular plants are small in size, because they are restricted in their ability to transport substances internally. They also lack a root system, which restricts them to moist environments where water is readily available. Examples of non-vascular plants are mosses, liverworts, hornworts and some species of algae.

LINK **2A** THE NATURE OF SUBSTANCES AND THEIR MODES OF TRANSPORT

LINK **2B** OSMOSIS

## Vascular plants

There are more than 260 000 species of vascular plants. They range from grasses to flowering plants, ferns to pine trees, shrubs to fruit trees. The California redwood and the Australian mountain ash are examples of vascular plants. Put simply, any land plant that transports water and nutrients through a specialised system of tissue is a vascular plant.

ISBN 978-1-108-88711-3

**Root system** the parts of a plant that lie below the surface of the soil

**Shoot system** the parts of a plant that are above the ground

Vascular plants contain two connected systems:

- the **root system** – the parts of the plant that lie below the surface of the soil and are responsible for providing a constant supply of water and minerals to the stems and leaves
- the **shoot system** – the parts of the plant that are above the ground and are responsible for exchanging oxygen and carbon dioxide with the atmosphere and for carrying out photosynthesis.

Just like animals, plant systems consist of various organs that perform specialised tasks within the organism (Table 4E–1).

**VIDEO 4E–1** VASCULAR PLANT SYSTEMS

**Table 4E–1** Vascular plant systems

| System | Primary organ | Function |
|---|---|---|
| Shoot system | Leaves | Photosynthesis |
| | Stems | Structural support, transport of substances |
| Root system | Roots (primary) | Grow downwards for strength and anchorage; can source water from very deep underground and store large amounts of food |
| | Roots (secondary) | Branch to the side, increasing surface area for absorption of water and minerals |

**2C** SURFACE AREA TO VOLUME RATIO LINK

**Xylem** a component of vascular tissue responsible for the distribution of water upward from the roots

**Phloem** a component of vascular tissue responsible for the distribution of sugar throughout the plant

The key feature that differentiates vascular plants from non-vascular plants is the presence of a special type of transport system, known as *vascular tissue*. This consists of two types of conducting tissue, known as the **xylem** and the **phloem**, each with its own kind of specialised cells. The xylem is responsible for transporting water and dissolved minerals from the roots to the rest of the plant. The phloem is responsible for transporting sugar throughout the plant. Together, they ensure that all plant organs receive what they need to survive. Vascular tissue runs in bundles through the centre of each root, up into the stems and leaves of the shoot system.

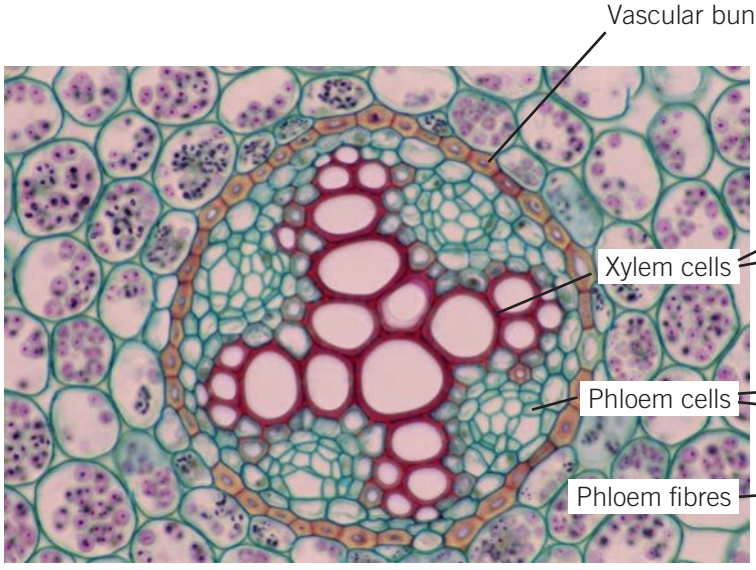



**Figure 4E–4** Root cross-section showing the location of the vascular bundle running through it. Xylem cells form the central red cross. Phloem cells are stained green and lie between the arms of the xylem cross.

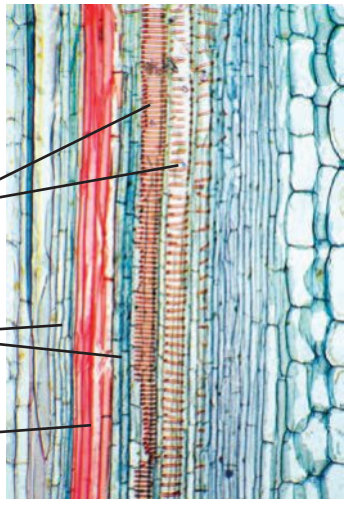


**Figure 4E–5** Micrograph of a longitudinal cross-section through a plant's stem. In the middle are two rows of xylem, identifiable by their spiral structure. To the left of these is a bundle of phloem fibres (red) sandwiched between two groups of phloem cells (blue).

ISBN 978-1-108-88711-3

## Check-in questions – Set 1

1 Structurally, what is the difference between a vascular plant and a non-vascular plant?
2 What are the two types of systems and their corresponding organs that make up vascular plants?
3 What is the difference between xylem and phloem?

## The shoot system – leaf structure

The main organ of the shoot system in all plants is the leaf. The combination of a leaf and a stem form the plant shoot. Photosynthesis occurs primarily in the leaf. To maximise the rate of photosynthesis, leaves consist of highly specialised layers, and each performs a specific function. A cross-section through a typical leaf is shown in Figure 4E–6.

LINK 2D ROLE OF CHLOROPLASTS AND MITOCHONDRIA

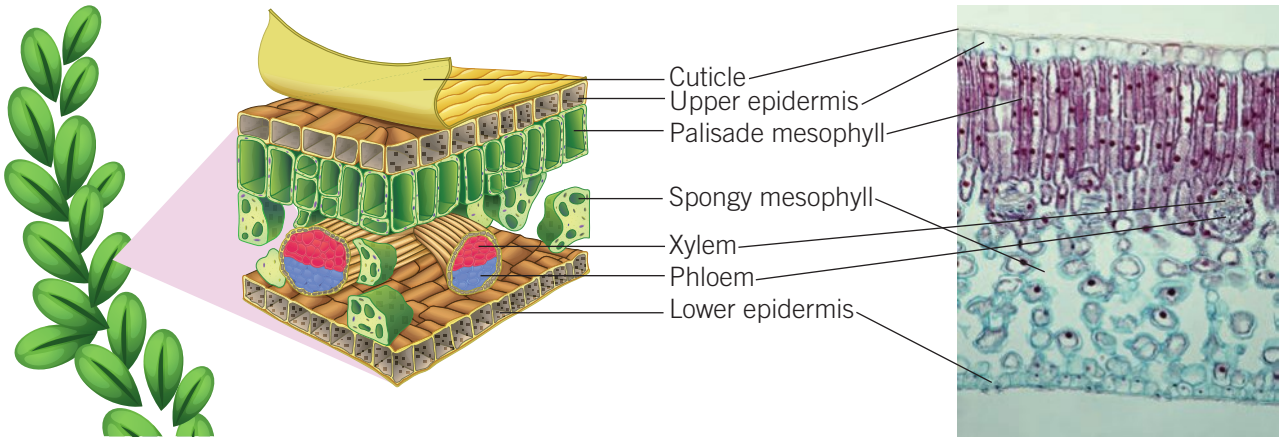



**Figure 4E–6** The leaf is a collection of different tissues. Each tissue layer consists of highly specialised cells crucial to the shoot system's ability to photosynthesise.

**Table 4E–2** Specialised layers of leaves and their roles

| Layer | Roles |
|---|---|
| Cuticle | A waxy, waterproof coating that reduces the rate of water loss from the leaf surface; also responsible for defence against plant pathogens |
| Upper epidermis | A transparent outer layer of cells that allows sunlight to easily pass into the leaf tissue; contains **stomata** for release or entry of gases (oxygen and carbon dioxide) to or from the leaf |
| Palisade mesophyll | Densely packed photosynthetic cells with large numbers of chloroplasts; most photosynthesis occurs in this layer |
| Spongy mesophyll | Loosely arranged cells with large amounts of air space between cells; this space allows easy diffusion of carbon dioxide and oxygen gas between layers of the leaf and stomata |
| Xylem and phloem | Vascular bundles that run between the leaves and the roots, transporting water and sugar |
| Lower epidermis | A transparent outer layer of cells that allows sunlight to easily pass into leaf tissue; contains stomata for entry or release of gases to or from the leaf |

WORKSHEET 4E–1 LEAF STRUCTURE
LINK UNIT 4
LINK 2D ROLE OF CHLOROPLASTS AND MITOCHONDRIA
LINK 2A THE NATURE OF SUBSTANCES AND THEIR MODES OF TRANSPORT

**Stomata** pores in the epidermis of leaves or stems in plants that allow the movement of gases and water vapour in and out of intracellular spaces; singular: stoma

ISBN 978-1-108-88711-3

## The root system – absorbing water

**Root hairs** elongated structures that grow from the outer layer of root cells and maximise the absorption of water and minerals from the soil

It's easy to forget about the root system of a plant. It lies underground in the soil, invisible from the surface, but it is hard at work performing three key functions essential to the plant's survival:

- absorbing water and dissolved minerals from the soil
- providing anchorage and support for the plant
- storing food and nutrients.

Water enters a plant from the roots. Whether the plant is a low-growing shrub or a 100-metre-tall tree, the roots must source enough water to provide the plant with a constant supply. To meet this demand, the plant's underground network of roots is extensive, and often larger than its entire shoot system.

**2C** SURFACE AREA TO VOLUME RATIO LINK

**4B** THE DIGESTIVE SYSTEM: GETTING THE NUTRIENTS WE NEED LINK

**2B** OSMOSIS LINK

Because the root system provides the exchange surface for water entry into the plant, it is important that this surface area is maximised. Lining the surface of every root tip are thousands of **root hairs**, which increase the surface area of the root in much the same way that villi increase the surface area of the small intestine. Each root hair acts like a sponge, soaking up water and minerals from the soil, significantly increasing the overall surface area of the root system.

**Figure 4E–7** A plant's stems, leaves and roots dramatically increase its surface area.

ISBN 978-1-108-88711-3

Root hairs can be found on the epidermal layer of every root tip in a plant. As their name suggests, they are long and thin in shape. This assists them to navigate through soil particles in search of water, which they then immerse themselves in. This ensures that a constant stream is supplied to the plant. Water passes from the soil into the root through the process of osmosis. This creates root pressure, which pushes water up the root. Once inside the root, water continues to move osmotically through and between adjacent cells until it reaches the vascular bundle at the centre of the root (Figure 4E–8). Here it is drawn into the xylem and transported up towards the leaves of the plant.

**Transpiration** evaporative water loss through plant leaves that results in the movement of water through the plant

Root pressure acts to push water and minerals into the plant from the soil and then into the vascular tissue. Once in the vascular tissue, **transpiration** takes over to transport water and dissolved ions upward into the rest of the plant.

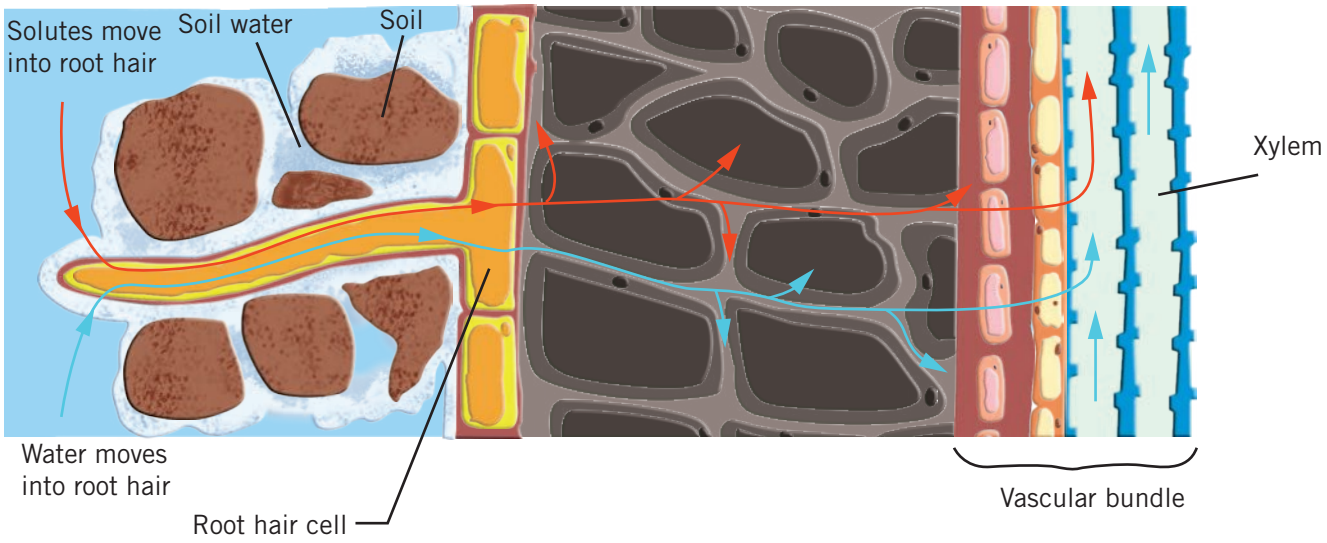



**Figure 4E–8** A cross-section of one side of a root showing the path of water and solutes from the soil to the xylem in the centre of the root

PPS

## NOTE

Root pressure alone is able to transport water as high as 6.4 metres.

## Check-in questions – Set 2

1 What are the three functions of a plant's root system?
2 How is the surface area of the root system maximised?
3 How is the movement of water through the roots different from the movement of dissolved mineral ions?
4 What is root pressure and why is it important?

ISBN 978-1-108-88711-3

**Vessel element**
an elongated, hollow cell that contributes to the structure of xylem in vascular tissue

1D ORGANELLES LINK

**Tracheid**
a hollow cell that tapers inwards at both ends and contributes to the structure of xylem in vascular tissue

## Xylem – water transport through vascular tissue

As you have just read, the xylem is the component of vascular tissue that transports water and dissolved minerals from the roots to the leaves. Xylem tissue also provides the plant with structural support, assisting it to remain upright. Xylem tissue consists of two types of specialised cells: **vessel elements** and **tracheids**. They have the following features in common:

- a nucleus and a cytoplasm that disintegrate as the cell matures
- movement of water through cells in one direction – upward against gravity
- walls that consist of dead cells joined end-to-end, forming a continuous tube
- cells walls that are strengthened with lignin (an organic polymer).

In woody plants, the older xylem tissue no longer participates in water transport. Its sole purpose becomes trunk strength. Wood is simply xylem. When counting the rings of a tree to determine its age, you are counting rings of xylem.

**Figure 4E–9** Count the rings and determine the age of the tree.

### Lignin

**Lignin**
a component of the cell walls of vascular tissue that makes them rigid and woody

**Lignin** is a complex carbohydrate found in the vascular tissue of plants. It is located in the cell wall, in the spaces between cellulose and other components of the wall, providing strength to the wall and contributing to the structural support of the plant, preventing it from collapsing as water is pulled through the xylem. It is also the reason that trees can grow so tall. Chemically, lignin is less hydrophilic than its cell wall counterpart, cellulose. This property is useful as it prevents water from being absorbed, assisting it to stay in the xylem for efficient transport through the plant.

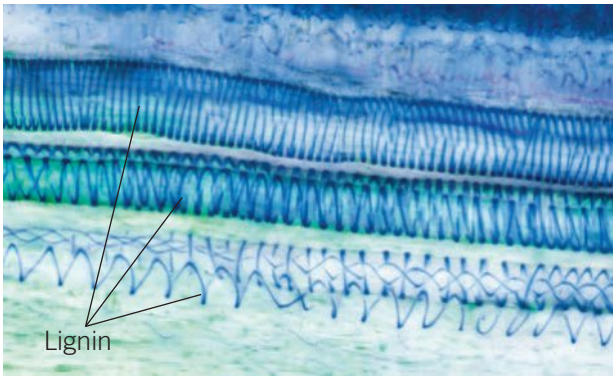



**Figure 4E–10** Light micrograph of xylem tissue. The spiral thickening of lignin in the cells can clearly be seen.

### Specialised cells of the xylem

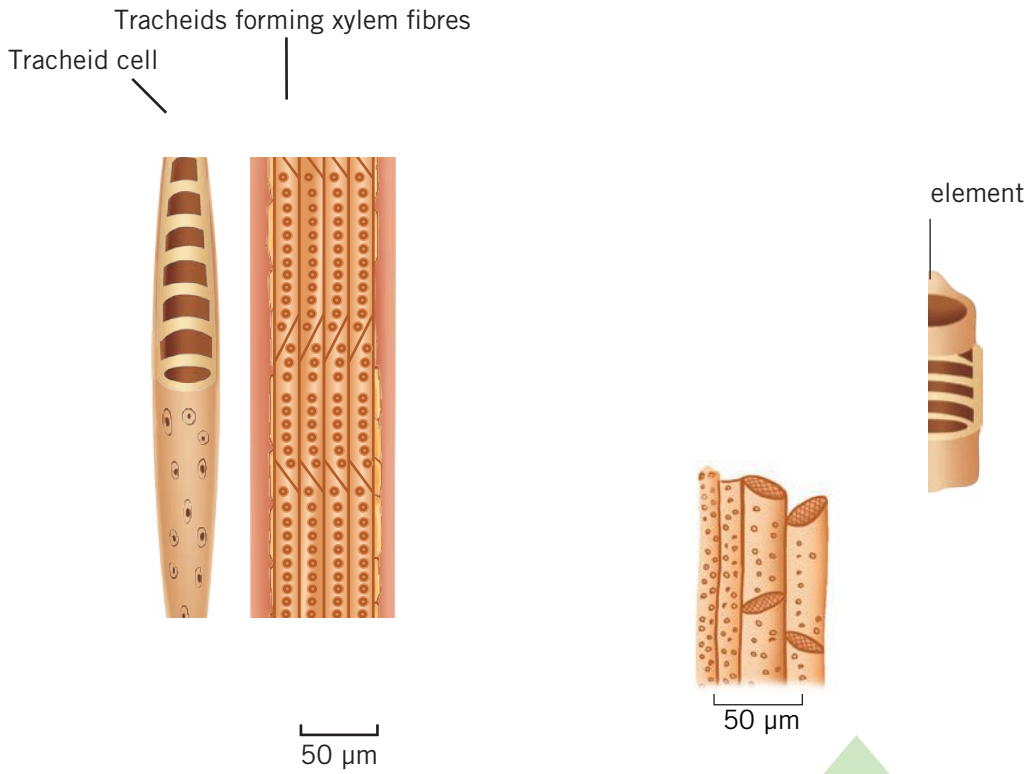
Vessel elements and tracheids are the specialised cells that make up the xylem component of vascular tissue. They are elongated cells that stack end-to-end, forming a long continuous tube known as a xylem vessel. Both types of cells die as they mature, leaving behind a hollow skeleton of lignified cell walls for water to stream through.

ISBN 978-1-108-88711-3

### Tracheids

Like vessel elements, tracheids die as they mature, leaving behind a hollow skeleton for water to stream through. The presence of lignin also gives the tracheid a strong, rigid structure. Mature tracheids have the following key distinguishing features:

- They originate from a single cell.
- Each cell has ends that taper inwards.
- The tapered ends of cells overlap each other, rather than connecting end-to-end.
- Horizontal transfer of water occurs between tracheid cells via overlapping pits in the cell wall.




### Vessel elements

Mature xylem vessels have the following key features:

- They originate from a single file of cells.
- They provide a strong, rigid structure as a result of lignin accumulation in the cell wall.
- The cylindrical, tube-like shape that they form enables easy water flow through the vessel.
- The ends of each cell are completely open, like a straw, allowing a continuous flow of water.

**Figure 4E–11** The specialised cells of the xylem: tracheids and vessel elements. Try to identify in the diagrams the key features described in the text.

## Check-in questions – Set 3

1 What are the two types of cells that make up the xylem?
2 What is the relationship between vessel elements and xylem vessels?
3 Draw a simple diagram that shows the difference in shape between a vessel element and a tracheid.

ISBN 978-1-108-88711-3

## Transpiration – through the shoot system

As you read this, your heart is hard at work pumping blood down to the tips of your toes and up to the top of your head. Plants lack a pump to assist in the transport of substances. So how are they able to provide their leaves with water that originates from the root system, sometimes more than 100 metres away? The answer is *transpiration*.

**Transpiration stream** the continuous column of water that forms inside the xylem as a result of evaporative water loss through the leaves

Transpiration is the movement of water through a plant from the roots and its evaporation through the leaves into the atmosphere. The continuous column of water that forms inside the xylem is known as the **transpiration stream**. Only a very small amount of water in the transpiration stream is used for photosynthesis. Over 97% of the water that is absorbed by the roots is lost through transpiration. Despite the significant water loss that transpiration causes, it is vital to the plant's survival because it:

- transports minerals to leaves, flowers and shoot.
- provides water necessary for photosynthesis to the leaves
- keeps the plant cool and prevents it from overheating.

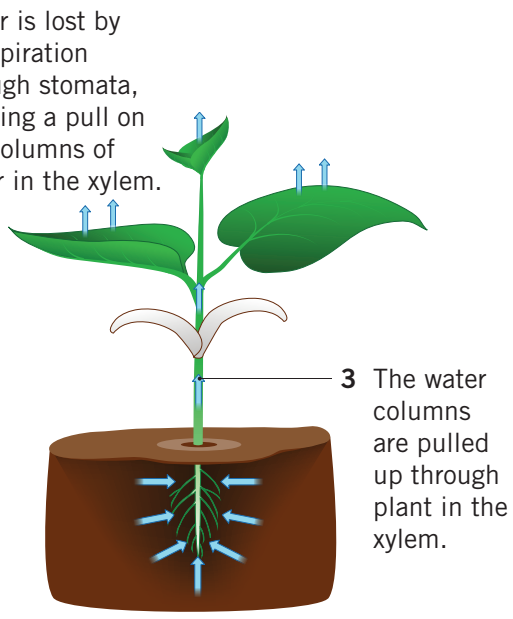



**Figure 4E–12** A simple overview of transpiration

All internal spaces within the tissue of a plant are coated with water. As this water evaporates through pores in the leaf, it must be replaced. The loss of water through the leaf creates an upward pull or tension force in the column of water in the xylem, causing water to be pulled up through the xylem from the roots to the leaves, where it replaces the water that evaporates from the leaves, and evaporates in its turn. Provided there is soil water available to enter the roots by osmosis, this upwards pull on the water columns takes over from root pressure to create the transpiration stream.

Transpiration is a passive process, requiring no energy from the plant. The ability of a plant to generate a continuous water column through the xylem is due to the adhesive and cohesive properties of water.

**2A** THE NATURE OF SUBSTANCES AND THEIR MODES OF TRANSPORT LINK

### Cohesion and adhesion of water

Water molecules are polar. This means that the oxygen end of the water molecule has a slight negative charge and the hydrogen end has a slight positive charge. So when water molecules are close together, their positive and negative ends are attracted to the positive and negative ends of other water molecules, causing them to stick together. This sticking together is known as *cohesion* and is the property that draws nearby water from the xylem to replace water lost through transpiration.

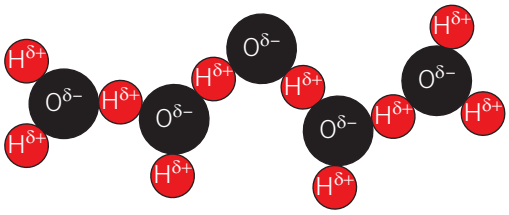



**Figure 4E–13** The attraction between the partial positive and negative ends of a water molecule gives water its cohesive property or 'stickiness'.

ISBN 978-1-108-88711-3

As well as sticking to itself, water sticks to other surfaces, such as cells of the xylem. This is known as *adhesion* and refers to an attraction between two different types of molecules – in this case, water and xylem walls. If you were to place a thin glass tube (capillary tube) into water, you would notice that the water column rises in the tube. The water that comes into direct contact with the glass extends the highest, and in the middle the water dips at the most distant point from the glass tube. This is the result of the glass molecules being even more polar than the water molecules, and providing the greatest level of attraction.

## Stomata

If a stick of celery is left in a coloured solution for 30 minutes, the coloured dye moves up the celery stem and into the leaves (Figure 4E–14). Even without roots, the coloured dye is able to move through the plant. If you were to cut off the leaves of the stick of celery and repeat the experiment, you would find that there is no movement of the coloured dye through the celery stem.

**Figure 4E–14** Experiment showing capillary action. Left: Water is drawn up through the xylem in the stems, driven by transpiration. The longer the celery is left, the higher up the stem the red dye will be seen. Right: The red pigment is visible in a cross-section of the stem.

This simple experiment highlights the importance of leaves, by showing that the loss of water through transpiration is facilitated by the leaves of the plant. It is also assisted by the stomata. A stoma is composed of two guard cells that control its opening and closing (Figure 4E–15).

- When water leaves the guard cells, the stoma closes.
- When water enters the guard cells, the stoma opens.

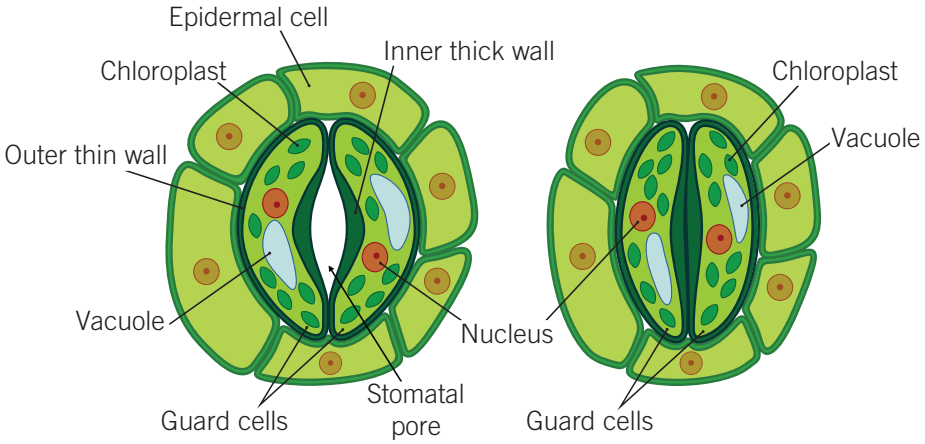



**Figure 4E–15** Left: When guard cells are turgid, the stoma is open, which allows the exchange of substances (such as water) between the plant and its environment. Right: When guard cells are flaccid, they cover the stoma and no exchange can take place. This helps to conserve water in dry conditions.

LINK 2B OSMOSIS

ISBN 978-1-108-88711-3

It is through open stomata in the leaves that water is lost through transpiration. By far the biggest factor affecting the rate of transpiration is the number of open stomata present in leaves. The more stomata in leaves, and the more open they are, the greater the surface area for water vapour loss to occur. Several other factors that can also affect the rate of transpiration are summarised in Table 4E–3.

**2C** SURFACE AREA TO VOLUME RATIO LINK

**Table 4E–3** Factors that affect the rate of transpiration

| Factor | Effect on transpiration | Explanation |
|---|---|---|
| Light intensity | Rate **increases** as light intensity increases | Light causes stomata to open wider for greater entry of carbon dioxide for photosynthesis, which then allows greater evaporation of water. |
| Temperature | Rate **increases** as temperature increases | As temperature increases, so does the kinetic energy of molecules, which means osmosis and evaporation occur faster. |
| Wind | Rate **increases** in windy conditions | In windy conditions, water vapour is removed more quickly from stomata, which keeps the concentration gradient between the leaf and the air high, for faster water evaporation. |
| Humidity | Rate **decreases** in humid conditions | When the air is humid, there is more water vapour present. Humid air is less able to accept water molecules by evaporation, which reduces the concentration gradient and slows down evaporation. |

**2D** ROLE OF CHLOROPLASTS AND MITOCHONDRIA LINK

**2B** OSMOSIS LINK

**2A** THE NATURE OF SUBSTANCES AND THEIR MODES OF TRANSPORT LINK

It is important that plants find a way to balance the opening and closing of their stomata. Opening stomata allows carbon dioxide into the plant for photosynthesis but it also means loss of water through transpiration, which is problematic, particularly on a hot day. Closing stomata prevents transpiration and therefore water loss, but it also limits the amount of photosynthesis that can occur. As is often the case, balance is the key to success.

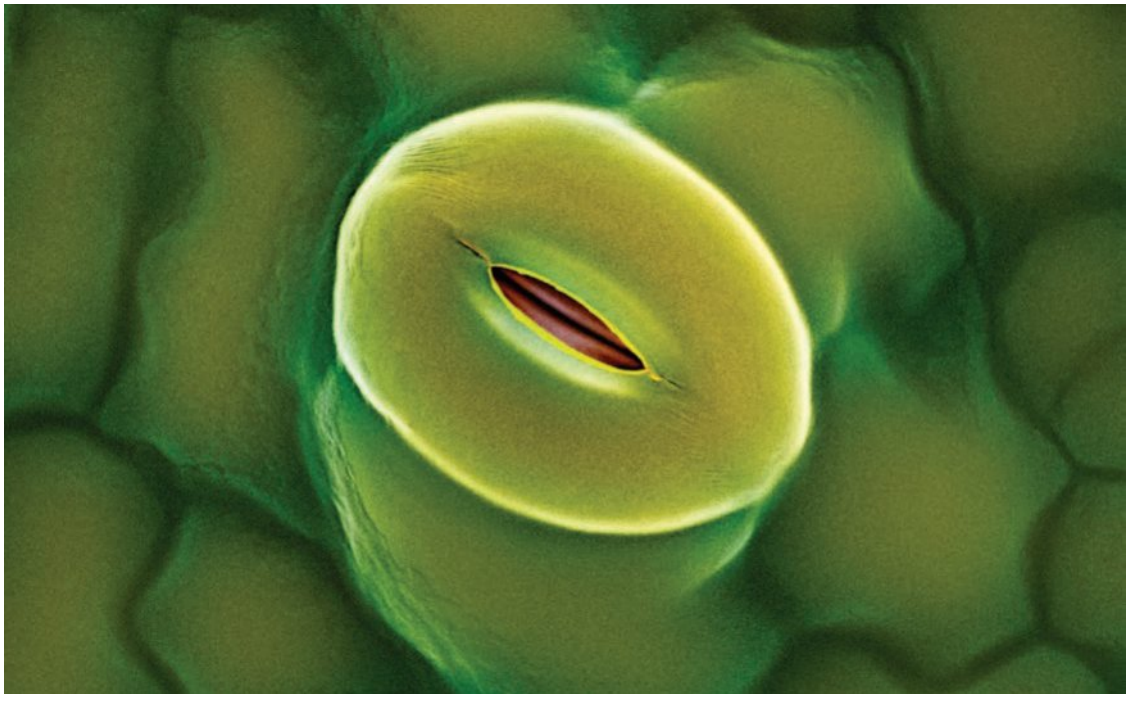


**Figure 4E–16** A scanning electron micrograph of a closed stoma on the surface of a leaf

ISBN 978-1-108-88711-3

## Water transport in plants: summary

It takes the combined action of the different forces working together to draw a continuous stream of water throughout a plant more than 100 metres tall. The movement of water in a plant can be summarised as follows.

- Water moves into the plant by *osmosis*, which generates root pressure that forces water upwards over a short distance.
- The main upward pull of *transpiration*, water loss from the leaves, draws water through the xylem along the length of the plant.
- The *adhesion and cohesion* properties of water enable transpiration to pull a continuous stream of water from the roots up to the highest shoots.

LINK 2B OSMOSIS

WORKSHEET 4E–2 TRANSPIRATION IN ACTION

## Check-in questions – Set 4

1 Define 'transpiration'.
2 What three purposes does transpiration serve in a plant?
3 What is the relationship between stomata and transpiration?
4 Name the environmental factors that increase and decrease the rate of transpiration.

## 4E SKILLS

VIDEO 4E–2 SKILLS: PLANT SYSTEMS

**Plant systems: using diagrams to represent key processes**

In Biology, you will often be required to answer questions about complicated processes that require a lot of information. It is easy to become overwhelmed, particularly under assessment conditions and, as a result, leave out key information that is required to gain marks. However, if you include a simple diagram in your answer, it will help to guide you through your response. It will also encourage you to include more detail at each stage and enable you to show a higher level of knowledge. Regardless of your artistic ability, including a simple diagram can be very useful.

Consider the following question.

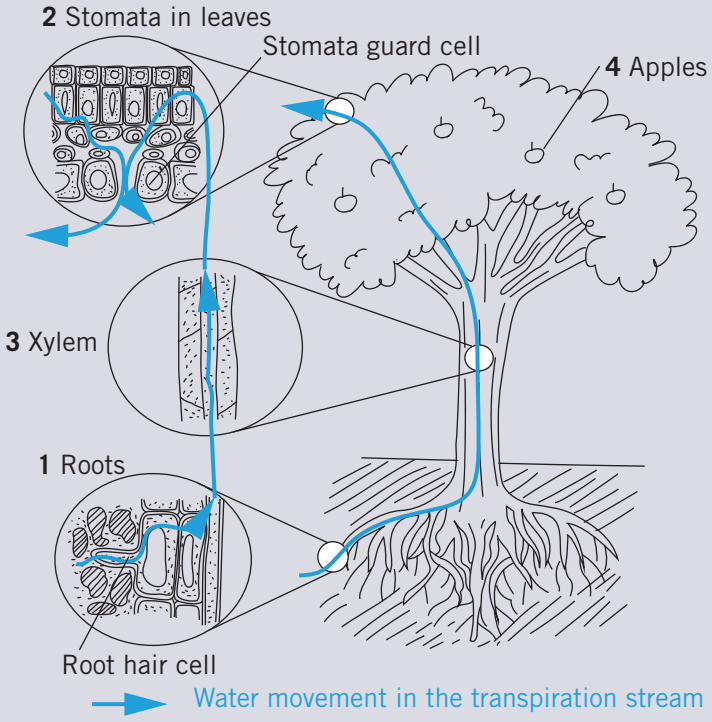
> *Question*: Below is a picture of an apple tree.
>
> Explain in detail how the fruit on this tree is provided with the water it needs to grow. (3 marks)

ISBN 978-1-108-88711-3

*Typical answer*: Water enters the roots and travels through the xylem to the leaves by the pull of transpiration. Water vapour then exits the plant through stomata in the leaves. Transpiration is how the water reaches the apples.

What do you think of this answer? Does it contain enough information to receive full marks for the question? Now look at the answer below, which uses a diagram as well as a written response.

1. Roots – water moves passively by osmosis from the soil (high concentration of free water) into the roots of the plant (low concentration of free water) via root hairs that increase the surface area for absorption.
2. Stomata – at the other end of the tree, water vapour is being lost through stomata, creating the transpiration pull needed for water movement.
3. Xylem – the transpiration pull draws water up the tree through the xylem. The adhesion and cohesion properties of water create one continuous water stream.
4. Apples – steps 1–3 result in apples getting the water they need to grow.




Each labelled number on your diagram can be used as a guide to help you include the key components of each stage. It is easy to see the difference in detail on a diagram, compared with answering only in sentences.

You can see more examples of how diagrams can be used to explain key features of structures or processes throughout this chapter – for example, leaf structure in Figure 4E–6 (on page 215), and the role of a nephron in Figure 4D–4 (on page 205).

As you work your way through the Section 4E questions, ask yourself: Will a diagram help me to explain my answer more clearly? Quite often the answer is yes, so be sure to practise including diagrams. Remember, getting full marks comes down to an assessor reading your work and deciding how well you know your stuff.

ISBN 978-1-108-88711-3

## Section 4E questions

1 Look at the following pictures of plants. Which of these would you expect to contain vascular tissue?


2 What would happen to plant structure if lignin was not present in the walls of xylem tissue?

3 Complete a Venn diagram that shows the similarities and differences between vessel elements and tracheids.

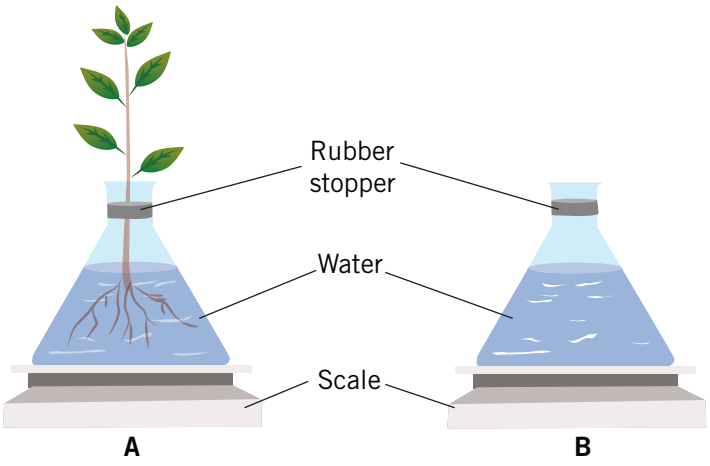
4 Observations of plant stomata over 24 hours have shown that the number of open stomata is lowest at midday. Explain this observation.

5 Plants do not use energy (ATP) to absorb water through their roots. Do you agree with this statement? Explain.

6 Rodney was preparing to move the position of his rose bush in the backyard. Before digging the plant out of the ground, he pruned the plant, removing most of its leaves. Explain the importance of pruning the plant before removing it.

7 An indoor plant was left by the window in direct sunlight on a hot summer day for 8 hours. It was not watered during this time. Draw (and label) the expected shape of the plant's stomata at the following time intervals.
   - **a** the beginning of the eight hours
   - **b** halfway through the eight hours
   - **c** at the end of the eight hours.

8 The experiment on the right was set up in a laboratory for 24 hours. Initially, both scales showed the same mass but, after the 24 hours, flask B's mass had not changed and flask A's had.
   - **a** How would the mass of flask A have changed? Explain your answer.
   - **b** Why was there no change in the mass of flask B?




ISBN 978-1-108-88711-3

# Chapter 4 review

## Summary

Create your own set of summary notes for this chapter on paper or in a digital document. A model summary is provided in the Teacher Resources which can be used to compare with yours.

## Checklist

In the Interactive Textbook, the success criteria are linked from the review questions and will be automatically ticked when answers are correct. Alternatively, print or photocopy this page and tick the boxes when you have answered the corresponding questions correctly.

| Success criteria – I am now able to: | | Linked question |
|---|---|---|
| **4A.1** | Understand how the specific structure of a cell relates to its function and provide examples of specialised cells in the context of mammals, e.g. red blood cells, cardiac cells | 11☐ |
| **4A.2** | Describe the relationship between cells, tissues, organs, organ systems and organisms in mammals | 1☐, 2☐, 11☐ |
| **4A.3** | Explain the need for transport systems in multicellular animals in terms of size, level of activity and surface area to volume ratio | 12a☐, b☐ |
| **4B.1** | Define the overall role of the digestive system within a mammal | 13☐, 17☐ |
| **4B.2** | Recognise the structures of the digestive system | 13☐, 17☐, 18☐ |
| **4B.3** | Describe the key function(s) each structure performs to enable the digestive system to carry out its role successfully | 6☐, 13☐, 17☐, 18☐ |
| **4B.4** | Explain the processes that occur within the digestive system and the role of specialised cells in performing these | 7☐, 17☐, 18☐ |
| **4B.5** | Describe the cause and consequences of digestive system malfunctions for the sufferer | 19☐ |
| **4C.1** | Define the overall role of the endocrine system within a mammal | 13☐ |
| **4C.2** | Recognise the structures of the endocrine system | 13☐ |
| **4C.3** | Describe the key function(s) each structure performs to enable the endocrine system to carry out its role successfully | 13☐ |
| **4C.4** | Explain the processes that occur within the endocrine system and the role of specialised cells in performing these | 8☐, 20a☐, 21a☐, b☐ |
| **4C.5** | Describe the cause and consequences of endocrine system malfunctions for the sufferer | 20b☐, 21c☐ |
| **4D.1** | Define the overall role of the excretory system within a mammal | 13☐, 24☐ |
| **4D.2** | Recognise the structures of the excretory system | 9☐, 23☐, 13☐, 24☐ |
| **4D.3** | Describe the key function(s) each structure performs to enable the excretory system to carry out its role successfully | 10☐, 13☐, 22a☐, 23☐, 24☐ |
| **4D.4** | Explain the processes that occur within the excretory system and the role of specialised cells in performing these | 22b☐, c☐, 24☐ |

ISBN 978-1-108-88711-3

| Success criteria – I am now able to: | | Linked question |
|---|---|---|
| **4D.5** | Describe the cause and consequences of excretory system malfunctions for the sufferer | 25a☐, b☐, c☐ |
| **4E.1** | Understand how the specific structure of a cell relates to its function and provide examples of specialised cells in the context of plants, e.g. guard cells, root hair cells | 11☐, 17☐, 14☐ |
| **4E.2** | Describe the relationship between cells, tissues, organs, organ systems and organisms in plants | 11☐ |
| **4E.3** | Define vascular plants | 15☐ |
| **4E.4** | Explain how the structure of a root hair cell is specialised for the uptake of water | 17☐ |
| **4E.5** | Explain the various methods of movement that are used for the distribution of water, ions and minerals throughout the plant | 4☐, 5☐, 17☐, 14☐, 24☐ |
| **4E.6** | Describe the composition, arrangement and role of xylem tissue in vascular transport throughout plants | 4☐, 16b☐ |
| **4E.7** | Explain the cause and role of transpiration in plants | 16a☐, b☐, c☐ |
| **4E.8** | Explain how transpiration rate is influenced by various environmental factors | 3☐, 14☐ |

## Multiple-choice questions

**1** Which of the following lists the structures in order from smallest to largest?
- **A** vacuole, chloroplast, shoot system, leaf
- **B** lung, cheek cell, mitochondrion, muscular system
- **C** chromosome, ribosome, stomach, villus
- **D** mitochondrion, nucleus, pancreas, excretory system

**2** Organs are grouped into systems on the basis that they
- **A** are similar in appearance.
- **B** are close together in the organism.
- **C** cooperate to perform a common function.
- **D** all consist of the same type of cells.

**3** Which of the following does *not* increase the rate of transpiration?
- **A** increase in humidity
- **B** increase in temperature
- **C** increase in light intensity
- **D** increase in wind

**4** The direction of the passage of water through the xylem of a plant could be
- **A** from the xylem to the roots.
- **B** from the roots to the xylem.
- **C** from the roots to a root hair.
- **D** from the shoot system to the root system.

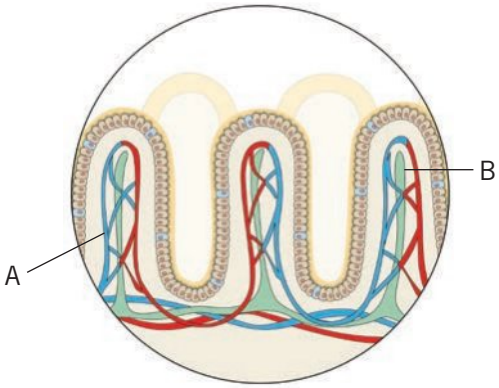
**5** The transpiration stream from the roots to the leaves of a tree is aided by the
- **A** use of energy to pump water through the xylem.
- **B** capillary action of water, which assists it to move up through the xylem.
- **C** reduction in the adhesion and cohesion properties of water as it moves into the xylem from the roots.
- **D** capillary action of water, which assists it to move up through the phloem.

## The digestive system

**6** Which of the following is *not* an example of physical digestion?
- **A** chewing in the mouth
- **B** churning of the stomach
- **C** bile breaking down fats
- **D** amylase breaking down starch

ISBN 978-1-108-88711-3

**7** The surface area of the small intestine is increased by structures called villi (see below).




Select the correct statement.

**A** Fats in the form of glycerol and fatty acids pass into the digestive system through structure A.
**B** Fats in the form of glycerol and fatty acids pass out of the digestive system through structure A.
**C** Fats in the form of glycerol and fatty acids pass into the digestive system through structure B.
**D** Fats in the form of glycerol and fatty acids pass out of the digestive system through structure B.

## The endocrine system

**8** Hormones can be classified as protein based or lipid based. Which of the following is *not* true for lipid-based hormones?

**A** They bind to intracellular receptors.
**B** They bind to membrane receptors.
**C** Testosterone belongs to this class of hormones.
**D** Oestrogen belongs to this class of hormones.

## The excretory system

**9** Which of the following is *not* a paired structure of the excretory system?

**A** ureter
**B** urethra
**C** renal vein
**D** renal artery

**10** The main function of the loop of Henle in a nephron is

**A** the passage of urine to the bladder.
**B** the filtration of blood.
**C** reabsorption of amino acids and glucose.
**D** reabsorption of water and ions.

## Short-answer questions

**11** Complete the following table to show how the named cell contributes at each level to the overall structure of the organism. (2 marks)

| In animals | | In plants |
|---|---|---|
| Smooth muscle cell (of artery) | Cell | Vessel element |
| | Tissue | |
| | Organ | |
| | System | |
| Lion | Organism | Oak tree |

**12 a** Which of these organisms requires the assistance of a transport system(s) to meet their survival needs? (1 mark)

Paramecium

Lion

**b** Explain two reasons which justify your choice. (2 marks)

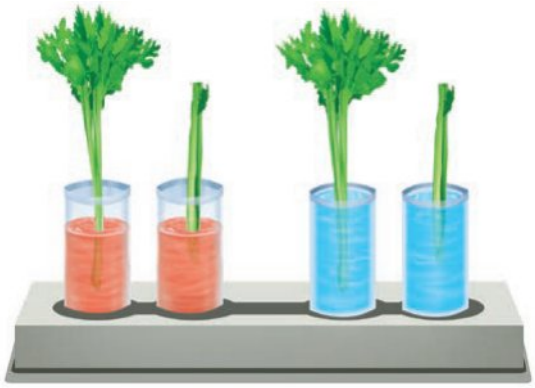
ISBN 978-1-108-88711-3

**13** In this chapter you have read about three mammalian body systems. Describe an example that shows how systems work together to maintain balance and the survival of the organism. (2 marks)

**14** Heavy rain or floods can result in roots becoming waterlogged. Most land plants will die if their roots remain in water for too long. Explain why this is the case. (*Hint*: You will need to draw together your knowledge from Chapters 1–3 to answer this question.) (3 marks)

**15** Explain, with the use of examples, the difference in size between vascular plants and non-vascular plants. (2 marks)

**16** The following experiment was set up by students in a lab. The two celery sticks on the left were placed in water with red dye; the two on the right were place in water with blue dye.



**a** Draw what you would expect to see in the four celery sticks 24 hours after the experiment was set up. (3 marks)

**b** Explain the difference in results between the celery with leaves and the celery without the leaves. (2 marks)

**c** The students noticed that after a couple of days, the celery without leaves was beginning to wilt and die. Explain these observations with reference to the importance of transpiration. (1 mark)

## The digestive system

**17** Compare the absorption of water in the root system of plants with the absorption of water in the digestive system of mammals. (2 marks)

**18** You have just eaten your lunch, which consisted of spaghetti bolognaise left over from last night's dinner. The bolognaise mince is high in protein and the pasta is high in starch. Describe the similarities and differences in the breakdown of your meal through the digestive tract. (2 marks)

**19** Diarrhoea, constipation, weight loss and growth problems are common symptoms of coeliac disease. Use your knowledge of the digestive system to explain the occurrence of these symptoms in coeliac sufferers. (2 marks)

## The endocrine system

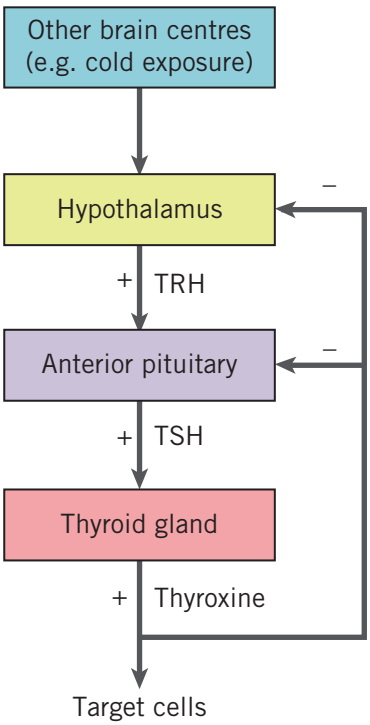
**20** Cortisol is a lipid-based hormone that is produced in the adrenal glands located on the top of each kidney. It is usually released at times of stress and results in many important changes within the body.

**a** Explain, at a cellular level, the interaction between cortisol and its target cells. You may wish to include a diagram to support your answer. (1 mark)

**b** When cortisol is released in response to a perceived threat, it results in increased glucose levels in the blood. Explain why the perception of a threat leads to such an increase. (2 marks)

ISBN 978-1-108-88711-3

**21** The flow chart on the right shows the release of thyroxine in the human body.




**a** How would TRH, TSH and thyroxine travel to their target cells? (1 mark)

**b** Name one area of the body where a target cell would be. What effect would thyroxine have on this body part? (2 marks)

**c** Choose one of the following and explain the effect it has on an individual who suffers from the condition. (1 mark)
Hyperthyroidism
Hypothyroidism

## The excretory system

**22** Use the table below to answer the following questions.
*Percentage composition of fluid in a healthy human being*

| Substance | Blood plasma (%) | Glomerular filtrate (%) | Urine (%) |
|---|---|---|---|
| Water | 90 | 90 | 94 |
| Glucose | 0.1 | 0.1 | 0 |
| Protein | 8 | 0 | 0 |
| Urea | 0.03 | 0.03 | 2.00 |
| Sodium ($Na^+$) | 0.33 | 0.33 | 0.29 |
| Potassium ($K^+$) | 0.02 | 0.02 | 0.24 |

**a** List the components of urine, from lowest concentration to highest. (1 mark)

**b** Why is the amount of glucose in urine so significant for the organism? (1 mark)

**c** Identify the change in urea concentration from the blood to the urine. Why is this change so important? (2 marks)

**23** Explain the role of the liver in the excretory system. Why is this organ important in mammals but not in aquatic creatures such as fish? (2 marks)

**24** Compare the absorption of ions and minerals in the root system of plants with the absorption of ions and nutrients in the excretory system of mammals. (2 marks)

**25** During a marking contest in a football match, Rashad was involved in a heavy collision that resulted in him taking a heavy knock to his left kidney. Tests at the hospital revealed severe kidney damage and resulted in removal of the damaged kidney.

**a** Explain whether or not Rashad would need to replace the kidney that was removed. (1 mark)

**b** What advice would doctors have given Rashad regarding future lifestyle choices? Why is it important that Rashad follows this advice? (2 marks)

**c** On the way to the hospital, Rashad noticed blood in his urine. Explain the likely cause of this occurrence. (1 mark)

ISBN 978-1-108-88711-3

ISBN 978-1-108-88711-3

UNIT 1

HOW DO ORGANISMS REGULATE THEIR FUNCTIONS?

CHAPTER 5

# REGULATION OF SYSTEMS

## Introduction

Have you ever stopped to think about how amazing life is? Not just the actual process of us being alive, but the fact that we manage to stay alive in an environment where things are changing all the time and we are being constantly challenged. Just think about all of the different things that your body does on a daily basis: eating meals, exercising, being outside in differing weather conditions.

All these things may feel like they have an impact on you. For example, if you go outside without a jumper and it's cold, you may feel chilly. However, internally, these things are actually handled incredibly well. Indeed, most of the internal workings of the body (in humans and in animals in general) are very tightly regulated by a process called homeostasis. In this chapter, you will learn about homeostasis, the processes by which it is maintained and what happens when it goes wrong.

## Curriculum

**Area of Study 2 Outcome 2**
**Regulation of systems**

| Study Design | Learning intentions – at the end of this chapter I will be able to: |
|---|---|
| • Regulation of body temperature, blood glucose and water balance in animals by homeostatic mechanisms, including stimulus–response models, feedback loops and associated organ structures | **5A Homeostasis**<br>**5A.1** Recall the five stages of a stimulus–response model<br>**5A.2** Describe the stimulus–response model<br>**5A.3** Describe, using diagrams, negative and positive feedback loops<br>**5A.4** Distinguish between examples of negative and positive feedback loops<br>**5A.5** Define homeostasis<br>**5A.6** Explain the importance of homeostasis to an organism's survival |

ISBN 978-1-108-88711-3

| Study Design | Learning intentions – at the end of this chapter I will be able to: |
|---|---|
| • Regulation of body temperature, blood glucose and water balance in animals by homeostatic mechanisms, including stimulus–response models, feedback loops and associated organ structures<br>• regulation of water balance in vascular plants | **5B Homeostasis in animals and plants**<br>**5B.1** Using diagrams and the stimulus–response model, explain how temperature is maintained<br>**5B.2** Using diagrams and the stimulus–response model, explain how blood glucose is maintained<br>**5B.3** Using diagrams and the stimulus–response model, explain how water balance is maintained<br>**5B.4** Explain how water balance is maintained in vascular plants |
| • Malfunctions in homeostatic mechanisms: type 1 diabetes, hypoglycaemia, hyperthyroidism | **5C Homeostasis gone wrong**<br>**5C.1** Explain, using a diagram, how type 1 diabetes results in a breakdown in blood glucose homeostasis<br>**5C.2** Explain the treatment of type 1 diabetes<br>**5C.3** Define hypoglycaemia and explain how it differs from type 1 diabetes<br>**5C.4** Explain, using a diagram, how hyperthyroidism (in the form of Graves' disease) occurs |



## Glossary

Autoantibodies
Autoimmune disease
Effector
Homeostasis
Hyperthyroidism
Negative feedback loop
Osmoreceptors
Positive feedback loop
Receptor
Reflex
Response
Sensor
Stimulus
Stimulus–response model

ISBN 978-1-108-88711-3

## Concept map

**5A Homeostasis**

*Maintaining a constant internal environment despite changes in the external environment*

*Applying the stimulus–response model and feedback pathways to specific regulatory systems*

**5B Homeostasis in animals**

**5C Homeostasis gone wrong**

*Disorders in humans where the normal homeostasis balance and feedback pathways are not effective*

**Hypoglycaemia**

**Hyperthyroidism**

*See the Interactive Textbook for an interactive version of this concept map interlinked with all concept maps for the course, and for a quiz of prior knowledge from Years 9 & 10 science.*

ISBN 978-1-108-88711-3


# Homeostasis

**Study Design:**
Regulation of body temperature, blood glucose and water balance in animals by homeostatic mechanisms, including stimulus–response models, feedback loops and associated organ structures

**Glossary:**
Effector
Homeostasis
Negative feedback loop
Positive feedback loop
Receptor
Reflex
Response
Stimulus
Stimulus–response model

## ENGAGE

## Stimulus and habituation

Have you ever felt the sensation of a spider crawling across your skin and responded by taking rapid evasive action, twitching that part of your body, or flicking the spider off your skin, or even screaming? Conversely, if you feel your shirt or a piece of fabric lightly touching the same area of skin, you essentially ignore this stimulus. This behaviour is called 'habituation'. Without habituation, living in a complex environment with many unimportant stimuli would be overwhelming. Hypersensitivity to the environment is thought to be common in individuals with autism.

In 2014, Mani Ramaswami, a neuroscientist in the School of Genetics and Microbiology at Trinity College in Dublin, Ireland, proposed a theory for why organisms tend to ignore certain stimuli and therefore not produce a response or action. His model proposed that the 'repeated activation of any group of neurons that respond to a given stimulus results in the build-up of "negative activation", which inhibits responses from this same group of cells' (*Science Daily*).

Think about all the different things that occur around you every day, and how you respond (or don't respond) to them. Why do you respond in the way that you do? What happens inside your body that controls these actions? This section will explore these questions in detail.

ISBN 978-1-108-88711-3

7C ADAPTATION, DIVERSITY AND SURVIVAL WITH INDIGENOUS PERSPECTIVES

LINK

VIDEO 5A–1 HOMEOSTATIC MECHANISMS

## EXPLAIN

# What is homeostasis?

In Chapter 7, you will read about how plants and animals adapt to changes in their environment. However, the processes that lead to these developments often take a long time to occur, and so they can't help the organism with the many day-to-day changes that happen around it. It is therefore important that the body has mechanisms to be able to handle those changes and maintain a constant internal environment. This process is known as **homeostasis**.

This section explains the mechanisms by which the mammalian body, using the human body as an example, maintains a constant internal environment, and discusses these in relation to three important variables in our body: temperature, blood sugar (glucose) levels and water balance.

## Stimulus–response model

Imagine you are in the kitchen and you accidentally put your hand down on the hot stove. What happens? Without even thinking about it, you'll remove your hand very quickly. This is a **reflex** action. The body's process of detecting a change and reacting to it is explained by the **stimulus–response model**.

The stimulus–response model involves two major systems in the body: the nervous system and the endocrine system. While there are certainly differences in how these two systems act and respond, they also have a number of things in common. Let's examine these key features of the stimulus–response model through an example (Figure 5A–1).

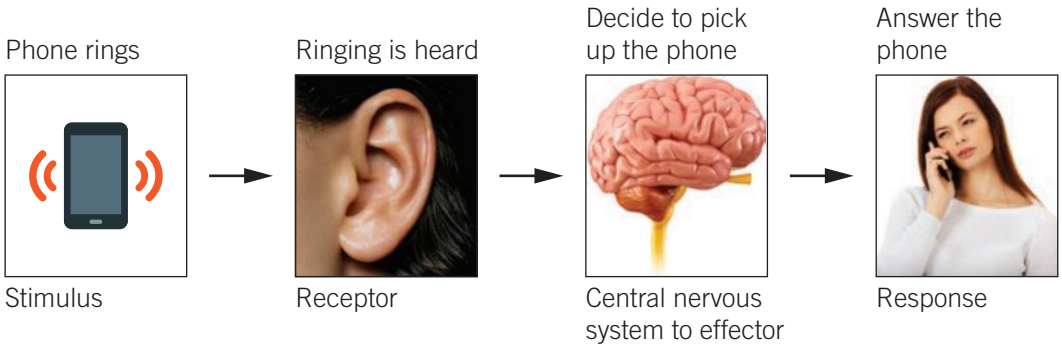



**Figure 5A–1** The key features of the stimulus–response model, using a phone ringing as an example

This basic example shows all the key elements of the stimulus–response model. The phone ringing is the signal that there is something different occurring (a change) that requires a reaction – this is the **stimulus**. If you are not within earshot of your phone, you won't hear it ringing, so you won't generate a response. In this case, what is missing is something to detect the stimulus: your ears. The part of the mechanism that is responsible for detecting a stimulus is the **receptor**. Next, there needs to be a return signal that generates a response to the stimulus. In this instance, it is the decision to get up, or reach over, and pick up the phone. The sending of the signal (by the control centre, in this example the central nervous system) leads to the generation of a response by the **effector**. Lastly, you do something to react to the stimulus, such as answering the phone so that the ringing stops. This is known as the **response**.

This example shows the key concepts of the stimulus–response model. Now let's look at how they function in the body, particularly while helping to maintain homeostasis.

**Homeostasis** the maintenance of a constant internal environment despite changes in the external environment

**Reflex** a response to a stimulus that doesn't require thought, as the nerve signal does not involve the central nervous system

**Stimulus–response model** the pathway from a stimulus or change to response or action taken by a cell/organism

**Stimulus** a change in the internal or external environment that can be detected

**Receptor** specialised proteins or glycoproteins in the cytosol or on the plasma membrane that receive a stimulus

**Effector** the part of the body that is capable of responding to a stimulus

**Response** a change in an organism resulting from the detection of a stimulus

ISBN 978-1-108-88711-3

## Regulation and feedback loops

It is important to realise that variables in the body aren't all kept at a constant level; rather, they are kept within a tight range. The body responds to variations above and below this range – too high and the level is brought back down, too low and the level is brought back up.

This is a little like using your phone camera to take a panorama shot (Figure 5A–2). While you try and keep the phone steady and as close to the line as possible, the reality is that often you go a little bit above it, and then try and adjust, but you go a little bit below it. However, as long as the movement away from the line isn't too great, the photo still turns out well.

**Figure 5A–2** A smartphone panorama photo requires you to follow a display of an arrow and a line that you have to try to keep to when moving the phone smoothly.

### Negative feedback

In the body, this process is more complicated, but the principle is the same. One of the main ways in which the body maintains homeostasis is through **negative feedback loops**. All negative feedback loops have five main stages, as shown in the flow chart in Figure 5A–3.

**Negative feedback loop** a process that regulates a variable within an organism, whereby the last step in the process (response) reduces the initial stimulus and so is self-limiting

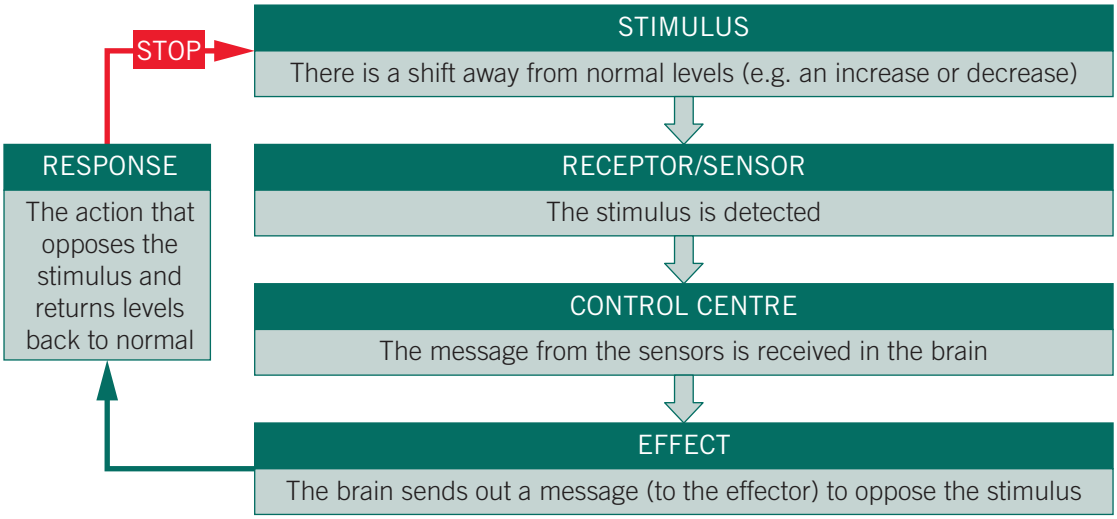



**Figure 5A–3** A generalised pathway for a negative feedback loop. The effect generated at the final step restores normal levels and this stops the process from continuing.

ISBN 978-1-108-88711-3

To help you remember the steps involved in a negative feedback loop, use the acronym STRICTER (**S**timulus **T**o **R**eceptor, **I**nput to **C**ontrol, **T**hen **E**ffect and **R**esponse). The important thing to remember here is that the effect that is generated has a direct impact on opposing the stimulus. This means that once normal levels have been restored in the body, the stimulus is no longer present, and the loop will stop.

Biological examples of negative feedback will be given in the next section. Meanwhile, another way to picture this process is through a non-biological example: the heater in your house. When you turn it on, you set it to a certain temperature. If the temperature of the room is below that value, the heater turns on to warm up the room. Once the room warms to the appropriate temperature, a thermostat or sensor in the heater detects this and causes it to turn off. Over time, with the heater off, the room will cool down again and the process will begin again. The effect of this is that the room temperature is kept fairly constant, or at least within a narrow range, at all times.

**Positive feedback loop** a process that controls a variable within an organism, whereby the last step in the process causes the action to be repeated

4C THE ENDOCRINE SYSTEM: CHEMICAL CONTROL LINK

## Positive feedback

It is important to recognise that feedback loops exist that also generate responses that *increase* the initial stimulus. These are known as **positive feedback loops**. One of the best known examples of a positive feedback loop occurs during childbirth (Figure 5A–4) and is responsible for the contractions that help deliver the baby. In this situation, the initial stimulus is provided by the baby pushing against the cervix, triggering stretch receptors in the uterus. This signal travels to the brain, which generates an effect through the release of the hormone oxytocin. Oxytocin causes the uterine muscles to contract. As the muscles contract, the space in the uterus gets smaller around the baby, which causes the stretch receptors to be triggered, and the whole process to restart. As you can see, this is the opposite of a negative feedback loop. In these situations, instead of opposing the initial stimulus, the end product of the loop initiates the stimulus and repeats the cycle.

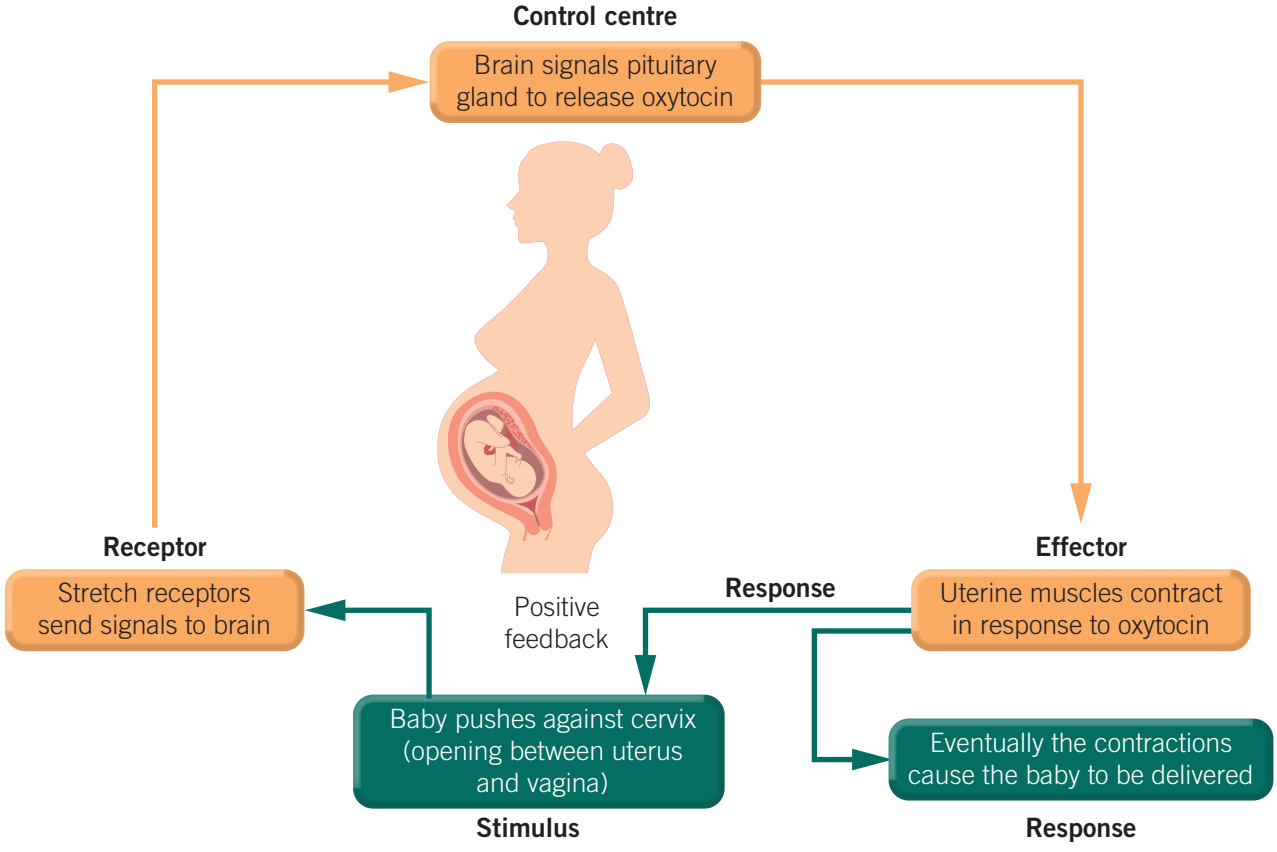



**Figure 5A–4** The positive feedback loop that occurs with oxytocin inducing contractions during childbirth. The process goes around the loop numerous times until the baby is delivered.

ISBN 978-1-108-88711-3

These feedback loops involve two major systems in the body: the nervous system and the endocrine system. You can revise what you have previously learned about the endocrine system by reviewing Section 4C. The two systems share a characteristic: they use chemical messengers, either neurotransmitters or hormones, to send signals to cells throughout the body to generate an effect or a response.

LINK **4C** THE ENDOCRINE SYSTEM: CHEMICAL CONTROL

## Check-in questions – Set 1

1 What are the two types of feedback loops?
2 What is the term for a response to a stimulus that does not involve the central nervous system?

DOC **WORKSHEET 5A–1** USING THE STRICTER MODEL TO DESCRIBE FEEDBACK LOOPS

## 5A SKILLS

**VIDEO 5A–2** SKILLS: USING A FRAMEWORK TO ANSWER QUESTIONS

**Using a framework to answer questions**

Regardless of whether we are talking about temperature, blood glucose, water balance or even contractions during pregnancy, these processes all follow the same series of steps. As this pattern repeats in every situation, you should be able to construct a response when given limited information. Always begin with a known framework – that is, write down that there must be a stimulus, receptor, control centre, effector and response. From the information given, determine what part of this pathway is already known, and then try to fill in the gaps using your knowledge. It is important that you also use this framework to structure your answer. The more logically you piece together the information in your answer, the easier it will be for an examiner to see that you understand the theory, and to give you full marks. Here is an example:

*Question:* Describe the steps involved in a negative feedback loop.

*Answer:* Apply the STRICTER model to structure your answer to this question.

All negative feedback loops consist of five key steps, which are:

S (stimulus): A shift away from normal homeostatic levels

TR (to receptor): The stimulus is detected by a receptor

IC (input to control): The message from the sensors is received in the brain (or other control area)

TE (then effect): The control centre sends out a message (to the effector) to oppose the stimulus

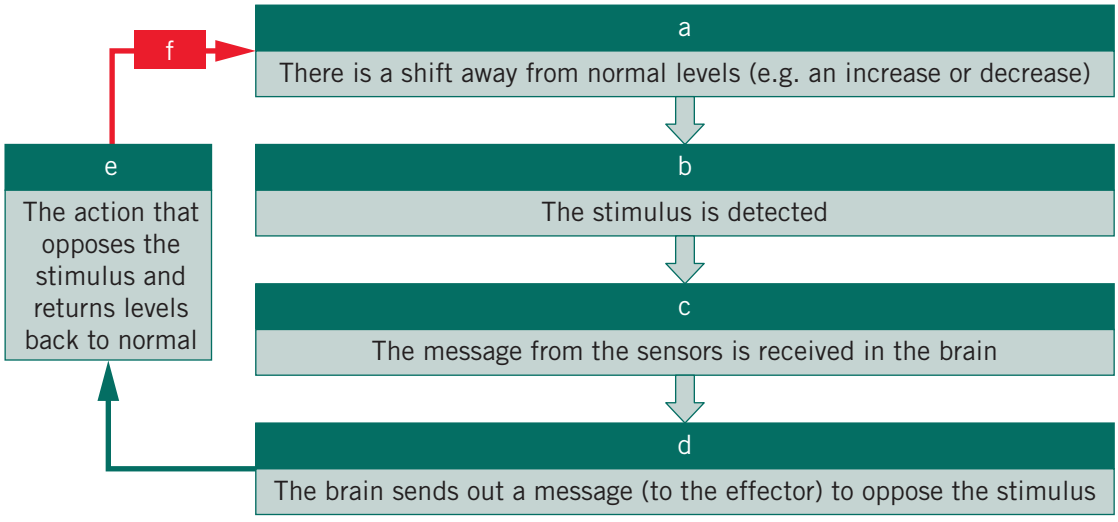
R (response): The action that opposes the stimulus and returns the levels back to normal homeostatic ranges.

ISBN 978-1-108-88711-3

**Figure 5A–5** A positive feedback loop in plants uses ethylene as a plant hormone to bring on fruit ripening. The first fruit to ripen releases ethylene which causes neighbouring fruit to start ripening, releasing more ethylene, resulting in a cascade of ripening. The fruit industry exploits this to control fruit ripening to minimise wastage, and Australia is a leader in the technology. Banana bunches like these are harvested when green and hard to enable them to be transported to distribution centres where they are placed in ripening rooms. Ethylene gas is introduced at a controlled level which produces ripening to a desired schedule, enabling bananas to reach supermarket shelves at the right degree of ripeness.

## Section 5A questions

1 List the key components of the stimulus–response model.
2 In this section, answering a ringing phone was given as an example of how the stimulus–response model works. Provide another real-life example that follows this model, ensuring that you clearly indicate the key features listed in your answer to Question 1.
3 Define 'homeostasis'.
4 Compare and contrast a positive and a negative feedback loop.
5 Give an example of a process that uses a positive feedback loop.
6 Fill in the blanks on this diagram of a negative feedback loop with the names of steps a to f.




ISBN 978-1-108-88711-3


# Homeostasis in animals and plants

**Study Design:**
- Regulation of water balance in vascular plants
- Regulation of body temperature, blood glucose and water balance in animals by homeostatic mechanisms, including stimulus–response models, feedback loops and associated organ structures

**Glossary:**
Osmoreceptors
Sensor

## ENGAGE

### Body temperature and fever

As you will see in this section, the regulation of temperature in the body of most warm-blooded animals, such as mammals and birds, within a narrow range of 36.6–37.5°C, is crucial to their survival. This narrow range is the same in humans.

An exception to this is when you have a fever. This occurs when the body becomes infected with a foreign pathogen, such as a bacteria or virus. Many people assume that this elevated temperature is due to the bacteria or virus. However, it is actually part of the body's defence mechanism. At slightly higher temperatures, enzymes within the immune system work more effectively. Also, at higher temperatures, the body is a less suitable environment for replication of invading pathogens. These effects help to clear the infection.

However, even this onset of fever needs to be tightly regulated by the body. During fever, the blood and urine volumes decrease as a result of loss of water through increased sweating. In addition, proteins are rapidly broken down, leading to increased excretion of nitrogenous waste in the urine.

Severe fevers, where the body temperature can rise to 42°C or more, can result in continuous convulsions, serious brain damage and even death.

LINK UNIT 4

LINK 4D THE EXCRETORY SYSTEM: ELIMINATING WASTE

## EXPLAIN

### Regulation of body temperature

Body temperature is one of the variables in the human body that we notice the most. Walk outside in the middle of winter not wearing enough layers, and your body starts to feel cold, and you shiver. Go for a run in the middle of summer and you end up drenched in sweat. Why do these things happen? As you probably realise by now, most things in biology aren't accidental – they have a role and a purpose.

Our normal body temperature is maintained at about 37.5°C (with one exception, which is discussed above). Severe consequences, including death, can result from the body temperature getting too low or too high. So how is core body temperature maintained?

**Figure 5B–1** Sweating or shivering is part of a feedback loop designed to restore normal body temperature.

VIDEO 5B–1 REGULATION OF BODY TEMPERATURE

ISBN 978-1-108-88711-3

**Sensor**
a structure that detects a stimulus; a receptor

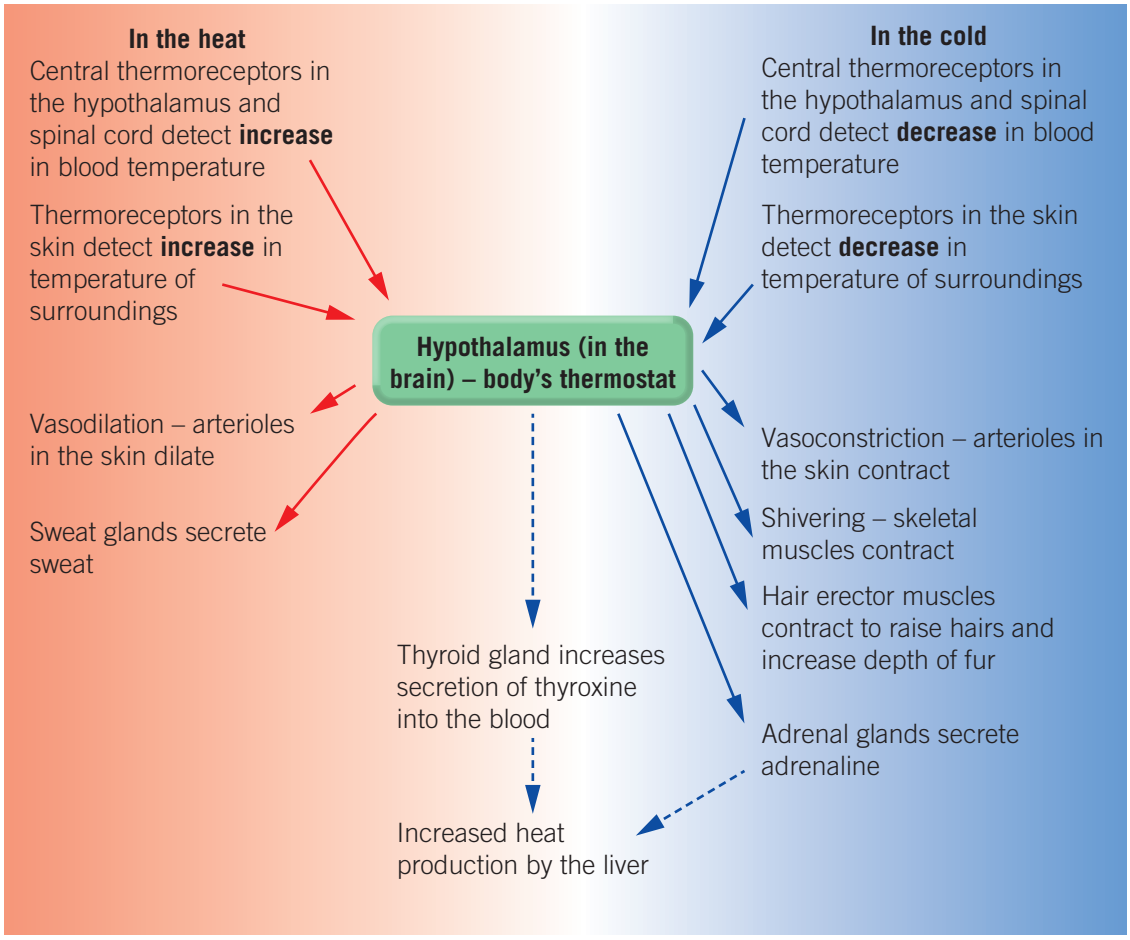
The first step in the regulation of body temperature is that any change – an increase or decrease in body temperature – is registered. This happens via **sensors**, in this case thermoreceptors within the skin. These sensors are not capable of creating a response themselves. The message first needs to be transmitted to the control centre. In the case of temperature regulation, the control centre is a part of the brain known as the hypothalamus. The hypothalamus then sends signals to various parts of the body to generate the necessary response.

**4C** THE ENDOCRINE SYSTEM: CHEMICAL CONTROL LINK

A very simple model of the feedback loops and responses involved in temperature regulation in the body is shown in Figure 5B–2. As body temperature decreases, a response (such as shivering) is generated that results in the normal temperature being restored. If body temperature rises, the higher temperature activates cooling mechanisms (such as sweating) that reduces the temperature to the normal range.

As you can see in Figure 5B–2, one of the key mechanisms that controls the regulation of body temperature is dilation (widening) or constriction (narrowing) of blood vessels. These are referred to as vasodilation and vasoconstriction respectively, as 'vaso' is a term that relates specifically to vessels (usually blood vessels).

The regulation of body temperature in other mammals is similar to humans but with some differences, such as panting or licking the fur, rather than perspiring to cool down. This is because sweat secreted on the skin would be prevented by fur from evaporating effectively.




**4C** THE ENDOCRINE SYSTEM: CHEMICAL CONTROL LINK

**Figure 5B–2** The homeostatic regulation of body temperature is controlled by the hypothalamus in the brain.

ISBN 978-1-108-88711-3

Birds do not sweat or pant like dogs, but may flutter their throat membranes to do the same kind of thing. Birds and mammals also have different kinds of behavioural adaptations from humans to help regulate body temperature, with the aim of seeking out cold or warm places as required.

In order to understand how vasodilation and vasoconstriction work, it is useful to look at the structure of the major blood vessels – arteries and veins. These structures can be seen in Figure 5B–3. As you can see in this figure, the vessels contain elastic and muscular layers, which allow for the stretching movements described above. By contracting, as happens when the body temperature is too low, the blood vessels move further away from the surface of the skin, and so less heat is lost to the surroundings. In the opposite way, dilation of blood vessels (through relaxation of the elastic layers) moves the vessels closer to the skin surface and more heat is lost, thus cooling down the body.

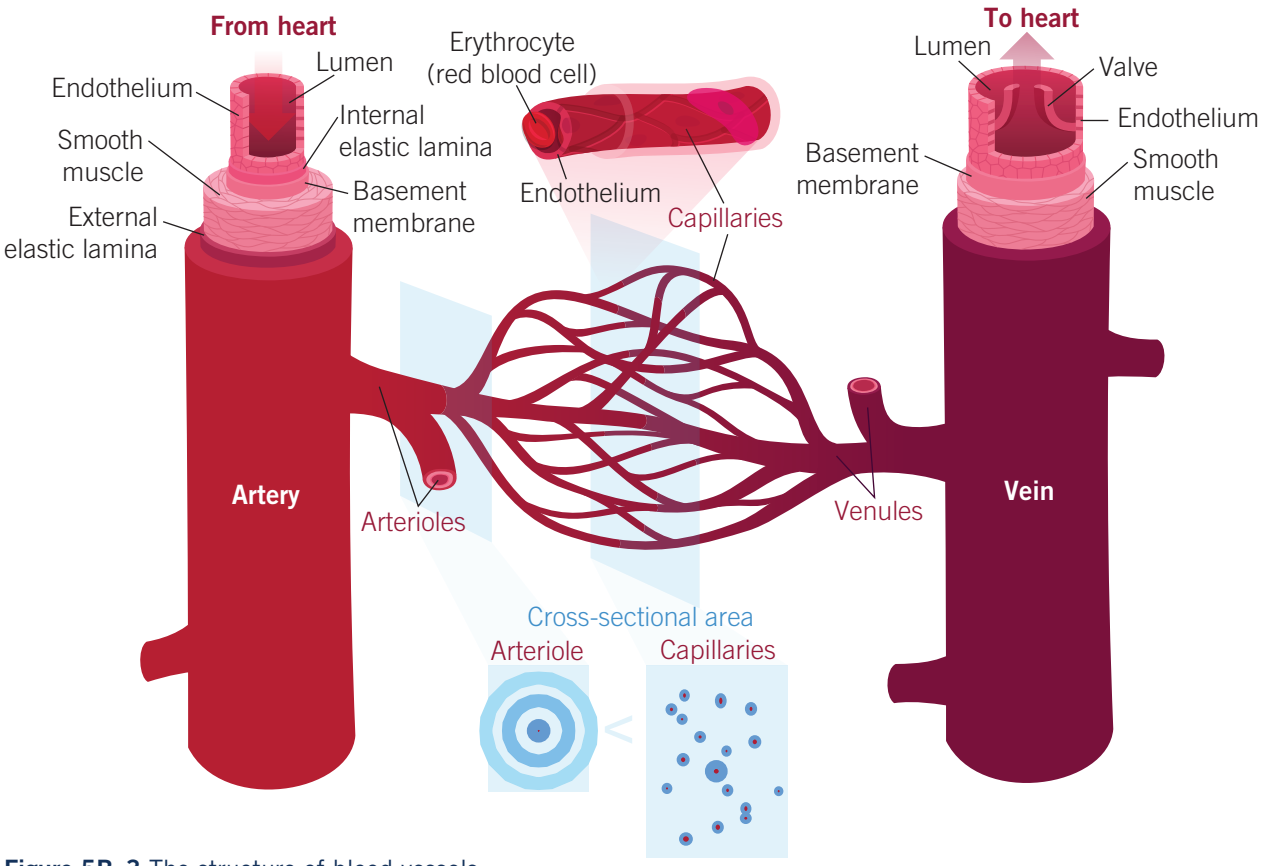



**Figure 5B–3** The structure of blood vessels

## Regulation of blood glucose

Glucose is one of the most important molecules in the human body. It is one of our primary sources of energy, as the body converts it into ATP during cellular respiration. It is not surprising, then, that glucose levels in the body must be very tightly regulated. In this instance, homeostasis is maintained through two hormones: insulin and glucagon. The two hormones are produced by the pancreas, and have opposing effects.

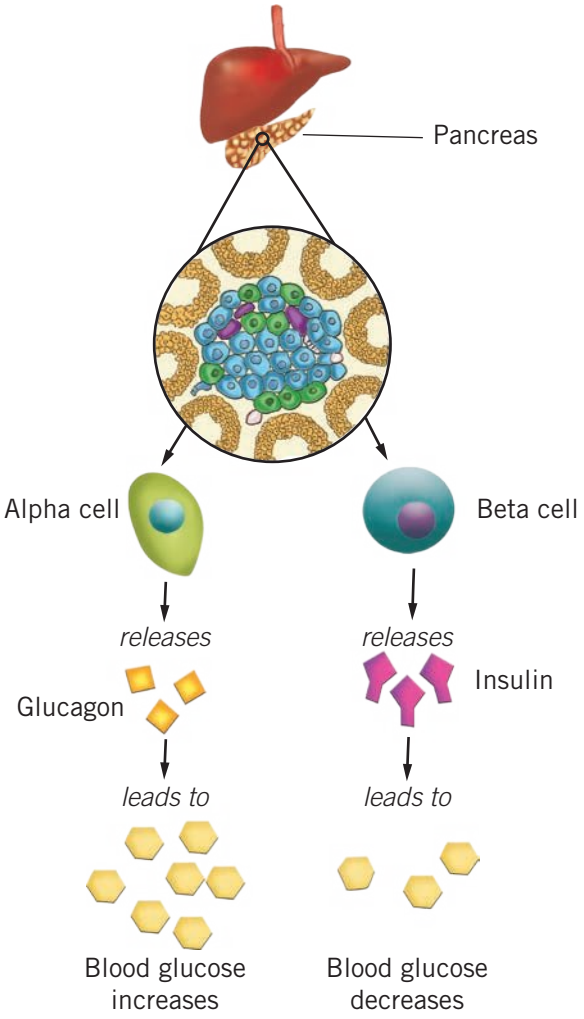
LINK **2D** ROLE OF CHLOROPLASTS AND MITOCHONDRIA

You may have learned about the pancreas in Section 4C (depending on the body system chosen). If not, you can turn back to that section of this book and read up on the details. Let's revisit some of the major points.

LINK **4C** THE ENDOCRINE SYSTEM: CHEMICAL CONTROL

The structure of the pancreas is shown in Figure 5B–4 on the following page.

ISBN 978-1-108-88711-3




The pancreas is composed of two types of tissue: exocrine and endocrine. The exocrine tissue is responsible for producing pancreatic juices, which are necessary for digestion. The endocrine tissue or islets of Langerhans are responsible for the production of hormones, primarily insulin and glucagon, which, as has been mentioned, are regulators of the homeostasis of blood glucose levels.

Insulin is secreted in response to high blood glucose, such as after a meal, and is responsible for lowering glucose levels. It does this by promoting the uptake of glucose by cells, where it is either converted into energy (as ATP) or stored as glycogen for later use. Glucagon, conversely, is secreted in response to low blood glucose levels, such as during a period of exercise or starvation. It has a number of effects that all work to increase the concentration of glucose in the blood. This cycle is summarised in Figure 5B–5.

**Figure 5B–4** Islets of Langerhans in the pancreas contain specialised alpha and beta cells. These cells secrete the hormones responsible for keeping blood glucose concentration stable.

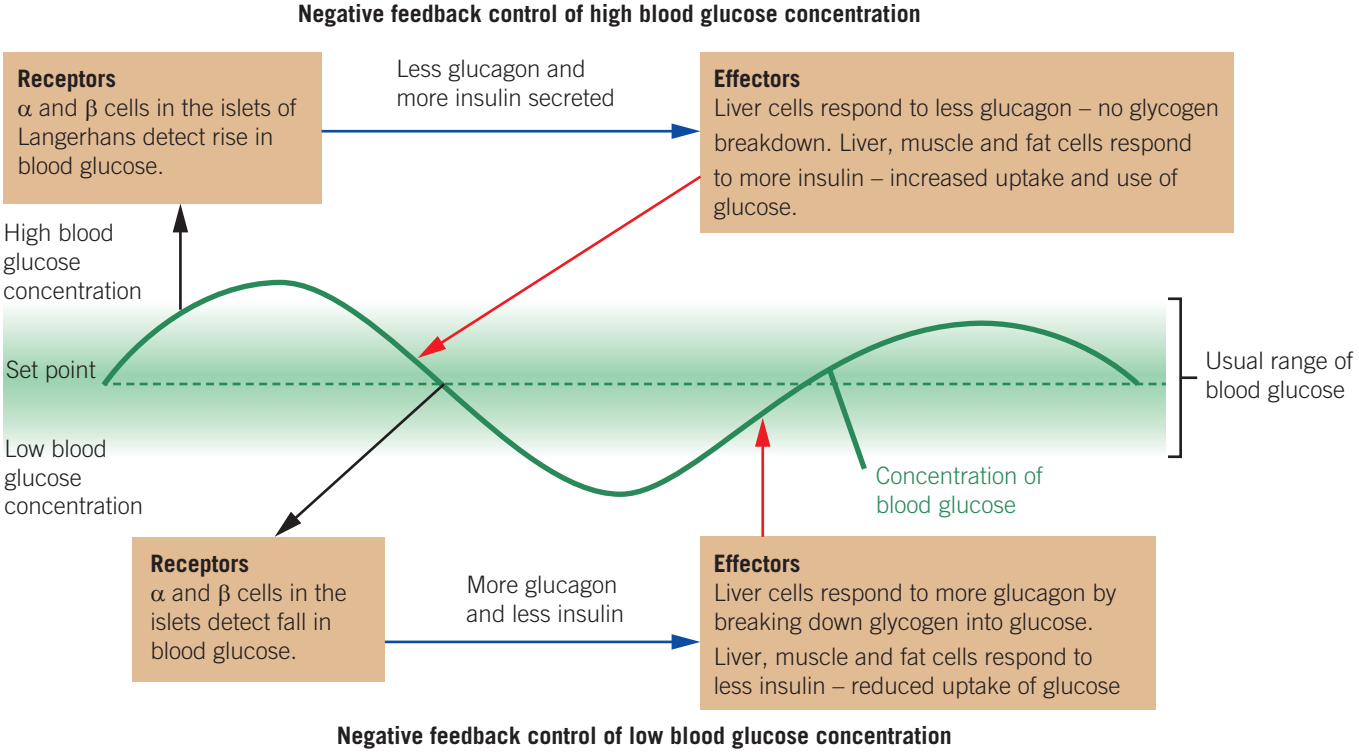



**Figure 5B–5** Homeostasis of blood glucose levels is maintained through the action of two hormones: insulin and glucagon.

ISBN 978-1-108-88711-3

Blood glucose is a good example of the importance of regulating levels within the body, and the problems that can occur when regulation goes awry. In Section 5C, you will learn about type 1 diabetes, a condition that results from the body not being able to maintain blood glucose homeostasis.

LINK 5C HOMEOSTASIS GONE WRONG

## Regulation of water balance in mammals

Maintaining water balance, a process known as *osmoregulation*, is critical for many processes in the body. It is essential for normal cell function, as well as healthy blood pressure and heart rate.

To maintain a factor within a constant range during homeostasis requires a receptor to detect when a change occurs. For water balance, these receptors are known as **osmoreceptors** and are located within the hypothalamus. If these receptors detect a change, such as a decrease in the water balance, they must generate a response that will reverse this change and restore homeostasis. The response comes in the form of a hormone known as *antidiuretic hormone* (ADH), which is released into the bloodstream and transported throughout the body. 'Antidiuretic' means reducing urination. When the water balance in the body decreases, the body's response is to absorb and reabsorb more water and excrete less in the urine – this is the function of ADH.

**Osmoreceptors** sensors in the body that detect changes in water balance away from homeostatic levels

So how exactly does ADH lead to the absorption of more water? The answer lies in the structure of the kidney, covered in Section 4D. However, let's revisit some of the major points. The main structural features of the kidney can be seen in Figure 5B–6 below.

LINK 4D THE EXCRETORY SYSTEM: ELIMINATING WASTE

As you can see, we are focusing on the part of the kidney known as the nephron. The nephron has three main functions: filtration, secretion and reabsorption (which is crucial in maintaining water balance). In situations where the water balance is low, ADH acts on target cells in the nephron, triggering them to increase their reabsorption and thus maintain homeostasis.

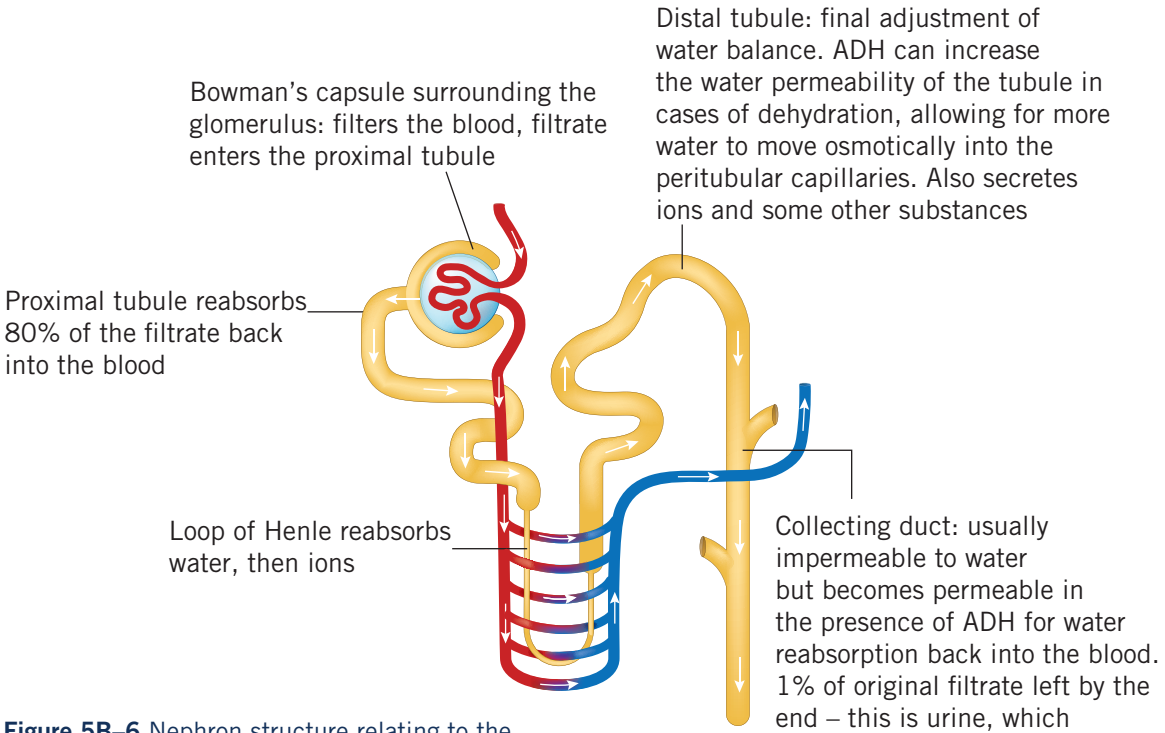



**Figure 5B–6** Nephron structure relating to the action of ADH in regulating reabsorption of water and thus water balance in the body. For more detail about other kidney functions see Table 4D–2.

ISBN 978-1-108-88711-3

With your knowledge of negative feedback loops, can you predict what would happen when the water balance is restored? To answer this, apply the steps of the feedback loop.

The osmoreceptors will stop detecting a change, and so the response (ADH release) will also stop. This means that ADH won't trigger cells in the nephron to increase reabsorption, and so more water will be excreted in urine. Eventually, if this water balance drops again, the process will restart.

**4D** THE EXCRETORY SYSTEM: ELIMINATING WASTE LINK

You may also wish to revisit Section 4D, to revise the excretory system and the organs involved, to try and work out where and how ADH increases the absorption of water back into the body.

## Regulation of water balance in plants

Plants rely on water for photosynthesis and survival. It is not common to relate water regulation in vascular plants through a model of negative feedback. However, as shown in Figure 4E–15, plants respond to a shortage of water by closing their stomata to stop water loss through transpiration. When water is available again to the roots the stomata will open again to restart transpiration. This has some features of a negative feedback loop.

**4E** PLANT SYSTEMS LINK

**2D** ROLE OF CHLOROPLASTS AND MITOCHONDRIA LINK

As the stomata are also the point of gas exchange by diffusion (carbon dioxide in, oxygen out) required for photosynthesis, closing them has a significant impact on the plant's ability to take in carbon dioxide, stopping photosynthesis. Additionally, as you will recall from Section 4E, the movement of water through the xylem via transpiration is needed to both cool the plant and provide minerals and ions to the leaves. This also stops when stomata close.

In mammals with an active circulation system, the importance of osmoreceptors in reversing a change in water balance and restoring homeostasis was outlined. In plants, this reversal is not as simple. Plants cannot just release a hormone that results in the absorbance and re-absorbance of water from other parts or systems as easily as animals can. If the plant is not adapted to long dry periods, it will wilt and die. This is why plants are typically not thought of as having a direct negative feedback homeostatic mechanism of controlling water concentration.

**7C** ADAPTATION, DIVERSITY AND SURVIVAL, WITH INDIGENOUS PERSPECTIVES LINK

However, guard cells which surround the stomata, like almost all cells in the plant, are capable of producing a plant hormone called abscisic acid under conditions of water stress, which results in the stomata closing. Although not fully understood to date, guard cells have receptors for abscisic acid on their plasma membrane and when the abscisic acid hormone binds to them, it stimulates potassium ions being pumped out of the cell. As you will recall from the process of osmosis, the results in a higher free water concentration inside the cell, meaning that water leaves the cell. The result is that the guard cells surrounding the stomata become flaccid and the stomata close, preventing excessive water loss from the plant.

**2B** OSMOSIS LINK

Section 4E also describes the role of root hair cells in taking up soil water by osmosis but this is not an actively-regulated process. Stomata controlling transpiration is the primary means of water regulation in plants.

**4E** PLANT SYSTEMS LINK

**WORKSHEET 5B–1** DIAGRAMS OF HOMEOSTATIC REGULATION DOC

## Check-in questions – Set 1

1 Referring to Section 4C, what is the term for a hormone that has an effect on cells throughout the body?
2 Referring to Section 4C, the cells of what organ are likely to be targeted by ADH?

ISBN 978-1-108-88711-3

## 5B SKILLS

**VIDEO 5B–2**
SKILLS: RELATING RESPONSES DIRECTLY TO CONTEXT PRESENTED

**Relating responses directly to context presented**

In Section 5A, you learned about using acronyms to help remember and structure answers. In that section, the STRICTER approach was used to explain the steps involved in negative feedback loops. In this section, a number of physiological examples of negative feedback loops were discussed: regulation of body temperature, regulation of blood glucose levels and regulation of water balance. All these processes involve the same general steps associated with negative feedback loops, and so the STRICTER approach is still valid.

However, when answering a question that has a specific context (e.g. regulation of blood glucose levels), it is important that your response includes information relevant to that specific situation, not just generic information about the underlying process. Let's examine this by seeing the best way to answer the following question.

> *Question*: Using your knowledge of feedback loops, discuss how the body regulates a high blood glucose level.

For this question, two responses are shown below, for each step of the STRICTER approach. The red text indicates a response that is too broad. The green text is the most appropriate answer because it includes information that is relevant to the context of blood glucose levels.

> *Answer*:
>
> S (stimulus): There is a stimulus where something is outside the appropriate homeostatic range.
>
> S (stimulus): Blood glucose levels increase beyond the normal homeostatic range, such as after eating a meal.
>
> TR (to receptor): The receptor detects this stimulus.
>
> TR (to receptor): Beta cells in the pancreas contain receptors (target cells) that detect the increased blood glucose level.
>
> IC (input to control): The control centre responds to the detected stimulus and coordinates a response.
>
> IC (input to control): The beta cells promote the expression and synthesis of insulin.
>
> TE (then effect): An action is taken to oppose the stimulus.
>
> TE (then effect): Insulin is released via exocytosis by the beta cells to promote the uptake of glucose by cells, particularly muscle and liver.
>
> R (response): The stimulus reverts back to homeostatic levels.
>
> R (response): The blood glucose levels decrease back to within the normal homeostatic range. Hence, this is an example of a negative feedback loop.

As you can see, the red answers aren't wrong – they correctly describe what is happening at each step, in terms of a generic negative feedback loop. However, they are not specific enough to address the issue of blood glucose homeostasis. It is useful to have a general approach that you can apply to many different scenarios, but you must make sure that you modify that response to answer the question fully in its correct context.

ISBN 978-1-108-88711-3

## Section 5B questions

1 What two hormones are involved in the maintenance of blood glucose homeostasis? Explain the action of both of these in the circumstances when they are required.

2 What property of proteins makes body temperature homeostasis particularly important?

3 A hiker gets lost on a walk and has to spend the night outdoors in close to freezing temperatures. Describe a response that would occur involving the blood vessels, and how that would help maintain a normal body temperature.

**Figure 5B–7** What homeostatic response would help maintain a normal body temperature for this hiker?

4 Where are the receptors for body temperature regulation located? What does this gland do in response to external (or internal) changes in body temperature?

5 What will the difference in your blood glucose level be from before a meal to two hours after the meal? Explain your answer.

6 Water balance is an essential process in the body that is regulated by homeostasis.

- **a** The receptors for detecting water balance are located in what part of the brain?
- **b** What are the five key steps involved in maintaining homeostasis via a negative feedback loop?
- **c** After going for a run, you notice that you have lost a lot of water through sweating. Explain the process that would happen in your body to restore your water balance.
- **d** Compare the process described in part **c** of this question with a positive feedback loop.

**Figure 5B–8** Excessive sweating will change the water balance in your body, which homeostatic responses will correct.

ISBN 978-1-108-88711-3

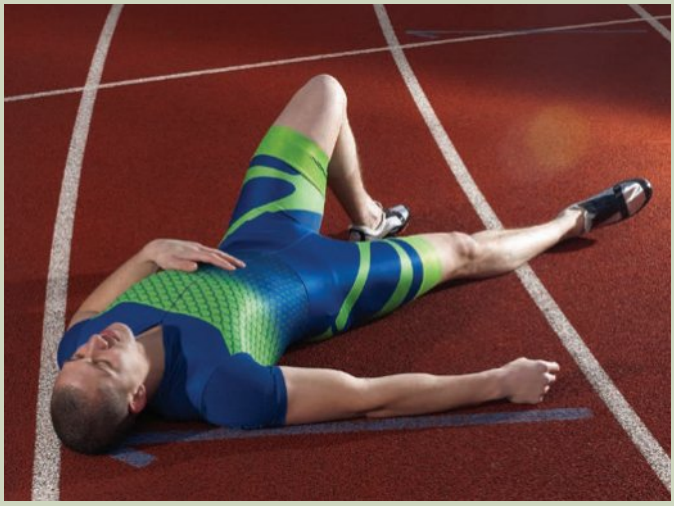

# Homeostasis gone wrong

**Study Design:**
Malfunctions in homeostatic mechanisms:
type 1 diabetes, hypoglycaemia, hyperthyroidism

**Glossary:**
Autoantibodies
Autoimmune disease
Hyperthyroidism

## ENGAGE

### Hyperthermia



You may have seen images or watched footage of athletes staggering at the end of a marathon or collapsing before the end of a triathlon. This extreme reaction is often the result of hyperthermia, or an elevated body temperature. In these instances, the exertion of the athlete and the conditions that they have been competing in have overwhelmed the normal homeostatic response that is meant to regulate body temperature. This hyperthermia can lead to symptoms such as headaches, cramps, dizziness and fainting, and can even be fatal. Not only does this help illustrate how important maintaining homeostasis is for humans, but it also highlights the problems that can occur when this process stops working. In this section, we will be looking at a number of other conditions that can occur in humans when homeostasis goes wrong.

## EXPLAIN

### Type 1 diabetes

In Section 5B, you read about the regulation of blood glucose levels in the body. As you will recall, this process is vital because glucose is one of the main molecules in the body that is converted into energy via cellular respiration. A well-known disorder that results from problems with this feedback loop is diabetes.

There are two types of diabetes: *type 1 diabetes* (T1D) and *type 2 diabetes* (T2D). Both result in an inability to control blood glucose levels, but the underlying cause of the problem for each is different. The discussion in this section focuses on T1D.

In T1D, the cells that produce insulin (beta cells in the pancreas) are targeted for destruction by the immune system. This is known as an **autoimmune disease**. (You will learn more about autoimmune diseases in Unit 4.) The destruction of these cells means that insulin can no longer be produced.

VIDEO 5C–1 TYPE 1 DIABETES

LINK 2D ROLE OF CHLOROPLASTS AND MITOCHONDRIA

**Autoimmune disease**
a disease in which the immune system acts abnormally and begins to target and attack the body's own cells ('self' cells)

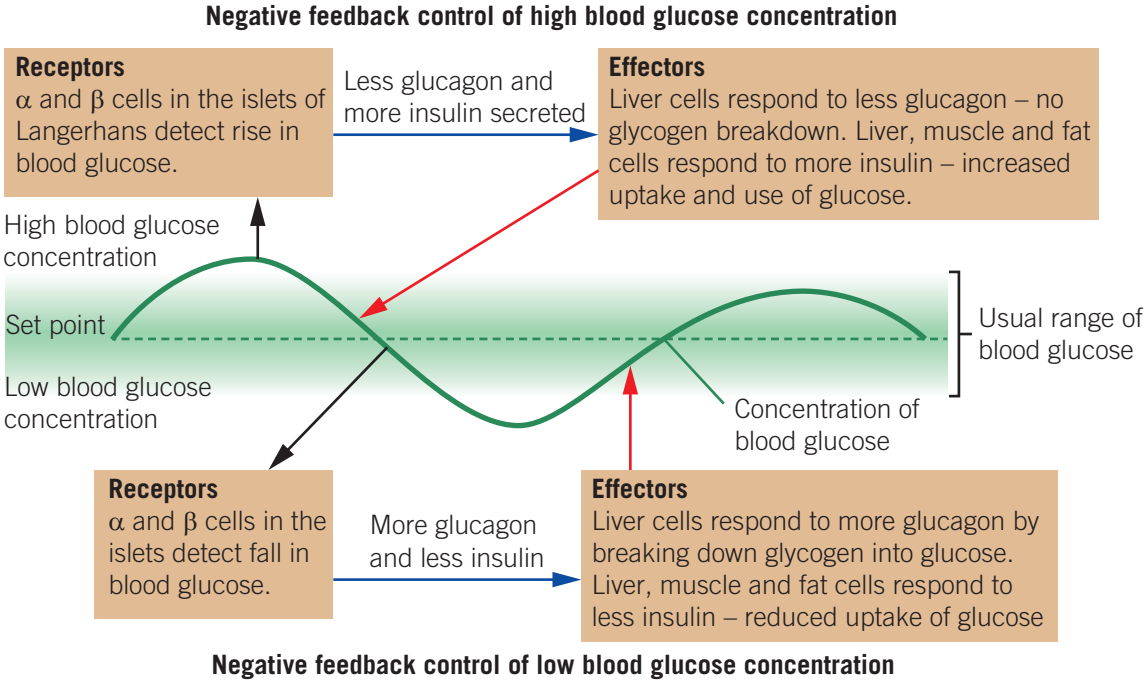
LINK UNIT 4

ISBN 978-1-108-88711-3

5A HOMEOSTASIS LINK

From your understanding of the negative feedback loop, you will probably have guessed at how the destruction of the beta cells may have a severe impact on the body's ability to correctly regulate blood glucose levels. Let's revisit that pathway for a healthy individual and for an individual suffering from type 1 diabetes, as shown in Figure 5C–1. This would also be a good time to check that it fits in with the earlier Figure 5B–5.

## A: Healthy individual




## B: Individual with type 1 diabetes

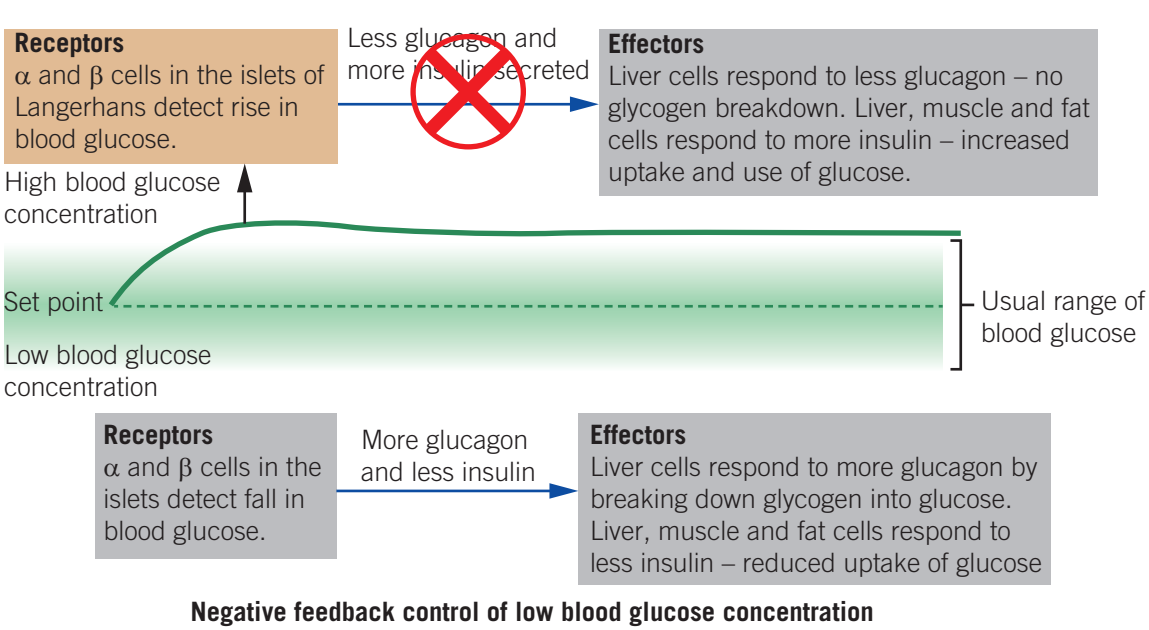



**Figure 5C–1** The normal response to high blood glucose levels (panel A) is disrupted in type 1 diabetes (panel B). This is due to destruction of beta cells, which prevents insulin production. Note the significant changes observed in the shape of the graph.

ISBN 978-1-108-88711-3

You will see from this pathway that the lack of insulin means that the body has no way of lowering blood glucose levels. When there is a concern that an individual may have developed diabetes, they undergo a test known as the 'glucose tolerance test'. In this test, the individual fasts (no food for a specified period before the test) and then they are given a large amount of glucose to ingest. Their blood glucose levels are then measured using a drop of blood from the finger at various times for 2 hours. The pattern of change in blood glucose levels that occurs in a person with diabetes compared with a healthy individual is shown in Figure 5C–2.

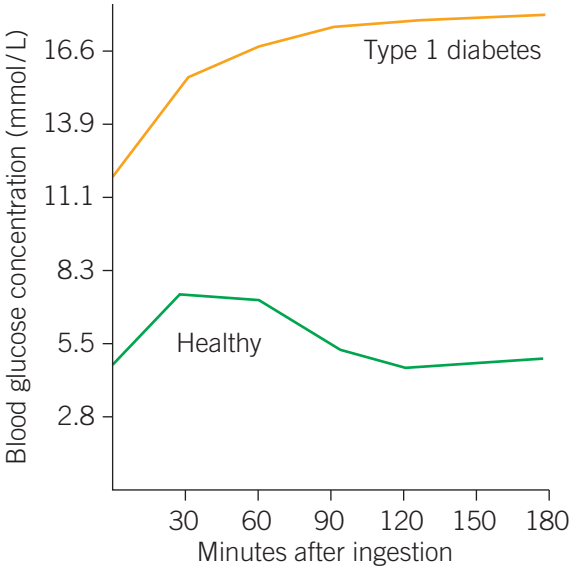



**Figure 5C–2** The results of a glucose tolerance test for a healthy individual and an individual with T1D

In T1D, both the fasting levels and the levels after taking the glucose solution are elevated. More importantly, there is a big difference in the response over time between healthy individuals and those with T1D. While the blood glucose levels spike (rise quickly) in healthy individuals after taking the solution (time = 0 minutes), over time the glucose in the blood is brought back down to original levels. This is homeostasis being maintained through a correctly functioning negative feedback loop. On the other hand, in individuals who are suffering from diabetes, not only does the level go much higher, but there is no observable response within the 2-hour time window to lower the amount of glucose in the blood.

If you look back at the feedback loop in Figure 5C–1, you can see where the block is that prevents the loop from working. But is there a solution? Fortunately, the disease can be managed through injections of insulin (Figure 5C–3). Once insulin is present, the body is able to maintain homeostasis in much the same way as it is in a healthy individual. Although it is a relatively easy 'fix', the injections are unpleasant and the fact that the body can't produce insulin means that people with T1D need to continually monitor their blood glucose levels to ensure they are correct.

**Figure 5C–3** Insulin injections into the stomach or thigh is an everyday practice for anyone with type 1 diabetes.

It is estimated that more than 40 million people worldwide are living with T1D, and it is staggering to think how much insulin must be produced for them all to have multiple injections each day. How can such large quantities of insulin be produced on an industrial scale? The answer is to get bacteria to do it, in a process known as gene cloning, which you will learn about in Unit 3.

LINK UNIT 3

ISBN 978-1-108-88711-3

## Hypoglycaemia

If you have ever heard someone being called 'hangry', they may have been hypoglycaemic. As the name suggests, hypoglycaemia is the opposite of what is observed in T1D. That is, in hypoglycaemia the regulation of blood glucose levels is disturbed in a way that sees the levels fall below the set range (blood glucose levels are too low). Hypoglycaemia can result in many symptoms, including:

- dizziness
- confusion
- shaking
- difficulties with concentration
- problems with eyesight
- headaches
- mood swings.

There are many potential causes of hypoglycaemia, most of which are temporary and, unlike T1D, don't require ongoing treatment. The simplest cause of hypoglycaemia is not eating enough, especially if it is combined with lengthy and intense exercise. In this instance, blood glucose levels will drop quite low before glucagon is able to restore them to their normal homeostatic range. Glucose levels can also be restored simply through the intake of energy in the form of food or glucose supplements, as is often done by marathon runners (Figure 5C–4).

Strangely, hypoglycaemia can also be quite common in people with diabetes. This often results from either taking too much insulin, not eating enough after having the insulin injection, or doing too much strenuous exercise shortly after administering the injection. Once again, this is a temporary problem and can be fixed through simply consuming a sugar-rich food or drink (e.g. fruit-flavoured yoghurt, fruit juice, sports drink, granola, protein or cereal bar).

## Check-in questions – Set 1

1 What is one of the most likely cause of a person with type 1 diabetes experiencing hypoglycaemia?
2 Type 1 diabetes is caused by the destruction of which insulin-producing cells?

**Figure 5C–4** Marathon runners often take glucose supplements to offset the effects of hypoglycaemia.

ISBN 978-1-108-88711-3

## Hyperthyroidism

Another condition that can arise from malfunctions in homeostasis is **hyperthyroidism**. While many diseases can result from this problem, one of the most common is Graves' disease. Graves' disease has many symptoms, including the one that is most recognisable: bulging eyes. Other symptoms are:

- anxiety
- weight loss
- fatigue
- tremors
- sometimes an irregular heartbeat.

LINK 4C THE ENDOCRINE SYSTEM: CHEMICAL CONTROL

**Hyperthyroidism** overproduction of thyroxine by the thyroid gland

To understand this condition, you first need to understand how homeostasis of thyroid hormones is maintained in healthy individuals, and then analyse how this process goes astray in hyperthyroidism.

The diagram in Figure 5C–5 shows that homeostasis of thyroid hormones occurs in a pathway that involves the hypothalamus, pituitary gland and thyroid gland. (Section 4C introduced the thyroid hormone thyroxine, also known as thyroid hormone T4, and we will call it T4 here). In this loop, the end products (thyroid hormones T3 and T4) act on the hypothalamus and the pituitary gland to stop them from secreting hormones. As thyrotropin-releasing hormone (TRH) and thyroid-stimulating hormone (TSH) are required for the thyroid gland to secrete T3 and T4, the negative inhibition stops the production of these thyroid hormones. After a while, the levels of T3 and T4 decrease, which means that the inhibition stops, and the pathway starts again to restore the normal levels of the thyroid hormones.

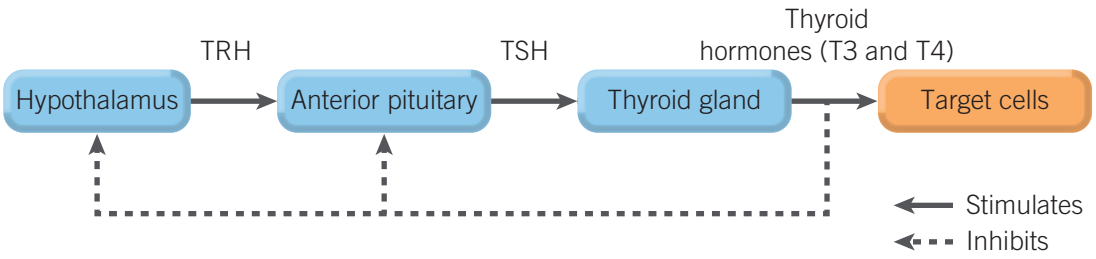



**Figure 5C–5** Thyroid hormones are regulated by a negative feedback loop that involves a number of hormones.

**Figure 5C–6** Location of the thyroid gland

ISBN 978-1-108-88711-3

**Autoantibodies** antibodies that target and destroy the body's own cells ('self' cells)

In Graves' disease, the body produces **autoantibodies** that bind to the TSH receptor on the thyroid gland and constantly stimulate it to produce T3 and T4, which means they are continuously secreted. So, although T3 and T4 inhibit the secretion of TRH and TSH from the hypothalamus and pituitary gland respectively, the autoantibodies continue to stimulate T3 and T4 production. Therefore, the negative feedback mechanism has no effect, and thyroid hormones continue to be produced, which results in hyperthyroidism. The mechanism and underlying processes involved in Graves' disease, as well as the symptoms that they cause, are summarised in Figure 5C–7.

**WORKSHEET 5C–1** DIAGRAMS OF MALFUNCTIONS IN HOMEOSTATIC MECHANISMS

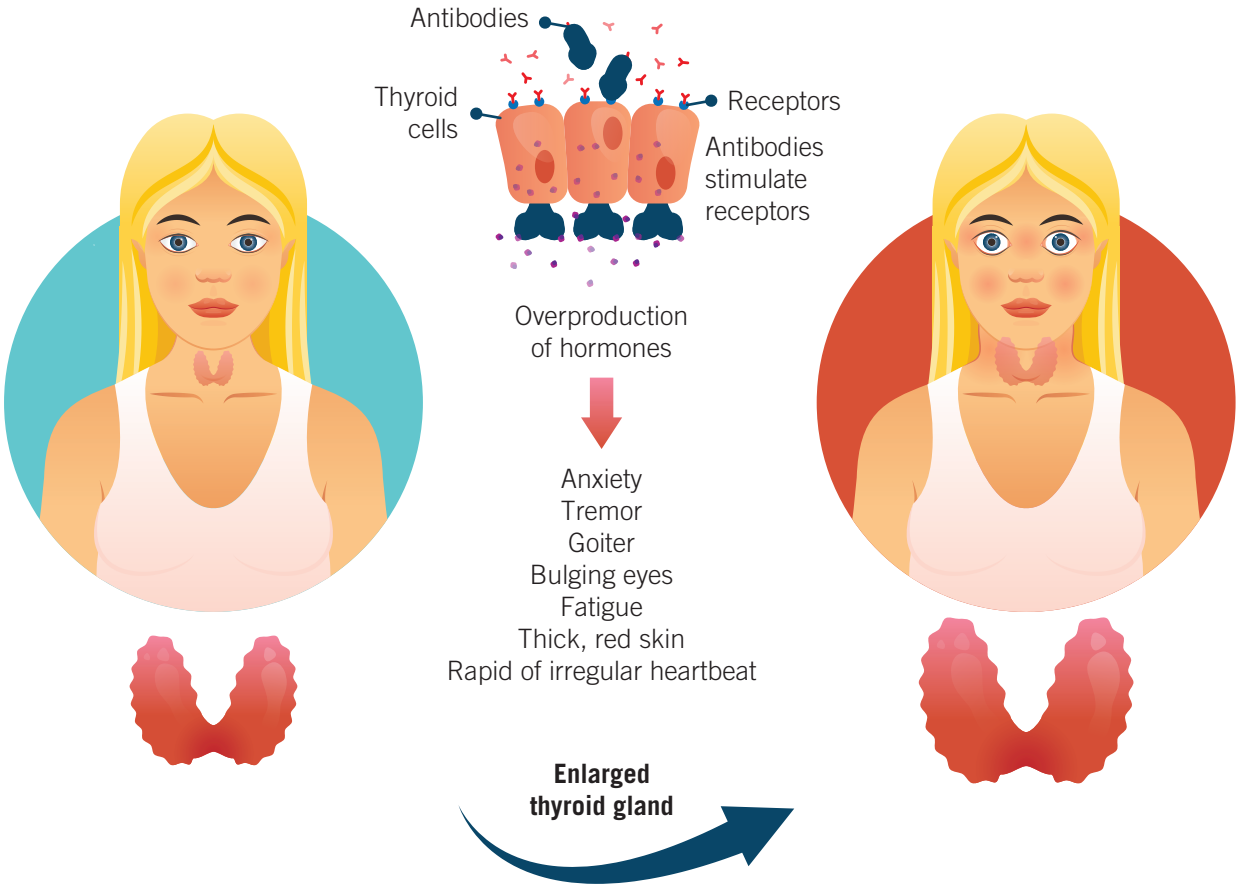



**Figure 5C–7** Graves' disease is caused by autoantibodies binding to thyroid hormone receptors, resulting in uncontrolled overproduction of these hormones.

## 5C SKILLS

**VIDEO 5C–2** SKILLS: STRUCTURING RESPONSES

### Structuring responses

In this section, you have seen a number of examples of the process of homeostasis going wrong. You may asked questions that require you to explain the issues that arise in such situations. It is important that you structure your answer in a way that shows a clear understanding of the general process, and where the problem exists that prevents it from functioning correctly. Let's look at this using a specific example. Then you will see how to develop a structure for the answer, and a model answer using that framework.

ISBN 978-1-108-88711-3

*Question*: What causes type 1 diabetes?

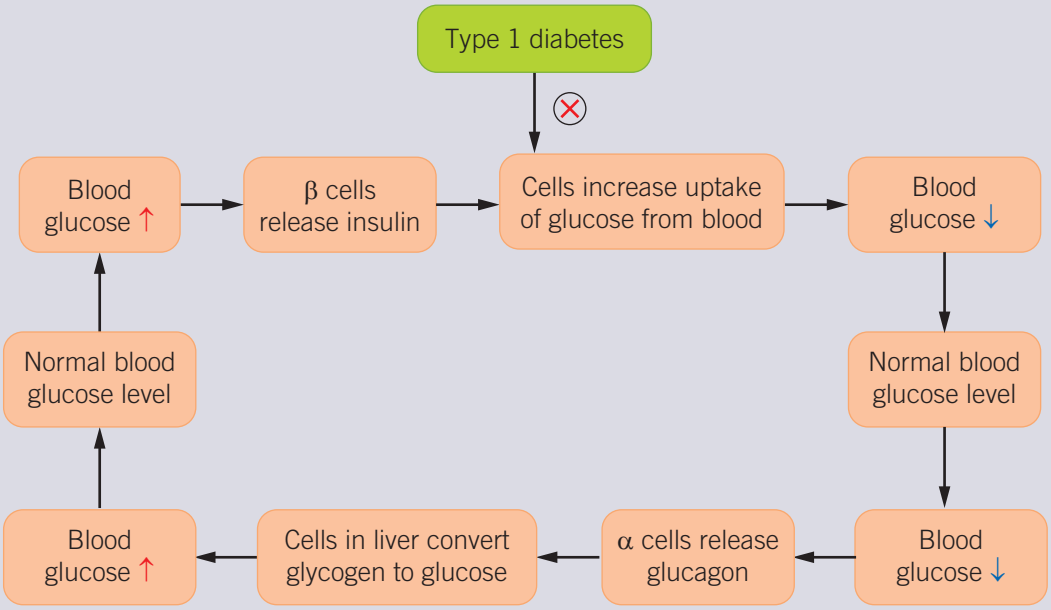
First, you need to work out what key information to include in this answer. This would include:

- a definition of type 1 diabetes
- an overview of the negative feedback loops involved in regulation of blood glucose levels (using a diagram would be the easiest way to do this)
- a description of the issue that arises in type 1 diabetes
- an explanation of how that issue impacts on the feedback loop described previously.

Let's now piece those dot points together to provide a model answer.

*Answer*:

Type 1 diabetes is an autoimmune disease that results in the inability to effectively lower blood glucose levels. In healthy individuals, blood glucose levels are regulated through two negative feedback loops. These feedback loops are illustrated below:




It can be seen that these feedback loops are under the control of two hormones: insulin is responsible for lowering blood glucose levels when they get too high, and glucagon has the opposite effect (e.g. raising blood glucose levels when they get too low). In type 1 diabetes, the beta cells in the pancreas, which are responsible for producing insulin, are destroyed. This results in a lack of insulin production in the body. Looking at the diagram again, we can see that this would result in the body not being able to respond properly when a stimulus of 'high blood glucose levels' is received. This explains why people with type 1 diabetes are unable to properly regulate their blood glucose levels and require insulin injections to do so artificially.

The end-of-section questions will provide you with more opportunities to work on structuring your responses to address different contexts.

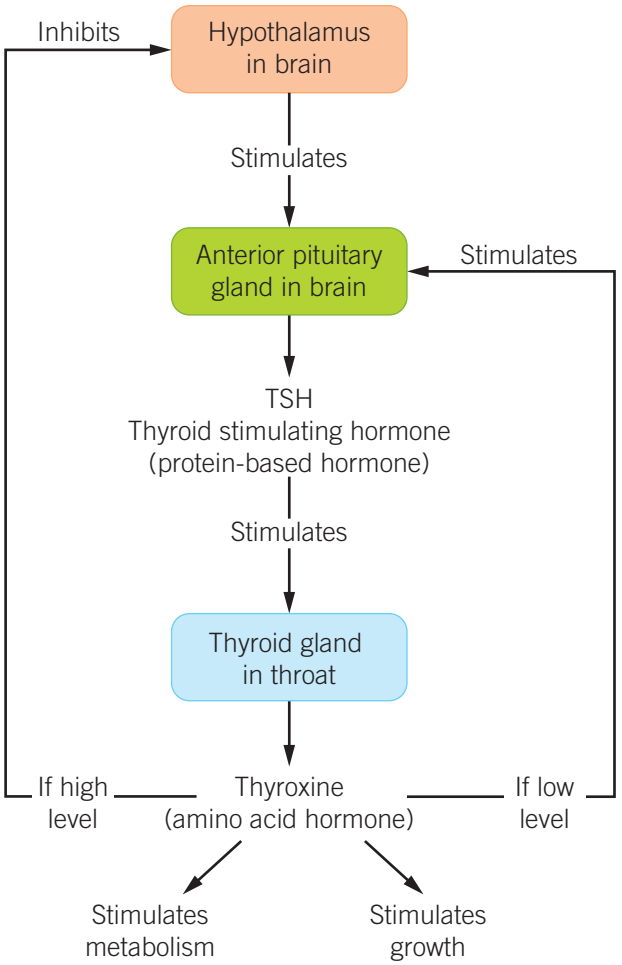
ISBN 978-1-108-88711-3

## Section 5C questions

**1** You go for a run in the middle of the day, in summer, and your body starts to register that your core temperature is increasing.

- **a** Describe the steps that occur in the body to keep your temperature in the normal range.
- **b** What is the name given to the type of process described in part **a**?
- **c** After your run, when you return home, you sit on the couch and don't have anything to eat for the next 6 hours. What condition is likely to arise from this?
- **d** Would glucagon be the best treatment for the condition that develops in part **c**? Explain your answer.

**2** An animal's metabolism is largely controlled by thyroid hormones. One of these hormones thyroxine, is produced by the thyroid gland via the pathway shown in the diagram below.






- **a** Using your knowledge of the endocrine system, outline where the receptor would be located for the TSH on the thyroid gland.
- **b** Other cells in the body, including other areas of the brain, do not respond to the release of thyroxine. Why is this?
- **c** Using two pieces of evidence from the stimulus–response model shown, explain why this is an example of a negative feedback model.
- **d** Name a disease that can occur when excessive thyroid hormones are produced.
- **e** Explain, using the stimulus–response model shown, how the negative feedback loop for thyroid hormones is disrupted in Graves' disease. Also outline this clearly on the diagram.

ISBN 978-1-108-88711-3

# Chapter 5 review

## Summary

Create your own set of summary notes for this chapter on paper or in a digital document. A model summary is provided in the Teacher Resources which can be used to compare with yours.

## Checklist

In the Interactive Textbook, the success criteria are linked from the review questions and will be automatically ticked when answers are correct. Alternatively, print or photocopy this page and tick the boxes when you have answered the corresponding questions correctly.

| Success criteria – I am now able to: | | Linked question |
|---|---|---|
| **5A.1** | Recall the five stages of a stimulus–response model | 9☐ |
| **5A.2** | Describe the stimulus–response model | 9☐ |
| **5A.3** | Describe, using diagrams, negative and positive feedback loops | 10☐, 11☐ |
| **5A.4** | Distinguish between examples of negative and positive feedback loops | 8☐ |
| **5A.5** | Define homeostasis | 3☐ |
| **5A.6** | Explain the importance of homeostasis to an organism's survival | 13☐ |
| **5B.1** | Using diagrams and the stimulus–response model, explain how temperature is maintained | 2☐, 13☐ |
| **5B.2** | Using diagrams and the stimulus–response model, explain how blood glucose is maintained | 1☐, 6☐, 12☐ |
| **5B.3** | Using diagrams and the stimulus–response model, explain how water balance is maintained | 4☐, 7☐, 13☐ |
| **5B.4** | Explain how water balance is maintained in vascular plants | 13a☐, 14☐ |
| **5C.1** | Explain, using a diagram, how type 1 diabetes results in a breakdown in blood glucose homeostasis | 12☐ |
| **5C.2** | Explain the treatment of type 1 diabetes | 5☐, 12☐ |
| **5C.3** | Define hypoglycaemia and explain how it differs from type 1 diabetes | 12☐ |
| **5C.4** | Explain, using a diagram, how hyperthyroidism (in the form of Graves' disease) occurs | 11☐ |

## Multiple-choice questions

**1** Which hormone is responsible for lowering blood glucose levels?
- **A** glucagon
- **B** glycogen
- **C** TSH
- **D** insulin

**2** Which of the following is a response to an increase in body temperature?
- **A** shivering
- **B** thirst
- **C** sweating
- **D** constricting blood vessels

**3** The objective of homeostasis is best defined as
- **A** maintaining levels within a constant range.
- **B** maintaining levels at a constant value.
- **C** increasing levels that are too low.
- **D** decreasing levels that are too high.

**4** Which of the following processes is about maintaining water balance in animals?
- **A** transpiration
- **B** perspiration
- **C** osmoregulation
- **D** cellular respiration

ISBN 978-1-108-88711-3

5 The most appropriate treatment for type 1 diabetes is
   **A** ingesting glucose.
   **B** injecting insulin.
   **C** modifying diet.
   **D** none of the above, because there is no treatment.

6 What organ is responsible for producing insulin?
   **A** liver
   **B** brain
   **C** stomach
   **D** pancreas

7 The hormone responsible for regulating water balance in the body is
   **A** insulin.
   **B** glucagon.
   **C** antidiuretic hormone (ADH).
   **D** thyroid-stimulating hormone (TSH).

8 Which of the following is under the control of a positive feedback loop?
   **A** body temperature
   **B** contractions during childbirth
   **C** blood glucose levels
   **D** type 1 diabetes

9 What is the first step necessary for any negative feedback loop to be initiated?
   **A** stimulus
   **B** temperature change
   **C** response
   **D** hormone release

10 Which of the following hormones is involved in the positive feedback loop during labour in a pregnant woman?
   **A** insulin
   **B** TSH
   **C** glucagon
   **D** oxytocin

## Short-answer questions

11 You are working as a doctor, when a woman comes in presenting with bulging eyes. You immediately suspect that she might have Graves' disease.
   **a** First, you tell her your suspicions. What type of disease would you tell her Graves' disease is? (1 mark)
   **b** Second, you explain to her what the normal process is for the regulation of thyroid hormones in her body. What type of mechanism maintains homeostatic levels of these hormones? (1 mark)
   **c** Would treating this woman with synthetic TSH be appropriate? Explain. (2 marks)

ISBN 978-1-108-88711-3

**12** You come home from school and eat a large snack before beginning to study. You know that having a snack is important, as the food will be broken down into glucose to be used to create energy.

- **a** Describe what happens to your blood glucose levels in the two hours after you eat the snack. (2 marks)
- **b** What is the name of the process involved in breaking down glucose in cells? In your answer, also include the location of this process and the inputs and outputs in a balanced chemical equation. (1 mark)
- **c** Amylase is a type of protein. State the organelle involved in the synthesis of proteins. (1 mark)
- **d** Explain how glucose is transported into cells after a meal, and state what form of transport this is. (3 marks)
- **e** Draw a diagram to highlight the differences between a healthy individual and a person with type 1 diabetes after ingesting this meal. (2 marks)
- **f** On the diagram you drew for part **e**, indicate what would happen if the person with type 1 diabetes was treated with insulin. Ensure you show on the graph where the insulin is injected. (2 marks)
- **g** Define hypoglycaemia and explain how it differs from type 1 diabetes as discussed in parts **e** and **f**. (2 marks)

**13** A tree is growing in a desert, so it receives very little rainfall. However, there is an extensive underground water system, which it is able to access by a network of deep roots.

- **a** What is the process by which the plant transports water from its roots? (1 mark)
- **b** Plants require water to conduct photosynthesis. What is the word equation for this process? (1 mark)
- **c** A scientist who goes to research this tree finds himself lost in the desert, and his core temperature begins to increase. Using the stimulus–response model, describe how his body would react to this. (3 marks)
- **d** Explain why maintenance of a constant internal body temperature is so important. (2 marks)

**14** Explain the role that stomata play in the regulation of water in vascular plants. (2 marks)

ISBN 978-1-108-88711-3

UNIT 1

HOW DO ORGANISMS REGULATE THEIR FUNCTIONS?

CHAPTER 6

# SCIENTIFIC INVESTIGATIONS

## Introduction

Scientific investigation (practical) skills and understanding are fundamental to the daily work of a scientist. As a component of your assessment for Unit 1, you will be required to design or adapt an investigation related to the survival of an organism or a species. Most schools will conduct this as a practical investigation, followed by the production of a scientific poster, as this is a key requirement for School Assessed Coursework (SAC) in Unit 4. Many VCAA exam questions focus on practical understanding and skills. This is an opportunity for you to develop your knowledge and skills in this area.

This chapter outlines how to plan, conduct and present the results of a scientific investigation, with useful tips and examples along the way. The digital resource contains additional information about alternative formats for demonstrating your understanding of the survival of an organism, including:

- preparing an article for scientific publication
- preparing an oral, multimedia or visual presentation.

## Curriculum

**Area of Study 3 Outcome 3**

| Study Design | Learning intentions – at the end of this chapter I will be able to: |
|---|---|
| **Scientific evidence**<br>• Use of a logbook to authenticate generated primary data | **6A** **Investigative design**<br>**6A.1** Document investigations appropriately using a logbook |
| **Investigation design**<br>• The biological science concepts specific to the investigation and their significance, including the definitions of key terms | **6A.2** Define key terms related to scientific skills |

ISBN 978-1-108-88711-3

| Study Design | Learning intentions – at the end of this chapter I will be able to: |
|---|---|
| • 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 | **6A.3** Define the meaning of a controlled experiment<br>**6A.4** List the features that a controlled experiment includes<br>**6A.5** Distinguish between a positive and negative control<br>**6A.6** Understand the meaning of single variable exploration<br>**6A.7** Define and identify independent, dependent and controlled variables<br>**6A.8** Select and use equipment and procedures appropriate to an investigation |
| **Scientific evidence**<br>• The distinction between an aim, a hypothesis, a model, a theory and a law | **6A.9** Distinguish between an aim and a hypothesis<br>**6A.10** Define law, theory and models and identify examples of each<br>**6A.11** Construct aims and questions for investigations<br>**6A.12** Formulate hypotheses and predict possible outcomes |
| **Investigation design**<br>• Accuracy, precision, reproducibility, repeatability and validity of measurements in relation to the investigation | **6A.13** Define the terms reproducibility, repeatability and validity, and distinguish between these<br>**6A.14** Design an experiment that can be fully reproducible by others |
| • Health, safety and ethical guidelines relevant to the selected scientific investigation | **6A.15** Determine potential ethical issues with investigation design<br>**6A.16** Identify how bias can be minimised in an investigation<br>**6A.17** Follow clear guidelines for health and safety when undertaking practical investigations |
| **Investigation design**<br>• Techniques of primary qualitative and quantitative data generation relevant to the investigation | **6B Scientific evidence**<br>**6B.1** Define the terms qualitative and quantitative<br>**6B.2** Distinguish between qualitative and quantitative data<br>**6B.3** Include appropriate units of measurement for quantitative data |
| **Scientific evidence**<br>• The characteristics of primary data<br>**Investigation design**<br>• Accuracy, precision, reproducibility, repeatability and validity of measurements in relation to the investigation | **6B.4** Analyse generated primary data to determine whether it is accurate and/or precise, and define these terms |

ISBN 978-1-108-88711-3

| Study Design | Learning intentions – at the end of this chapter I will be able to: |
|---|---|
| • Ways of organising, analysing and evaluating generated primary data to identify patterns and relationships including sources of errors | **6B.5** Transform primary data into an appropriate format of results (table, flow chart, bar and/or line graph)<br>**6B.6** Identify trends in data<br>**6B.7** Define the different types of errors (random and systematic)<br>**6B.8** Identify sources of error and outliers from primary data |
| • Observations and investigations that are consistent with, or challenge, current scientific models or theories | **6B.9** Use evidence to determine whether an investigation supports or discounts a hypothesis |
| • The limitations of investigation methodologies and methods, and of data generation and/or analysis | **6B.10** Identify areas for improvement in investigation design and analysis to increase accuracy and precision and reduce the likelihood of errors |
| **Scientific communication**<br>• The conventions of scientific report writing including scientific terminology and representations, standard abbreviations and units of measurement | **6C Scientific communication**<br>**6C.1** Appropriately communicate all aspects of a scientific investigation<br>**6C.2** Apply correct abbreviations to biological terminology<br>**6C.3** Acknowledge sources of information using appropriate referencing system |
| • Ways of presenting key findings and implications of the selected scientific investigation | **6C.4** Justify conclusions and evaluate whether evidence supports or refutes the hypothesis<br>**6C.5** Infer investigation outcomes to broader biological concepts, including cell/system functioning, survival of an individual or species survival and the connections between these ideas<br>**6C.6** Use clear, coherent and concise biological communication to a specific audience, e.g. teachers and/or peers |



## Glossary

Aim
Accuracy
Conclusion
Continuous data
Control group
Controlled variable
Dependent variable
Discrete data
Hypothesis
Independent variable
Introduction
Line of best fit
Method
Negative control
Outlier
Placebo
Positive control
Precision
Qualitative data
Quantitative data
Random error
Reliability
Repeatability
Reproducibility
Single-variable exploration
Systematic error
Title
True value
Validity

ISBN 978-1-108-88711-3

# 6A Investigative design

**Study Design:**

**Scientific evidence**

- Use of a logbook to authenticate generated primary data
- The distinction between an aim, a hypothesis, a model, a theory and a law

**Investigation design**

- The biological science concepts specific to the investigation and their significance, including the definitions of key terms
- Scientific methodology relevant to the selected scientific investigation, selected from: classification and identification; controlled experiment; correlational study; fieldwork 'modellling' product, process or system development; or simulation
- Accuracy, precision, reproducibility, repeatability and validity of measurements in relation to the investigation
- Health, safety and ethical guidelines relevant to the selected scientific investigation

**Glossary:**

Aim
Control group
Controlled variable
Dependent variable
Hypothesis
Independent variable
Introduction
Method
Negative control
Placebo
Positive control
Reliability
Repeatability
Reproducibility
Single-variable exploration
Title
Validity

## ENGAGE

### Scientific breakthroughs

Scientists ask questions about things that interest them, trouble them or puzzle them. They plan for new investigations and adjust the practical investigations they are currently undertaking. They work both individually and in teams to share knowledge for the greater good of humanity and the existence and survival of many other species. Some of the greatest discoveries in the past two centuries have come from this process, and include:

- the discovery of the structure of DNA by James Watson, Francis Crick, Rosalind Franklin and Maurice Wilkins in 1953
- the discovery of penicillin by Alexander Fleming in 1928
- the development of a vaccine against the virus that causes cervical cancer, in Australia by a team of scientists led by Professor Ian Frazer in 2006. This was the first vaccine against cancer
- Gregor Mendel's published work with pea plants in 1865 after 8 years of growing thousands of pea plants and tracking their progeny and traits.

**Mendel's laws**

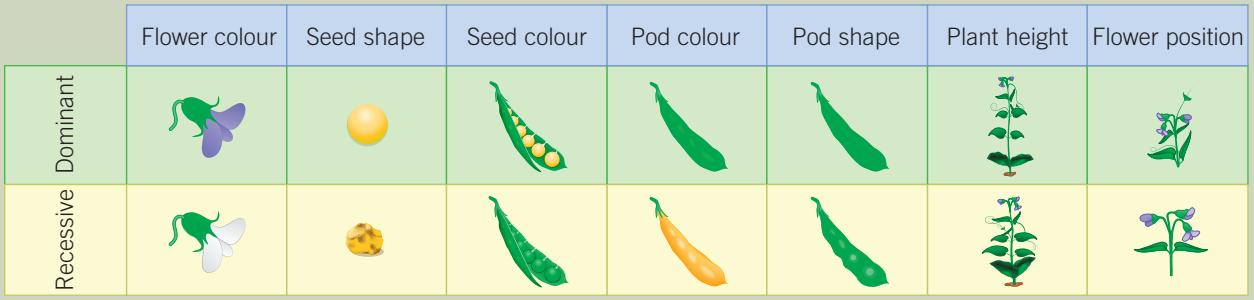
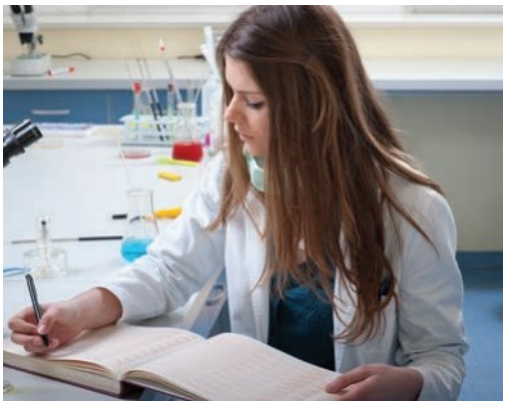



**Figure 6A–1** Mendel's laws on inheritance are one of the key scientific discoveries that have increased our biological understanding.

ISBN 978-1-108-88711-3

## EXPLAIN

# Structuring a logbook – investigative design



These scientific discoveries were possible because the scientists were persistent and determined and probably made effective use of logbooks. A logbook allows a scientist to keep track of the specific dates of their investigation ideas, planning, questions, important results, errors and any modifications required, thereby maintaining a record of all work conducted. The VCE requires that each student maintain a logbook of practical activities in Units 1–4 for assessment purposes. The need for a printed logbook, rather than an online or digital logbook, removes the likelihood of any tampering with results. Of course, this will depend on your school and your teacher's authentication practices, so it is best to work within your school's guidelines.

6C SCIENTIFIC COMMUNICATION LINK

In this section, you will learn how to develop a logbook for your own practical investigation and the importance of each section in contributing to the end product. This is usually in the form of a scientific poster (outlined in Section 6C). Other forms of representing results include oral, multimedia or visual presentation, and these are discussed in more detail in the digital resource that accompanies this textbook.

An important function of an effective logbook is that it clearly demonstrates the development of the ideas that come from your research and investigation, including changes in direction, equipment failures and so on, as well as your collaboration and discussion with peers. This is demonstrated in the example below, which shows two versions of the same investigation:

- **Investigation 1** is the initial version. The ideas that are highlighted for the investigation are not perfect but they show the initial planning coming together.
- **Investigation 2** is the final version. Adjustments have been made to the initial investigation to improve the validity and reliability of the results (terms explored in more detail later).

The transition between Investigation 1 (initial ideas) and Investigation 2 (final product), as well as tips on what to include in each of the key sections, are included to assist you with your own logbook development.

VIDEO 6A–1 LOGBOOK EXAMPLE

**Title**
the research question under investigation; includes information about what is being tested

### Logbook

**Title**

1 What temperature do enzymes work at?

2 What is the optimal temperature for the enzyme catalase to break down hydrogen peroxide into oxygen and water?

**Notes**
The title should include reference to the variables being changed (independent variable) and measured (dependent variable), along with enough detail for the reader to decide whether they want to continue reading.

ISBN 978-1-108-88711-3

**Introduction**
a detailed but succinct explanation of the reason for undertaking an investigation; includes key biological concepts, aim and hypothesis

## Introduction

1 Enzymes are essential to help reactions proceed more efficiently, in order to sustain life. They are made of proteins, which are coded for by an organism's DNA, and they are specific to the substance they act on.

2 The enzyme catalase reacts with the substrate hydrogen peroxide ($H_2O_2$), breaking it down into water and oxygen (products) in a catabolic reaction. Catalase is primarily found in the liver and is important in protecting the organism from damage caused by hydrogen peroxide, which is constantly produced by mammals.

The rate of reaction between an enzyme and the substrate can be affected by many things, such as concentration of enzyme and substrate, pH level and inhibitors. It can also be affected by temperature. Every enzyme has an optimal temperature, at which its rate of reaction is highest with the most successful collisions with the substrate. The general rule for this is that, as temperature increases, the rate of reaction increases until optimal temperature is reached. Any further increase in temperature will result in a dramatic drop in rate of reaction and may lead to denaturation of the enzyme. Denaturation is an irreversible process caused by the hydrogen bonds being broken, destroying the characteristic 3D structure of the protein and therefore changing its active site so it cannot bind to the substrate.

The normal functioning temperature for a human is 37°C, which is similar to that of a lamb, where the liver containing catalase was obtained from. If the temperature decreases in the lamb, then there is less kinetic energy and therefore fewer successful collisions between the enzyme and substrate, leaving the lamb vulnerable to damage occurring from the peroxide. Similarly, if the temperature increases to a certain point, the enzyme denatures again, leaving it vulnerable.

In the introduction (to a poster) it can also be appropriate to present a labelled diagram of the concept/idea being investigated.

LINK **2D** ROLE OF CHLOROPLASTS AND MITOCHONDRIA

LINK **4B** THE DIGESTIVE SYSTEM: GETTING THE NUTRIENTS WE NEED

**Aim**
the main purpose of an investigation and what you hope to achieve

## Aim

1 To determine the temperature at which catalase functions most efficiently.

2 To determine the optimal temperature for the enzyme catalase, by measuring the height of bubbles (oxygen gas) produced during the breakdown of the substrate hydrogen peroxide.

The aim includes explicit reference to the independent and dependent variable. This will be included in your introduction for the final scientific poster presentation.

**Hypothesis**
a prediction of the outcomes, which are testable experimentally and form the basis of the methodology

## Hypothesis

1 That the catalase will function best at 37°C.

2 That as the temperature to which the lamb liver is exposed increases, so too will the rate of reaction, producing a greater height of oxygen bubbles until the optimal temperature of 37°C (normal temperature of a live lamb) is reached. Any further increase in temperature will lower the rate of reaction due to the 3D conformational shape of the catalase denaturing.

The hypothesis is a prediction of what you think will occur. It does not have to be correct, but should be supported by knowledge of the theory, which is the difference between investigations 1 and 2.

ISBN 978-1-108-88711-3

**Independent variable**
the variable for which quantities are changed by the experimenter

## Independent variable

1 The temperature of the catalase

2 The temperature to which the enzyme catalase from lamb is exposed (0°C, 10°C, 20°C, 30°C, 37°C, 40°C, 50°C, 60°C)

The independent variable should be specific and list all quantities or changes being investigated. It should also list the control group, if one is included in the investigation.

**Dependent variable**
the variable that changes in response to changes in the independent variable; the experimenter measures these changes

## Dependent variable

1 The breakdown of hydrogen peroxide

2 The volume of oxygen produced (as bubbles) from the breakdown of hydrogen peroxide, measured in millimetres using a ruler.

State how the dependent variable will be measured in your experiment. This could be using an instrument and units of measurement, or even a simple scale of effects. The meaning of each number in the scale (e.g. 0 = no symptoms, 5 = extreme symptoms) must always be given.

**Controlled variable**
anything kept constant, or monitored, so it does not affect the independent and dependent variables, and therefore the validity of experimental results

## Controlled variables

1 Environmental conditions
Equipment
Catalase

2 Same mass of liver in each experiment (2 g)
Same surface area to volume ratio of the lamb liver
Same volume of hydrogen peroxide used (50 mL)
Same concentration of hydrogen peroxide used (3% solution)

There will always be more than one controlled variable in any investigation. List as many as you can for your investigation. (When answering questions on this, usually only two are required.)

The word 'same' is used for each variable, to show that the variables have been kept constant, and so the results are valid.

**WORKSHEET 6A–1**
IDENTIFYING VARIABLES


ISBN 978-1-108-88711-3

**Control group**
the set-up or group in an experiment that does not receive treatment; it is used as the 'standard of comparison'

**Placebo**
a substance that has no therapeutic effect but may have a psychological effect

**Negative control**
a control group that isn't expected to produce a result

**Positive control**
a control group that receives a treatment with a known response that can then be compared to the experimental group(s)

## Control group

1 The control group is the normal body temperature.

2 As this experiment is trying to determine the optimal temperature of the catalase enzyme from lamb liver, there is not really a control group included. A negative control could be included, which would be a set-up where no lamb liver is added to the hydrogen peroxide, to prove that the reaction is caused by the catalase present in the liver.

If possible, a control group should be included in an investigation. If the investigation has to do with drug administration in humans, then a **placebo** is included.

Including a control group gives a known result for comparison with the experimental groups. You may need to account for the difference between a **positive control** and a **negative control**.

**Method**
a series of numbered steps describing the procedure

## Method

1 1 Place hydrogen peroxide in a flask.
2 Add enzyme to flask.
3 Allow experiment to run.
4 Measure the maximum height of bubbles in the test tube.

The method must contain enough information for the investigation to be repeated by yourself (repeatability) and others (reproducibility). Therefore, it must include specific quantities of any substances and specific equipment used. This helps to establish validity.

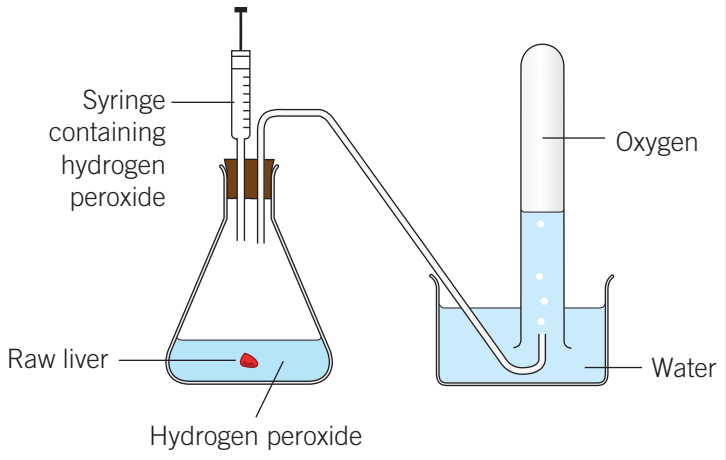
The investigation also needs to be repeated, ensuring there is a large sample of results – the larger the sample size, the more reliable the results.

The method should also include the set-up for the control group (if there is a control group).

ISBN 978-1-108-88711-3

2

1 Set up the equipment (conical flask, rubber stopper with two openings: one for syringe and one for tubing, beaker and test tube).
2 Cut liver into equal-sized pieces of equal mass (2 g).
3 Place the liver into a beaker of 150 mL of water at a temperature of 0°C. (Note: An ice water bath will be required for this.) Leave for 3 minutes.
4 Transfer the liver into a separate empty conical flask.
5 Using the syringe, inject 50 mL of 3% hydrogen peroxide solution into the flask.
6 Using a ruler, record the height of the oxygen bubbles (in millimetres) produced in the test tube. Alternatively, the displacement of water in the upside down test tube could be measured in millilitres.
7 Repeat steps 1–6 two more times at the same temperature.
8 Repeat steps 1–7, heating the liver to a different temperature each time (10°C, 20°C, 30°C, 37°C, 40°C, 50°C and 60°C). Liver is to be heated to required temperature as per step 3 in a water bath set at specific temperatures to be tested.




## Safety and ethical considerations

1 Wearing of lab coat, safety glasses and gloves.
There are no ethical issues to consider.

2 For this experiment, wearing of personal protective equipment (lab coat, safety glasses) is required, especially when handling chemicals such as hydrogen peroxide, and particularly if diluting this from a higher concentration stock solution. It is important to ensure that hands are washed thoroughly after the investigation.
Ethical issues:
The lamb liver was obtained from a verified butcher that only obtains meat from farms that practise correct handling of animals and processing of different body parts following death. When alive, these animals were treated well and given access to sufficient food and water and suitable environments for exercise.

Most schools have access to an online risk assessment program which allows you to input equipment and any chemicals specific to your own investigation, which generates safety requirements to be followed. With the use of living organisms, ethical integrity when using data and reporting on outcomes should be clearly considered and outlined.

ISBN 978-1-108-88711-3

**Repeatability**
recording of results produced when the experiment is repeated in one lab by one operator under the same conditions

## Repeatability

1. Repeat experiment three times to determine the temperature at which catalase works best.
2. This experiment was conducted three times for each of the eight temperatures tested, to increase the sample size and ensure reliability of results.

Without repeating your experiment, your results are potentially valid but not reliable (representative of normal conditions). It is important in any investigation to have a large sample size.

**Reproducibility**
when the same results are obtained for the same experiment by different operators using different equipment

**Reliability**
the extent to which an experiment always yields the same results under the same conditions

## Reproducibility

1. Repeat experiment three times to determine the temperature at which catalase works best.
2. The experiment could be repeated by other investigators using a different concentration of hydrogen peroxide or a different mass of liver containing catalase. Results could then be compared, based on the similarity of experimental set-up and aim of the investigation.

Other experimenters achieving the same result as you after conducting the same investigation further strengthens the validity and **reliability** of your results. It is worth researching if others have done your experiment previously, or getting your peers to perform your experiment using your method to see if they achieve the same results. It is important not to confuse reproducibility and repeatability.

**Validity**
the extent to which all variables in the experiment have been controlled, so that the independent variable is the only factor that changes

**Single-variable exploration**
an investigation that contains only one independent and one dependent variable

## Validity

1. All variables are controlled in this experiment, and therefore it is a valid test.
2. This experiment contains one independent variable (temperature at which the liver is incubated) and one dependent variable (height of oxygen bubbles, measured in millimetres), where all other factors in the experimental design have been controlled (concentration and volume of hydrogen peroxide, mass and surface area to volume ratio of the liver, etc). Hence it is a single-variable exploration.

It is crucial to ensure that the independent variable is the only aspect changing in your investigation (**single-variable exploration**), and that all other variables are controlled. If this is not done or noted, then your work is unable to be accepted by your peers, teacher or the broader community.

ISBN 978-1-108-88711-3

## Section 6A questions

1 What features does a controlled experiment include?
2 Define the following terms: independent variable, dependent variable, controlled variable.
3 What is the difference between a positive control group and a negative control group?
4 Compare validity and reliability.
5 Outline the difference between repeatability and reproducibility.
6 Explain what single-variable exploration means.
7 Two scientists are conducting an investigation on photosynthesis. Michael says that a suitable control group would be placing the plant in question in a dark cupboard away from any light. However, Simar says that the control group should be the volume of water given to each plant in the experiment.
   a Explain why Michael is correct.
   b What was the mistake Simar made in her comment?
   c Design an experiment to test the question: 'Does light cause photosynthesis?' In your answer include the following: independent variable, dependent variable, controlled variables, control group, method.

ISBN 978-1-108-88711-3


# Scientific evidence

**Study Design:**

**Investigation design**

- Techniques of primary qualitative and quantitative data generation relevant to the investigation
- Accuracy, precision, reproducibility, repeatability and validity of measurements in relation to the investigation

**Scientific evidence**

- The characteristics of primary data
- Ways of organising, analysing and evaluating generated primary data to identify patterns and relationships including sources of errors
- Observations and investigations that are consistent with, or challenge, current scientific models or theories
- The limitations of investigation methodologies and methods, and of data generation and/or analysis

**Glossary:**

Accuracy
Conclusion
Continuous data
Discrete data
Line of best fit
Outlier
Precision
Qualitative data
Quantitative data
Random error
Systematic error
True value

## Structuring the logbook – scientific evidence

This section discusses how to represent the results of your investigation in your logbook, including: drawing up tables and graphs, analysing the data collected, commenting on any errors, ensuring the precision and accuracy of the data, and noting areas for improvement.

Before recording your results, it is important to understand the difference between **qualitative data** and **quantitative data**. Qualitative data is *descriptive* – this means it is in the form of words, not numbers. For example, it could be the appearance of something (e.g. 'cloudy' or 'clear') or colour (e.g. 'red' or 'yellow'). Quantitative data is *numerical* – this means it is in the form of numbers, based on counting or measuring. For example, it could be temperature (e.g. 100°C) or symptoms recorded on a scale of 0 to 10 (e.g. 0 for no pain and 10 for intense pain).

**Qualitative data** data that is descriptive (not numeric)

**Quantitative data** data that is measured and represented numerically

**Results – table**

1

| | Temperature | | | | | |
|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 |
| Oxygen produced | 7 | 15 | 16 | 20 | 30 | 3 |

2 Title: Changes in temperature of catalase activity and resulting height of oxygen bubbles produced.

**Results – table**

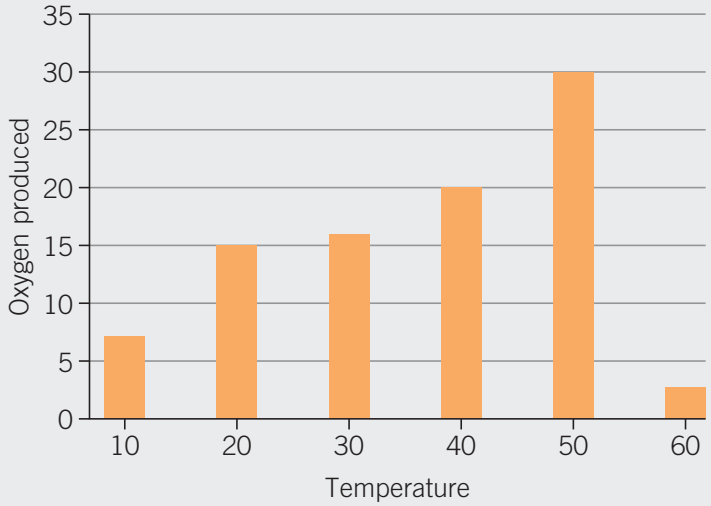
| Temperature (°C) | Height of oxygen bubbles (mm) | | | |
|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 3 | Mean |
| 0 | 0.8 | 1.0 | 0.9 | 0.9 |
| 10 | 2.0 | 2.5 | 2.7 | 2.4 |
| 20 | 8.0 | 9.2 | 8.8 | 8.7 |
| 30 | 12.5 | 11.1 | 13.6 | 12.4 |
| 37 | 16.4 | 15.8 | 17.3 | 16.5 |
| 40 | 20.1 | 18.2 | 17.8 | 18.7 |
| 50 | 8.8 | 9.3 | 9.9 | 9.3 |
| 60 | 1.0 | 1.2 | 0.6 | 0.9 |

A results table should include a title with both variables (independent and dependent) mentioned.
All columns/rows must be labelled with an appropriate heading and relevant units.
It is good to include an average, or a percentage, from multiple repeats.
The averages should be rounded to the same number of decimal places as the data, one decimal place in this case.
The table can be drawn by hand or generated digitally.

ISBN 978-1-108-88711-3

## Results graph – Investigation 1

1

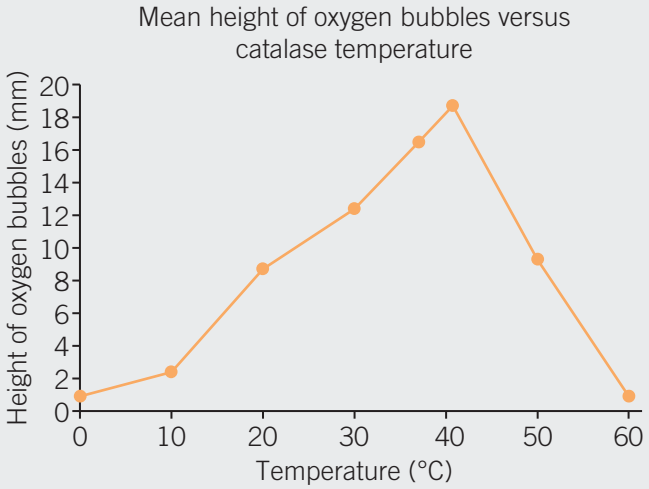



**Continuous data**
data that is measurable and continuous, with infinite possible values; best represented by a line graph

**Discrete data**
data that is countable and in discrete categories; contains distinct or separate values; best represented by a bar graph

2

## Results graph – Investigation 2




WORKSHEET 6B–1 REPRESENTING DATA

## Accuracy

**Accuracy**
how close the measurements are to the 'true' value of the quantity being measured

**True value**
the value or range of values that would be obtained if the quantity could be measured perfectly

1 *This experiment is accurate, as data was generated using correct experimental procedure.*

2 *To fully determine the accuracy of this experiment, the results would need to be compared to investigations done previously, or compared with the known optimal temperature of the lamb liver catalase at approximately 40°C. There is also not a definitive* **'true' value** *for the height of oxygen bubbles for each temperature in this experiment – this is evident from the variations in recordings of the three trials at each temperature.*

Graphs should include a main title and have both x- and y-axes labelled with units (if required). The x-axis is for the independent variable and the y-axis is for the dependent variable.

The correct type of graph must be used. If data is **continuous** (based on measuring, e.g. changing time, temperature, concentration, pH), the data should be represented as a line graph. **Discrete** data (based on counting), should be represented as a bar graph. Importantly, quantitative data could be represented as a line graph or a special type of bar graph called a histogram. Qualitative data is strictly represented in a bar graph.

Can be hand drawn or digital.

The accuracy of an experiment is not always known. It depends on how unique your investigation is. Most experiments you perform will have been completed by others previously, so you are just reproducing results. In those cases, a true value is known and you can compare your own results to them.

ISBN 978-1-108-88711-3

**Systematic error**
when the readings obtained from measurements differ from the 'true' value consistently in one direction every time

## Systematic errors

1. Each time the liver was transferred from the water bath to the set-up, its temperature changed, which could have affected the results.
2. For liver that was initially kept at temperatures below room temperature (0, 10 and 20°C), transferring it from the water bath to the conical flask resulted in a slight increase in temperature. Additionally, the way the experiment was set up meant that the oxygen produced from the reaction needed to travel from the conical flask through the tubing and into the test tube. This would not be an accurate representation of all the oxygen causing bubbles to be formed, as some of the oxygen each time would remain in the conical flask, thereby affecting the results for the investigation at each temperature.

A systematic error cannot be improved by repeating measurements, having a larger sample size or taking a mean. As the results are always out by a consistent value, they will always be inaccurate. Therefore, a change in the method or equipment must occur.

**Random error**
an unpredictable variation in the readings obtained, due to variables not all being controlled (extraneous variables), and resulting in the readings being higher or lower than expected

## Random errors

1. There were no random errors because the experiment was only conducted once.
2. Random errors were present in this experiment, as it is clear that there are differences in measurements between the three trials at each temperature. This could have been due to human errors in measuring the concentrations of hydrogen peroxide or in cutting and weighing pieces of lamb liver. It could also be due to fluctuations in the temperature of the water bath away from the set temperature when heating the 2g of liver. This is equally likely to be higher or lower at different times if not monitored correctly.

The effect of a random error can be reduced by repeating measurements, having a larger sample size and/or taking a mean. As results are equally likely to be high or low, averaging can improve the precision of results. For most experiments in a laboratory where multiple trials are conducted, you will need to account for the effect of these on your investigation. You may need to also account for **outliers** by repeating measurements.

**WORKSHEET 6B–2**
IDENTIFYING ERRORS IN EXPERIMENTAL DATA


**Outlier**
a reading that is very different from other results obtained for the same measurement

**Precision**
how close all the measurements are to each other

## Precision

1. The results were not precise as they increased up to 50°C before decreasing at 60°C.
2. The three results at 0°C were similar, but none of the results at other temperatures were similar for all three trials. However, an average of the three trials was taken, to improve the precision of the results as much as possible.

Precision can be achieved in your own investigations by ensuring that a large sample size (repeats) and taking a mean has been completed. More easily identifiable with continuous data measurements.

ISBN 978-1-108-88711-3

## Discussion

The discussion is the most crucial aspect of the investigation. Use your logbook to write down any notes about what you plan to address in this section. The discussion should include the following key content:

- *Interpret and evaluate the trends and patterns in your data* – use a graph if possible, as this will clearly show the relationship between the independent and dependent variables. It is important here to also quote relevant data from the table or graph when referring to trends in the data.
- *Acknowledge any deviations (outliers) in the data from the results that were expected* – relate the results to the relevant biological theory and key terms. This is very important, as this outlines how well you understand your results and can interpret them based on your knowledge of the theory. Therefore, use the knowledge in previous chapters of this book to help with the respective topic you are investigating.
- State whether the data you collected *supports or doesn't support the hypothesis*.
- Identify *any limitations in the data or the method* – refer to random and systematic errors, and accuracy and precision, as discussed earlier in this chapter.
- Suggest *future improvements to the investigation* if it were to be performed again – this means referring to experimental errors, not human errors (e.g. incorrect measuring of volume or not timing with a stopwatch appropriately). If your experiment is performed correctly, there should be no human errors.

6A INVESTIGATIVE DESIGN LINK

**NOTE**

Avoid terms such as 'proved', 'disproved', 'correct' and 'incorrect' in relation to your hypothesis, as it is unlikely that you can be this certain from a single investigation. Instead, use terms such as 'supported', 'not supported', 'indicated' and 'suggested'. If your results contradict your predictions, this would warrant repeating the experiment, if you have time. If you cannot repeat the experiment, then your report should include a discussion of flaws in the design or method, and suggestions for how the investigation could be altered to minimise or eliminate these.

## Conclusion

**Conclusion**
a summary of what you can deduce from the results of the investigation, including whether the tested hypothesis was supported

The main purpose of the **conclusion** is to briefly summarise the position of the experiment in the wider understanding of the biological topic(s). You need to state the important overall trend of the data (referring specifically to data from your results) and whether or not the results support the tested hypothesis. The conclusion should also assess whether the results of the experiment have contributed new information to what is known about the topic, and any further investigations that need to be undertaken. The conclusion should not introduce any information that has not already been discussed in the results and discussion section.

For example, in the experiment described in this chapter, the conclusion might read like this:

> In conclusion, the results indicate that the optimal temperature of the catalase enzyme in lamb liver is 40°C as shown by the highest mean height of oxygen bubbles produced, 18.7 mm. This is compared to the predicted optimal temperature of 37°C, which produced an oxygen bubble height of only 16.5 mm. As such, the results do not support the hypothesis. However, whether this was completely true should be further explored by conducting the investigation at smaller increments of temperature, to find the exact optimal temperature.

ISBN 978-1-108-88711-3

## Check-in questions – Set 1

1 What is the difference between qualitative data and quantitative data?
2 What is the appropriate method of representing discrete data?
3 Compare random and systematic errors, including what results from each type of error.
4 What is the difference between accuracy and precision?

## 6B SKILLS

When completing work within this 'scientific skills' section, you will draw upon some very important skills. Many of these you will have learned in previous years of studying science, but it is particularly important to highlight some here, to ensure that you maximise your performance on any given assessment.

VIDEO 6B–1 SKILLS: RECORDING RESULTS IN A TABLE

**Recording results in a table**

When constructing and recording your results in a table:

- Rule the table in pencil, so any amendments can be made easily.
- Give each column a clear heading, including both the quantity and the unit it is measured in. Do not enter the units in the table along with each numerical value – the units go in the heading only.
- The independent variable is usually placed in the first column, with the dependent variable to follow, in the other columns.
- Organise the results appropriately. For example, if your experiment involved testing an increasing concentration of a solute solution, your results should start with the lowest concentration and continue to the highest concentration.
- If recording quantitative results, all values should have the same number of decimal points.
- Include results for all repeats in the table, and the mean (average) calculated for these.
- Any results that are outliers should be recorded again (repeat the measurement). If there is no time to repeat the experiment, include the outliers but ignore them when calculating the mean.
- Give the table an overall title. This should include mention of both the independent and dependent variables.
- In most cases, data from a table also needs to be displayed as a graph: a line graph for continuous data, a bar graph for discrete data.

ISBN 978-1-108-88711-3

The top table below highlights errors in the representation of data. A corrected version is shown in the table below it.

Units are included in body of table, not column heading

Results not in increasing order

Results do not all have the same number of decimal places

Title of table missing

Column has no heading (only units)

No mean calculated for the two repeats

This result (3.31) does not seem to match the others, so it is a potential outlier. (Therefore, in the correct table below, it is not included in the mean of the two trials.)

| Concentration of solution | Initial mass of 10 potato discs (g) | | |
|---|---|---|---|
| | Trial 1 | Trial 2 | % |
| 0.0 M | 2 | 3.31 | +10 |
| 0.8 M | 2.05 | 2.13 | +4 |
| 0.4 M | 2.08 | 1.97 | -4 |
| 0.2 M | 2.05 | 1.95 | -5 |
| 0.6 M | 2 | 2 | -5 |

Effect of increasing solution concentration on mass of potato disc

| Concentration of solution (M) | Initial mass of 10 potato discs (g) | | |
|---|---|---|---|
| | Trial 1 | Trial 2 | Mean |
| 0.0 | 2.00 | 3.31 | 2.00 |
| 0.2 | 2.05 | 1.95 | 2.00 |
| 0.4 | 2.08 | 1.97 | 2.03 |
| 0.6 | 2.00 | 2.00 | 2.00 |
| 0.8 | 2.05 | 2.13 | 2.09 |

VIDEO 6B–2 SKILLS: DRAWING GRAPHS

## Drawing graphs

When constructing a graph:

- Use pencil, as this will allow you to make any amendments easily.
- Put the independent variable on the *x*-axis (horizontal axis) and the dependent variable on the *y*-axis (vertical axis).
- Fully label both axes must be fully and include units (units should be the same as the results table if headings are correct there).
- The scale on the axes should have increasing values spaced at equal intervals, and it should be easy to read values between these intervals. Do not extend the scales too far beyond the recorded data values. *Note*: You do not have to begin your scale at 0.
- Make the graph as large as possible, so it is easy to read precise values.

**Line of best fit** a line on a graph that shows the general trend of the data points; the distance to the points above the line should equal the distance to the points below the line

When drawing *line graphs*:

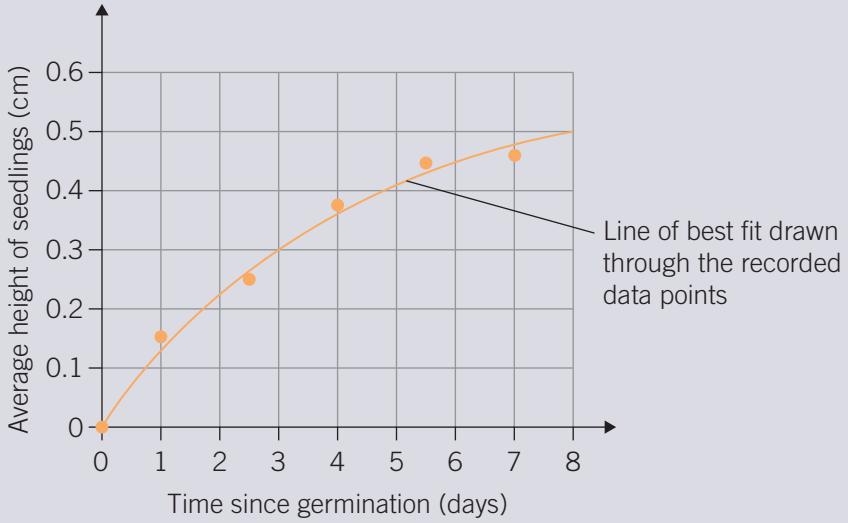
- Use a line graph to represent continuous data.
- Plot data points as crosses (×) or dots (•). If using dots, be sure to draw them large enough so that they are not covered by the line.
- Draw a **line of best fit**. This does not need to go through the first and last point, nor does it need to be a straight line (both common mistakes made by students).

When drawing *bar graphs*:

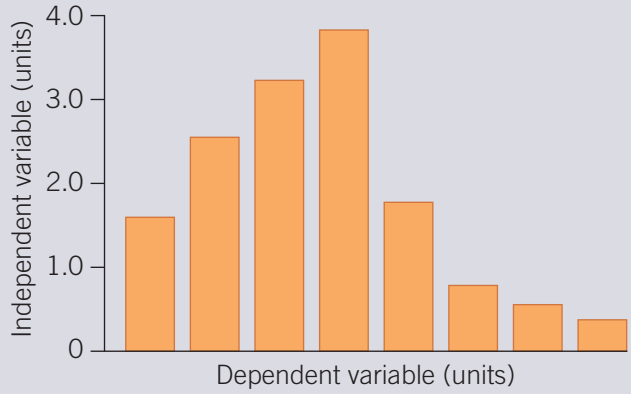
- Use a bar graph to represent discrete data, and draw the bars with gaps between them.
- However for a histogram, a special type of bar graph showing the distribution of numerical data, the rules are different. It displays the frequency of values on the vertical axis that fall into defined ranges called 'bins' marked on the horizontal axis.

ISBN 978-1-108-88711-3

**Line graph**




**Bar graph**




VIDEO 6B–3 SKILLS: ORDERING YOUR DISCUSSION

### Ordering your discussion

When choosing an order for all the points to talk about in your discussion, follow this sequence:

1. Describe the overall trend (overall relationship between the independent and dependent variable).
2. Describe any changes in the gradient of the graph, particularly focusing on sharp changes and where they occur.
3. Quote data from the graph.
4. Explain the results using your scientific knowledge of the key concepts studied in your investigation.
5. Identify sources of errors in the experiment. Begin this section with any *systematic errors* and how these affected the accuracy of your measurements due to limitations in the apparatus, experimental technique or experimental design. Do not include human errors (e.g. incorrectly measuring an exact volume of solution). Then identify any *random errors* and how these affected the precision of your measurements. You would include human errors here.
6. Identify areas for improvement. Focus on how to reduce the errors mentioned in step 5. This could include things such as:
   - using better techniques for measuring the dependent variable
   - using equipment that is more likely to keep controlled variables constant and therefore making your data valid, as well as more precise and accurate
   - repeating the investigation to increase reliability.

ISBN 978-1-108-88711-3

## Section 6B questions

**1** A student is investigating the effect of solute (sucrose concentration) on the rate of osmosis in potato cells. They cut 50 potato discs in total and placed 10 discs in a Petri dish covered with 50 mL of the sucrose solution at varying concentrations (0 M, 0.2 M, 0.4 M, 0.6 M and 0.8 M). The initial mass (in grams) of the potato discs was recorded and compared to the final mass (in grams) of the potato discs after 24 hours, allowing the student to calculate the percentage change in mass of the potato discs. The following results were produced.

| Concentration of sucrose solution (M) | Initial mass of 10 potato discs (g) | Final mass of 10 potato discs (g) | Change in mass (final – initial) (g) | Percentage change in mass (%) |
|---|---|---|---|---|
| 0.0 | 2.10 | 2.31 | +0.21 | +10 |
| 0.2 | 2.05 | 2.13 | +0.08 | +4 |
| 0.4 | 2.08 | 1.97 | –0.11 | –5 |
| 0.6 | 2.05 | 1.95 | –0.10 | –5 |
| 0.8 | 2.10 | 2.00 | –0.10 | –5 |

**a** Identify the independent variable and the dependent variable in this investigation.
**b** What would be two controlled variables required in this experiment? Explain by stating:
  **i** how you would control these variables
  **ii** the effect that these variables would have on the rate of osmosis if they were not controlled.
**c** What is the purpose of a control group?
**d** Does this experiment have a control group? If yes, identify which set-up it is. If no, identify and explain what would be an appropriate control group.
**e** Are the results of this investigation qualitative or quantitative? Explain.
**f** Describe whether the results of this investigation are reliable (use information in the question and results table to assist you).
**g** Use the information from the table to construct a graph of the results. Be sure to draw the appropriate type of graph.
**h** By looking at the table of results above, what could be done to improve the precision of these results?
**i** Using the graph you drew for question **g**, in which concentration of sucrose solution, 0.2 M or 0.6 M, is the concentration of free water molecules higher?

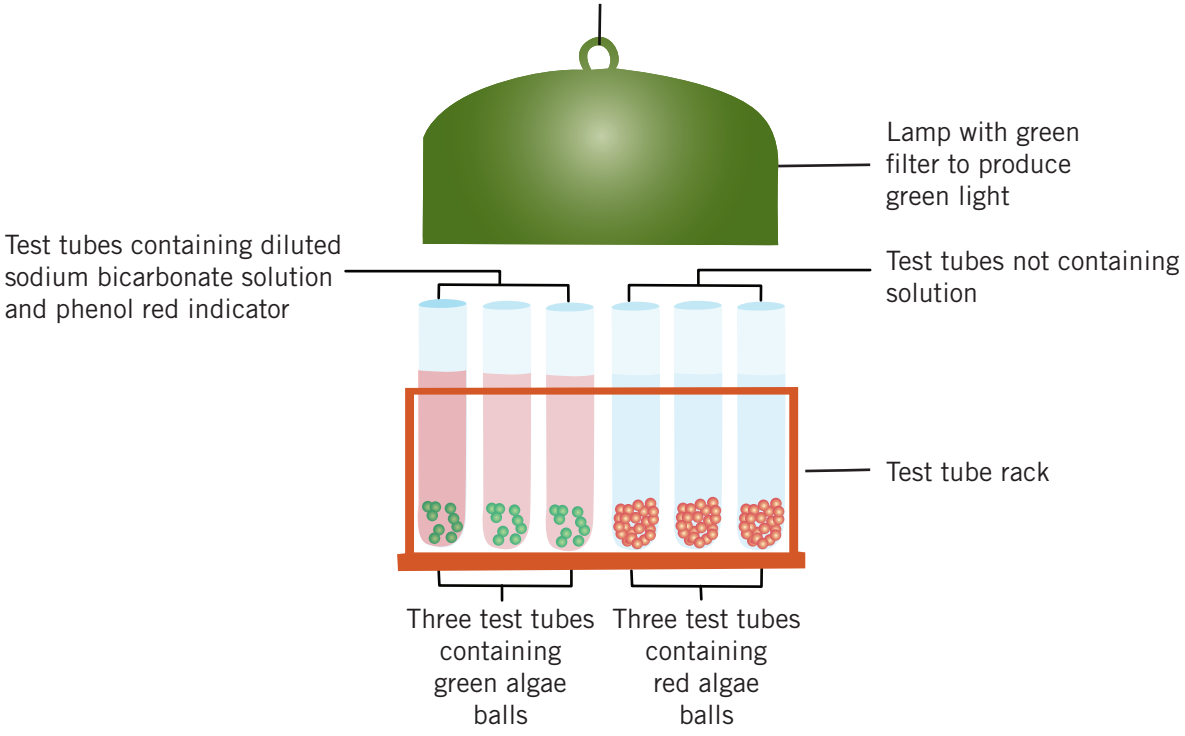
**2** Erin was performing an experiment based on one completed previously by other researchers. Their experiment confirmed that the survival of algae at different water depths was dependent on the algae's colour. Red algae, which contained a pigment called phycoerythrin, allowed the algae to absorb more light in the green wavelength. This allowed the algae to survive at increased water depths compared to green algae, which contained the pigment chlorophyll and absorbed light of the blue and red wavelengths better.

ISBN 978-1-108-88711-3

Like the previous researchers, Erin grew her own algal jelly balls, one set containing green algae and the other set containing red algae. She placed each of these groups of jelly balls into different test tubes and submerged them in a diluted sodium hydrogen carbonate solution (providing carbon dioxide and water to the algae). She also added three drops of phenol red indicator, which can detect changes in pH due to different concentrations of carbon dioxide. In low concentrations of carbon dioxide, the indicator remains red; in high concentrations of carbon dioxide, the indicator changes to yellow.

Erin measured the rate of photosynthesis using a stopwatch to record the time for a colour change to occur in any of the test tubes.

A diagram of Erin's experiment is shown here:






**a** If Erin managed to get the same results as those of the previous researchers, does this refer to 'reproducibility' or 'repeatability'?

**b** List three controlled variables that Erin would include in her experiment.

**c** State the independent variable in Erin's investigation.

**d** State a possible dependent variable in Erin's investigation and how this could be measured.

**e** Is the measurement of the dependent variable you identified in part **d** classified as qualitative or quantitative?

**f** What results from this investigation would support the results of the previous researchers?

**g** If the light in Erin's experiment was changed from green to blue, what results would she expect to see? Explain your answer.

**h** Erin's laboratory partner, Adrianne, suggested that they should also set up an identical experiment but keep the test tubes and their contents in the dark. Explain why this is a good suggestion.

ISBN 978-1-108-88711-3

# Scientific communication

**Study Design:**
**Scientific communication**

- The conventions of scientific report writing including scientific terminology and representations, standard abbreviations and units of measurement.
- Ways of presenting key findings and implications of the selected scientific investigation.

## ENGAGE

### Communicating your work

Think about how you've probably presented your experimental work in Science in previous years. You would have written up your planning stages and presented your results in a typical scientific report. While this is still done even at university, would you want to read a scientist's research presented to you in this way? Probably not. So scientists often communicate their findings in the form of a scientific poster. In the past few decades, posters have become a popular way to showcase new investigations and findings to the scientific community, nationally and internationally.

Producing a scientific poster is a skill and is not easy. It often requires a lot of thought and preparation, as well as the ability to keep your ideas concise.

## EXPLAIN

### Scientific poster template

UNITS 3&4 LINK

A key part of the School Assessed Coursework (SACs) in Units 3 & 4 Biology is a self-designed practical investigation presented in the format of a poster, using the following template:

VIDEO 6C–1 SCIENTIFIC POSTER EXAMPLE

<table>
<tr><td colspan="3">Title<br>Student name</td></tr>
<tr><td>Introduction<br><br>Methodology and methods<br><br>Results</td><td>Communication statement reporting the key finding of the investigation as a one-sentence summary</td><td>Discussion<br><br><br><br>Conclusion</td></tr>
<tr><td colspan="3">References and acknowledgements</td></tr>
</table>

This template is the same as the one provided in the VCAA Study Design. You'll notice from the template that the heading of each section correlates closely with the information that is recorded in your logbook from Sections 6A and 6B. This should therefore highlight the importance of the progression of information that is recorded there, as it will need to be transferred in a more succinct fashion onto your poster. The VCAA has also stipulated that this should not exceed 600 words. The centre of the poster occupies approximately one-quarter of the page and needs to be one sentence summarising the main outcomes of your investigation, thereby answering your investigation question (title). This should be as engaging as possible, to encourage any reader to want to read the other sections of your poster.

**6A** INVESTIGATIVE DESIGN LINK

**6B** SCIENTIFIC EVIDENCE LINK

ISBN 978-1-108-88711-3

You might be wondering where the aim and hypothesis from your logbook should be included on the poster. They are included in the introduction, following a brief explanation of the reasons for conducting your investigation, and link to the relevant biological concepts.

The poster can be produced either electronically or in hard copy format and may even be done in a different structure to this in Units 1&2. It will of course depend on what your school chooses as the preferred format, and you should therefore follow this.

### Purpose of the scientific poster

The scientific poster's main goal is to get your message, the findings of your investigation, across to everyone. It is designed not just for those with a scientific understanding of the investigation conducted, but those with a non-scientific background as well. The reason for setting it out in the template proposed on the previous page is for maximum impact and visual appeal. There are no large blocks of text that are not inviting to read. It is organised into columns, to help your readers follow the information. Including a table of results and a graph breaks up the text and avoids large blank areas. Lastly, the limitation on word count is so that the text is clear and concise. Your investigation should therefore be explicit and not too broad or overly complicated, so the results can be explained concisely.

In the poster, you should also include the sources of information (references) that you used when planning and conducting the investigation. You can also acknowledge those who supported your investigation, such as peers, your teacher or others. How to correctly complete references is explored in Chapter 9 (Unit 2, Area of Study 3, Research Investigation).

LINK CHAPTER 9

## Other methods for presenting an investigation

In addition to presenting your results in the form of a poster, you should be able to discuss your investigation with your peers, teacher, family or anyone from a non-scientific background. Most of those in the scientific community prefer to have individual discussions with other experimenters about their work, rather than reading it from a poster. Talking about their work with others also gives the experimenter a chance to discuss aspects of their investigation that have not been included in the final presentation, and to answer any follow-up questions.

Therefore, other methods for presenting the purpose and results of your investigation include: oral presentation, multimedia presentation, visual representation or even an article for a scientific publication. Tips and suggestions for these are included in the digital resource, in the form of downloadable documents on preparing an article for scientific publication, and preparing an oral, multimedia or visual presentation.

WORKSHEET 6C–1 PREPARING AN ARTICLE FOR SCIENTIFIC PUBLICATION

WORKSHEET 6C–2 PREPARING AN ORAL, MULTIMEDIA OR VISUAL PRESENTATION

## Section 6C questions

1 Where should you draw information from to complete your scientific poster?
2 What is included in the introduction section of the scientific poster?
3 What are the key sections of a scientific poster?
4 What is the purpose of the communicating statement in the centre of the poster?
5 What are some other ways of presenting the results of an investigation in Biology, and in general to the scientific community?

ISBN 978-1-108-88711-3

# Chapter 6 review

## Summary

Create your own set of summary notes for this chapter on paper or in a digital document. A model summary is provided in the Teacher Resources which can be used to compare with yours.

## Checklist

In the Interactive Textbook, the success criteria are linked from the review questions and will be automatically ticked when answers are correct. Alternatively, print or photocopy this page and tick the boxes when you have answered the corresponding questions correctly.

'ITB' in the linked questions columns means there is a question on this success criterion in the Interactive Textbook.

| Success criteria – I am now able to: | | Linked question |
|---|---|---|
| **6A.1** | Document investigations appropriately using a logbook | ITB☐ |
| **6A.2** | Define key terms related to scientific skills | 13d☐ |
| **6A.3** | Define the meaning of a controlled experiment | 13i☐ |
| **6A.4** | List the features that a controlled experiment includes | 13i☐ |
| **6A.5** | Distinguish between a positive and negative control | ITB☐ |
| **6A.6** | Understand the meaning of single variable exploration | 13i☐ |
| **6A.7** | Define and identify independent, dependent and controlled variables | 1☐, 2☐, 11a☐ |
| **6A.8** | Select and use equipment and procedures appropriate to an investigation | 8☐ |
| **6A.9** | Distinguish between an aim and a hypothesis | 3☐ |
| **6A.10** | Define law, theory and models and identify examples of each | 14☐ |
| **6A.11** | Construct aims and questions for investigations | 11b☐ |
| **6A.12** | Formulate hypotheses and predict possible outcomes | 13h☐ |
| **6A.13** | Define the terms accuracy, precision, reproducibility, repeatability and validity, and distinguish between these | 12☐, 13e☐, f☐ |
| **6A.14** | Design an experiment that can be fully reproducible by others | 8☐ |
| **6A.15** | Determine potential ethical issues with investigation design | ITB☐ |
| **6A.16** | Identify how bias can be minimised in an investigation | 13e☐, f☐ |
| **6A.17** | Follow clear guidelines for health and safety when undertaking practical investigations | ITB☐ |
| **6B.1** | Define the terms qualitative and quantitative | ITB☐ |
| **6B.2** | Distinguish between qualitative and quantitative data | 13a☐, g☐ |
| **6B.3** | Includes appropriate units of measurements for quantitative data | 6☐, 13g☐ |
| **6B.4** | Analyse generated primary data to determine whether it is accurate and/or precise, and define these terms | 13b☐, 4☐ |

ISBN 978-1-108-88711-3

| Success criteria – I am now able to: | | Linked question |
|---|---|---|
| **6B.5** | Transform primary data into an appropriate format of results (table, flow chart, bar and/or line graph) | 4☐ |
| **6B.6** | Identify trends in data | 13b☐ |
| **6B.7** | Define the different types of errors (random and systematic) | 13c☐ |
| **6B.8** | Identify sources of error and outliers from primary data | 4☐, 9☐ |
| **6B.9** | Use evidence to determine whether an investigation supports or discounts a hypothesis | 4☐ |
| **6B.10** | Identify areas for improvement in investigation design and analysis to increase accuracy and precision and reduce the likelihood of errors | 13h☐ |
| **6C.1** | Appropriately communicate all aspects of a scientific investigation | 5☐, 6☐ |
| **6C.2** | Apply correct abbreviations to biological terminology | ITB☐ |
| **6C.3** | Acknowledge sources of information using appropriate referencing system | ITB☐ |
| **6C.4** | Justify conclusions and evaluate whether evidence supports or refutes the hypothesis | ITB☐ |
| **6C.5** | Infer investigation outcomes to broader biological concepts, including cell/system functioning, survival of an individual or species survival and the connections between these ideas | ITB☐ |
| **6C.6** | Use clear, coherent and concise biological communication to a specific audience, e.g. teachers and/or peers | 7☐, 10☐ |

## Multiple-choice questions

**1** An investigation to observe the different organelles present in plant and animal cells, using an electron microscope is performed. What could be the dependent variable?

**A** the type of microscope used
**B** the type of cell observed under the microscope
**C** the organelles observed under the microscope
**D** the size of the cell

**2** Aside from the independent and dependent variables in an investigation, what other type of variable is included to ensure it is valid?

**A** changed
**B** controlled
**C** control group
**D** precise

**3** A hypothesis is best described as

**A** a statement describing what the investigation hopes to determine.
**B** a series of steps involved in planning an investigation.
**C** clear ethical guidelines for how any living organisms should be handled in the experiment.
**D** a prediction of what will be observed.

ISBN 978-1-108-88711-3

*The following information relates to Questions 4–6.*
The table below shows measurements from four sphygmomanometers, W, X, Y and Z.
A sphygmomanometer is an instrument used to measure blood pressure. Sphygmomanometer W is known to be accurate.

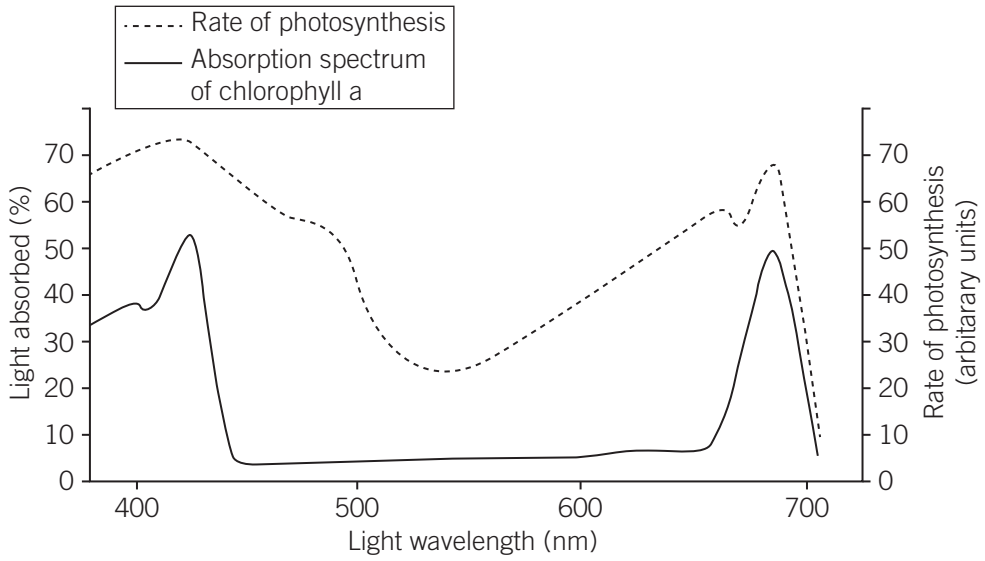
| Sphygmomanometer | Pressure (mmHg) | | | | |
|---|---|---|---|---|---|
| W | 20.00 | 20.00 | 20.00 | 20.00 | 20.01 |
| X | 19.91 | 20.23 | 20.13 | 19.42 | 19.59 |
| Y | 19.00 | 20.40 | 19.50 | 20.10 | 21.00 |
| Z | 19.00 | 19.00 | 19.00 | 19.00 | 19.00 |

**4** Which statement is correct?
- **A** The measurements from sphygmomanometer Z are more precise but less accurate than the measurements from sphygmomanometer Y.
- **B** The measurements from sphygmomanometer Z indicate a random error and are more accurate than the measurements from sphygmomanometer X.
- **C** The measurements from sphygmomanometer X indicate a systematic error.
- **D** The measurements from sphygmomanometer X have the same degree of precision as the measurements from sphygmomanometer Y.

**5** Which of the following is *least* likely to improve the quality of the data in this investigation?
- **A** more blood pressure measurements recorded for each sphygmomanometer
- **B** more sphygmomanometers being tested
- **C** all groups using the same sphygmomanometer, W
- **D** taking an average of the combined results of all groups

**6** The reasons sphygmomanometer W was included as a reference for accuracy for the investigation was to
- **A** remove any possible random errors from the results.
- **B** allow the pressure to be measured accurately.
- **C** ensure the other instruments were precise.
- **D** ensure the experiment generated qualitative data.

**7** The graph below compares the absorption spectrum of chlorophyll a with the rate of photosynthesis of a plant upon exposure to a range of light wavelengths.




ISBN 978-1-108-88711-3

From this graph, it can be concluded that chlorophyll a is not the only pigment involved in photosynthesis. Evidence that supports this conclusion includes the fact that

**A** the rate of photosynthesis remains high when the plant is exposed to light wavelengths between 450 nm and 650 nm. The percentage of light absorbed by chlorophyll a over these wavelengths is low.

**B** the rate of photosynthesis is low when the plant is exposed to light wavelengths such as 450 nm. Absorption of light by chlorophyll a is higher at these wavelengths.

**C** the rate of photosynthesis and the percentage of light absorbed by chlorophyll a are equal at 650 nm.

**D** between wavelengths 450 nm and 700 nm, the percentage of light absorbed by chlorophyll a is constant.

**8** Which of the following statements would be appropriate in the Methods section of a logbook?

**A** Exactly 50 mL of solution was measured using a measuring cylinder.

**B** Exactly 50 mL of solution was measured using a beaker.

**C** Solution was measured and placed in a tube.

**D** Add solution to a measuring cylinder.

**9** A systematic error

**A** can be minimised by increasing the sample size and taking a mean.

**B** is equally likely to be quantitatively higher or lower.

**C** affects the precision of results.

**D** occurs consistently in one direction.

**10** A conclusion should *not*

**A** summarise the key findings of an investigation.

**B** state key data from results.

**C** introduce new information relevant to the investigation.

**D** state whether or not the hypothesis was supported.

## Short-answer questions

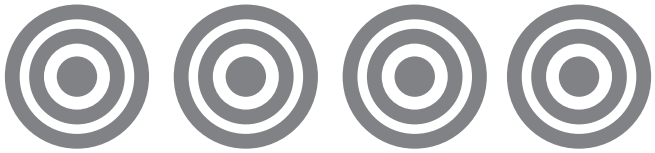
**11 a** Copy and complete the table. (4 marks)

| Hypothesis | Independent variable | Dependent variable | Controlled variables (×2) |
|---|---|---|---|
| That intelligence of a group of students is affected by the amount of oxygen inhaled | Amount of oxygen inhaled | Intelligence | Same number of students in each group<br>Same gender |
| That watching television while doing schoolwork decreases performance on the task | | | |
| That 'watering' lemon trees with urine makes them grow faster | | | |
| That antacid tablets dissolve faster in warmer water | | | |

**b** For each of the hypotheses in the table, write an aim that would be appropriate for that investigation. (4 marks)

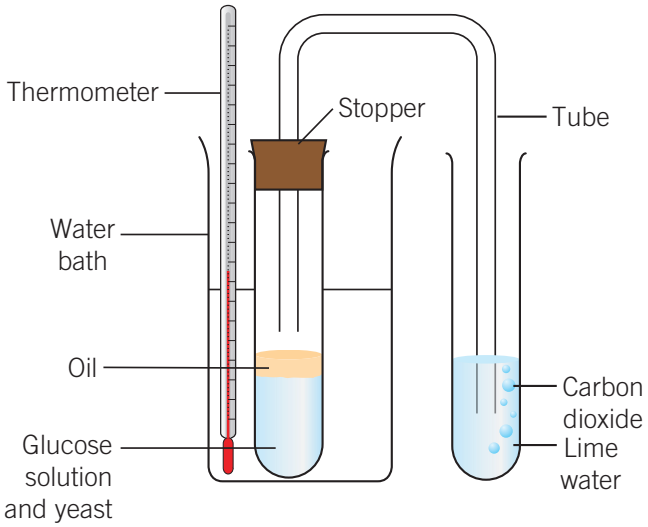
ISBN 978-1-108-88711-3

**12** Using the standard bullseye/dartboard-style shown, draw separate diagrams that clearly show each of the following types of data:



**a** accurate and precise
**b** accurate but not precise
**c** precise but not accurate
**d** neither accurate nor precise. (4 marks)

**13** A scientist decided to investigate the effect of temperature on yeast to determine the temperature at which yeast is best able to perform anaerobic cellular respiration. The experiment was set up as shown below and measured the cloudiness of the limewater (caused by production of carbon dioxide). The results are shown in the table.




| Temperature of water (°C) | Cloudiness of limewater solution* |
|---|---|
| 10 | 0 |
| 20 | 1 |
| 30 | 2 |
| 40 | 3 |
| 50 | 1 |
| 60 | 0 |
| 70 | 0 |

*0 = no change, 1 = partly cloudy, 2 = cloudy, 3 = very cloudy

**a** What type of graph should be drawn to represent these results? (1 mark)
**b** Draw a graph for the data shown in the table. Include axis titles and units. (4 marks)
**c** Describe the trend observed in the results. (2 marks)
**d** Using your understanding of the effect of temperature on the rate of reactions, describe the difference observed in the results at 20°C and 30°C. (2 marks)
**e** Suggest ways in which the scientist could ensure that the investigation results are valid. (3 marks)
**f** Suggest ways in which the scientist could ensure that the investigation results are reliable. (1 mark)
**g** Are the results of this experiment qualitative or quantitative? Explain. (3 marks)
**h** Before conducting this investigation, the scientist hypothesised that, as the temperature increased, the rate of anaerobic cellular respiration would also increase. Is the hypothesis supported by the results? Explain your answer. (2 marks)
**i** Identify the features of this experiment that make it a controlled experiment. In your answer, outline what a controlled experiment is. (4 marks)

**14** Outline the difference between the following terms: model, law, theory. (3 marks)

ISBN 978-1-108-88711-3

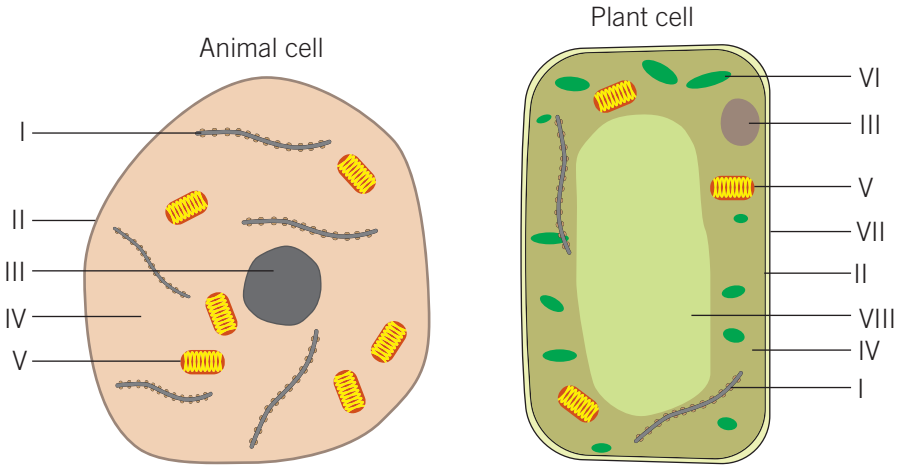
# Unit 1 Revision exercise

The following questions require you to draw knowledge together across all the content covered in Chapters 1 to 6. This will help you to determine how well you can apply your understanding of the content to different scenarios.

## Multiple-choice questions

**1** A major difference between prokaryotic and eukaryotic cells is that
- **A** prokaryotic cells are much smaller than eukaryotic cells.
- **B** prokaryotic cells contain a nucleus, whereas eukaryotic cells do not.
- **C** prokaryotic cells have a cell wall, whereas eukaryotic cells do not.
- **D** prokaryotic cells contain membrane-bound organelles, whereas eukaryotic cells do not.

*Use the diagram below to answer Questions 2 and 3.*




**2** The organelle that contains the molecule with instructions for making protein is
- **A** I
- **B** II
- **C** III
- **D** IV

**3** The process that occurs in structure IV is
- **A** anaerobic cellular respiration to generate useable energy for the cell.
- **B** photosynthesis to generate glucose.
- **C** protein modification and packaging.
- **D** storage of water and ions.

**4** An amoeba is a eukaryote because it:
- **A** contains ribosomes, a plasma membrane and cytosol.
- **B** belongs to the Protista kingdom and contains a membrane bound organelle.
- **C** is multicellular and can be as big as 100 μm.
- **D** is single-celled and does not contain a membrane-bound nucleus.

ISBN 978-1-108-88711-3

**5** The process responsible for the movement of glucose from a highly concentrated area in the villi to an area of lower concentration in the capillaries is
- **A** osmosis.
- **B** diffusion.
- **C** facilitated diffusion.
- **D** active transport

**6** Specialised cells can be defined on the basis that they
- **A** perform a particular function.
- **B** are found in unicellular organisms.
- **C** consist of only one type of organelle.
- **D** carry out many different roles.

*Use the following information to answer Questions 7 and 8.*

Two celery stems with their leaves attached were each placed in a beaker containing water and food colouring. One celery stem was placed next to a UV lamp, which generates an increase in temperature for the celery, and the other celery stem was left in the open, in the laboratory. After 1 hour, the movement of the food colouring was determined by measuring the distance it had travelled up the celery stem.

**7** It would be expected that the dye would
- **A** have moved further up the celery stem left in the open, as this best mimics its natural environment where transpiration rate would be greatest.
- **B** have moved the same distance up each celery stem, as conditions were identical.
- **C** not have moved up either stem, as the celery stems had been removed from the plant.
- **D** have moved further up the stem exposed to the UV lamp as the temperature would be higher, which increases transpiration rate.

**8** In this experiment, what is the dependent variable?
- **A** the time allowed for movement of the dye
- **B** the environment in which the celery stick was placed
- **C** the distance the dye travelled up the celery
- **D** the size of the celery stick

**9** The filtration component of the nephron is the
- **A** collecting duct.
- **B** loop of Henle.
- **C** glomerulus.
- **D** distal tubule.

**10** Which of the following correctly identifies a pair of antagonistic hormones?
- **A** thyroxine and thymosine
- **B** insulin and glucagon
- **C** TSH and FSH
- **D** testosterone and oestrogen

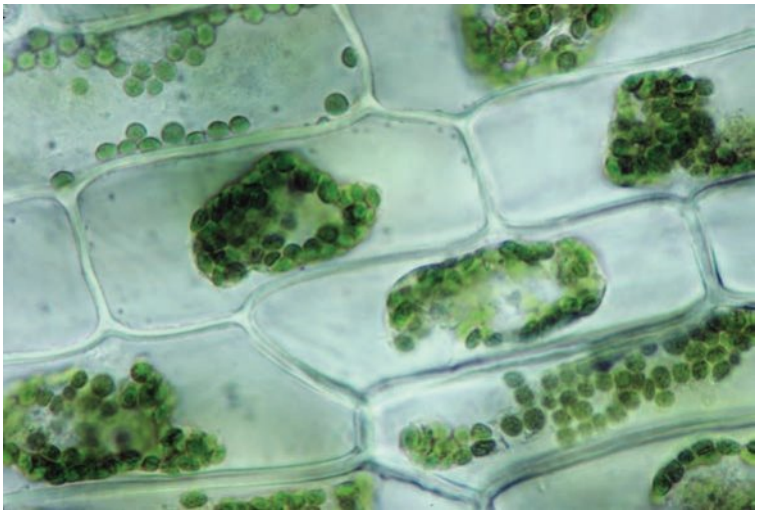
ISBN 978-1-108-88711-3

## Short-answer questions

**11** *Elodea* is an aquatic plant that is commonly used in experiments to identify the movement of water into or out of cells placed in different salt solutions.

**a** Which organelle(s) would you expect to see in *Elodea* cells but not in animal cells? (1 mark)

The image below was obtained using a light microscope. It shows *Elodea* cells exposed to 5% sodium chloride (NaCl).



**b** Using the image obtained from the light microscope, identify whether the 5% NaCl solution the *Elodea* cells were placed in is hypotonic, hypertonic or isotonic. (1 mark)

**c** Explain your reasoning for choosing your answer to part **b**. (2 marks)

**d** Provide drawings of a plant cell placed in a isotonic, hypertonic and hypotonic solution. Ensure you include annotations with arrows, indicating the direction of water movement. (3 marks)

**e** Explain what would happen to a cell if it was placed in an isotonic solution. (2 marks)

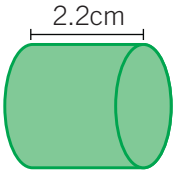
**f** Define 'osmosis'. (1 mark)

ISBN 978-1-108-88711-3

**12** Six different sucrose solutions were used to investigate osmosis for a potato core.

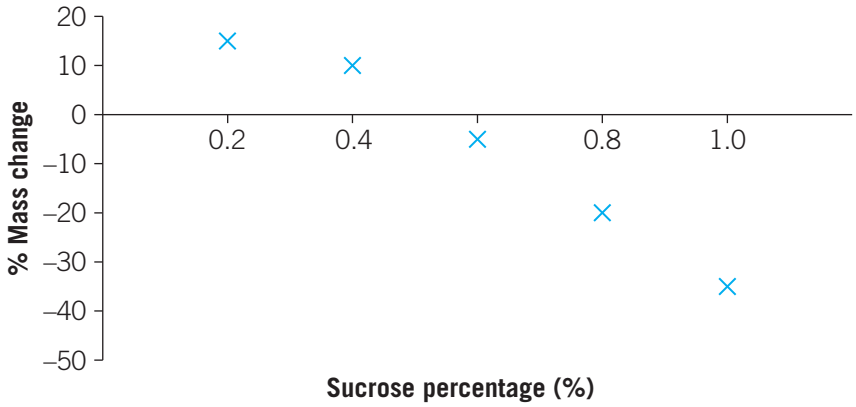
| | Beaker 1 | Beaker 2 | Beaker 3 | Beaker 4 | Beaker 5 | Beaker 6 |
|---|---|---|---|---|---|---|
| Sucrose % | 0 | 0.2 | 0.4 | 0.6 | 0.8 | 1.0 |

Using an apple corer, students carefully produced cylinder-shaped potato cores and cut each core to 2.2 cm long.




The initial mass of each potato core used in the experiment was measured and recorded. Five potato cores were placed in each of the sucrose solutions tested. After 24 hours the potato cores were removed and the mass measured again.

Average results for each solution were calculated and recorded in the graph below.




**a** According to these results, what would be the isotonic point for the potato cells? (1 mark)

**b** Identify the dependent variable, the independent variable and three controlled variables for this experiment. (3 marks)

**c** From the experimental set-up and results outlined in the graph, was a control group used in this experiment? If so, identify it. If not, explain what would have been an appropriate control to use. (2 marks)

**d** Provide a potential hypothesis for this experiment. (1 mark)

**13** Australia's national flower emblem is the golden wattle (*Acacia pycnantha Benth).* As winter changes to spring, these plants burst into flower, displaying our national colours of green and gold.

**a** Write the word equation and the balanced chemical equation for the reaction that generates glucose in the golden wattle plant. (2 marks)

**b** Water is a key input of the reaction that you have written for part **a**.

**i** In what stage of the reaction is water used? (1 mark)

**ii** In what part of the organelle does this stage occur? (1 mark)

**c** How does the golden wattle source the water it needs to survive? (1 mark)

**d** The roots of the golden wattle (and all vascular plants) are specifically adapted to maximise the absorption of water from the soil. Draw a labelled diagram that shows the structural features that maximise water absorption in the roots. (2 marks)

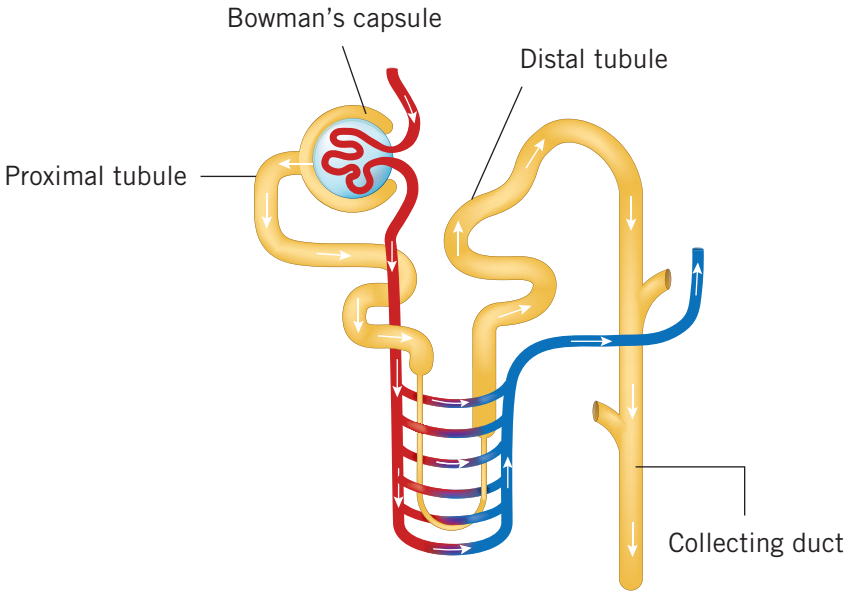
ISBN 978-1-108-88711-3

**e** How does the movement of water into the plant differ from the movement of ions and minerals into the plant? (3 marks)

**f** The surface of most leaves on plants is covered by a waxy cuticle. However, this layer is not found on the surface of roots. Explain why this is the case. (2 marks)

**g** The golden wattle must be able to survive hot Australian summers when water can be scarce. To assist with this, rather than have 'true leaves', the golden wattle has flattened leaf stalks called 'phylodes', which do not contain stomata. Explain how this structure helps the golden wattle survive dry climatic conditions. (2 marks)

**14** The diagram below shows the structure of a nephron in a human.




**a** The nephron is the functional part of the kidney that is responsible for the filtration of the blood plasma and reabsorption of key molecules within the filtrate by the body, leaving the eventual waste to be excreted from the body as urine. On a copy of the diagram above, or by drawing your own diagram, label the:

**i** ascending limb of the loop of Henle (1 mark)

**ii** descending limb of the loop of Henle. (1 mark)

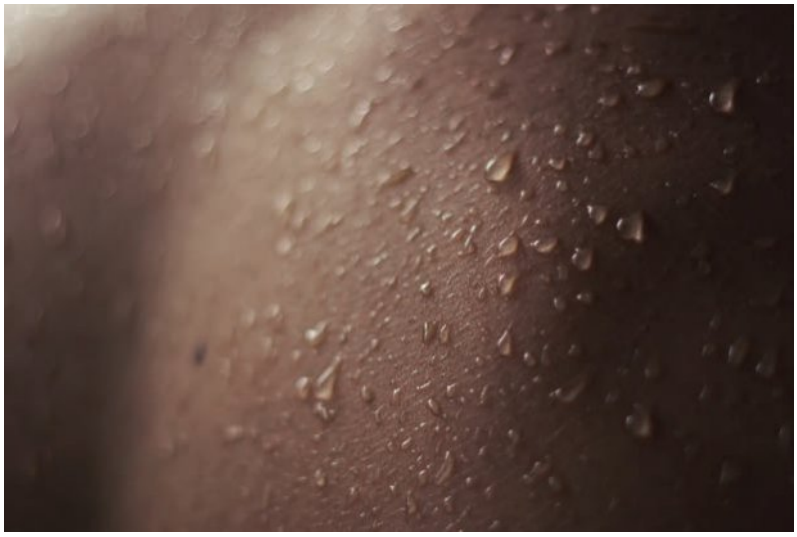
**b** The excretory system of the common desert kangaroo rat has a relatively similar structure to that of the human shown in the diagram. However, there is a noticeable difference in the size of the loop of Henle.
Identify this difference and explain the significance of this for the survival of the desert rat. (3 marks)

ISBN 978-1-108-88711-3

**c** It is important for animals such as the desert kangaroo rat to maintain their internal water balance. This is called osmoregulation.
Using a fully labelled diagram, describe the stimulus–response pathway required for this process. (6 marks)

**d** In addition to regulating their internal water balance, animals such as humans must also regulate their body temperature.
What is the usual internal body temperature of humans? (1 mark)

**e** When you exercise, your internal body temperature increases. To maintain thermoregulation, your body will begin to cool down by sweating. As water evaporates from the skin, heat is lost. This reduces the temperature of the skin, making you feel cooler.
Identify another advantage of sweating for the functioning of the body. (1 mark)



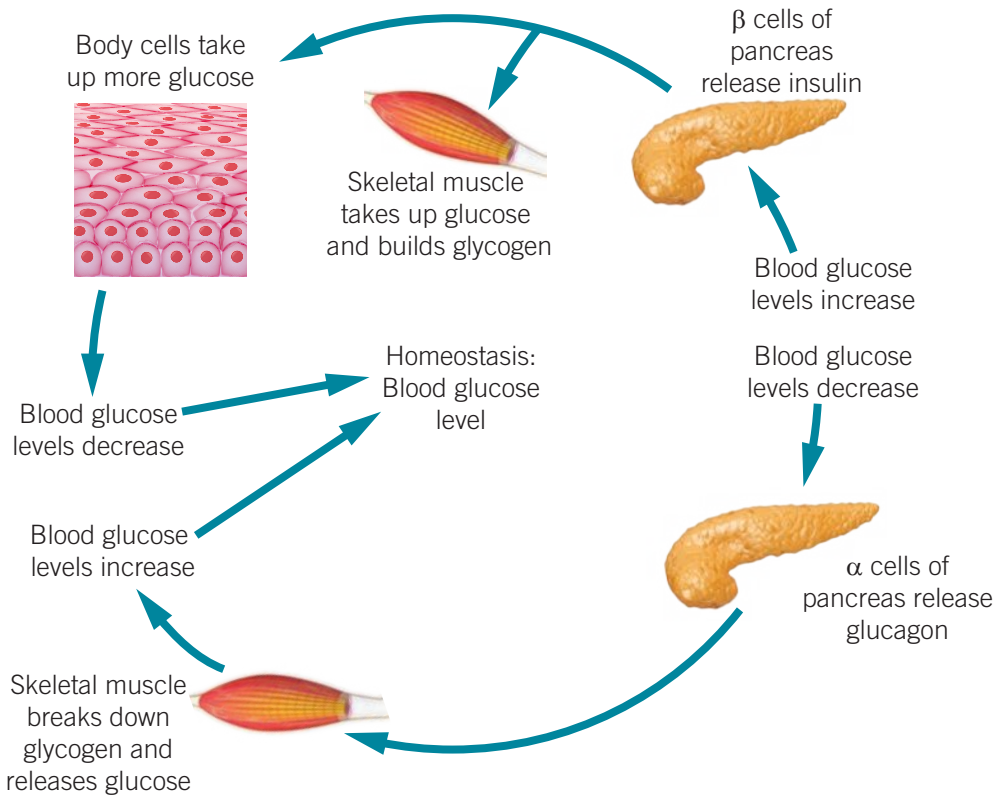
**f** During prolonged periods of exercise, large amounts of ATP are required by cells in the body. The endocrine system plays a significant role in the generation of ATP.
Identify the gland and hormone responsible for helping to generate large amounts of ATP, and explain how this occurs. (2 marks)

**g** What is the name of the process that produces this ATP? (1 mark)

**h** How does the process you identified in part **g** contribute to an increase in internal body temperature? (1 mark)

ISBN 978-1-108-88711-3

**15** Carbohydrates are an important food source in our diet. We eat carbohydrates in a variety of forms. Most are complex sugars (polysaccharides) that need to be broken down to simpler sugars (monosaccharides) to allow absorption into the bloodstream and cells. Glucose is a monosaccharide used as a fuel source in key cellular processes and it can be stored for short periods in the form of glycogen, in our liver and our skeletal muscle. Below is a feedback loop showing the regulation of blood glucose levels as a result of homeostasis.




**a** Define 'homeostasis'. (1 mark)

**b** Using the information in the diagram, identify both the 'stimulus' and 'response' parts of the stimulus–response model. (2 marks)

**c** The example shown in the diagram is of a feedback loop. Is this an example of positive or negative feedback? Explain. (2 marks)

**d** Insulin and glucagon, hormones released from the pancreas, are both composed of many amino acids joined together by peptide bonds to form a protein. List all the cell organelles involved in the release of these proteins from the pancreas and outline their individual roles. (5 marks)

**e** The final steps of the process listed in your answer to part **d** would include the protein being released from the cell with the aid of a vesicle. This process is called exocytosis. The endocrine system has many hormones. Some hormones, such as glucagon and insulin, are made of protein. Other hormones are made of lipids. Referring to the nature of lipids, explain the process in which they would be released from an endocrine gland. (3 marks)

**f** Typically, hormones need to travel large distances to reach their target cells in the body. How would both types of hormones reach their target cell? (1 mark)

**g** Once hormones reach their target cell, they bind to specific receptors that have a binding site that is complementary in shape to that of the hormone. Draw a fully labelled diagram of a 'target' cell that clearly demonstrates the difference between the binding of a protein-based hormone to its receptor and the binding of a lipid-based hormone to its receptor. (3 marks)

ISBN 978-1-108-88711-3

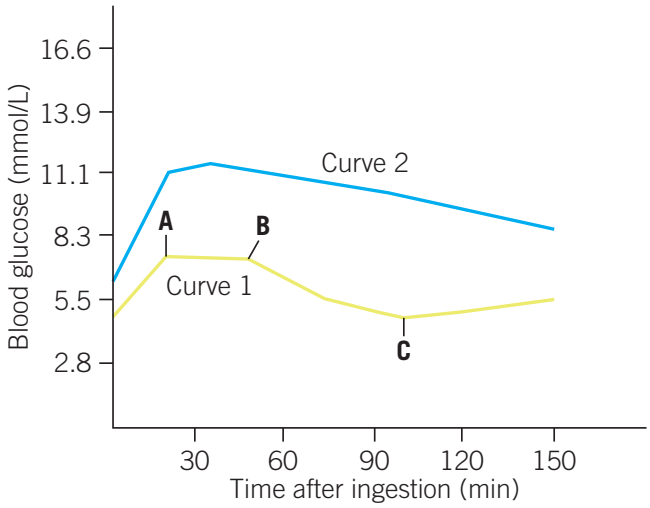
**16** Tilly and Giovanni both have a family history of type 1 diabetes. They decide to both visit the doctor and have a glucose tolerance test. The glucose tolerance test involves ingesting a large sample of glucose and then measuring the blood glucose levels over two hours.

**a** Glucose is a crucial molecule for the production of energy in organisms. Compare how glucose is obtained in autotrophs and in heterotrophs. (2 marks)

The instructions for the test indicate that you should fast (not eat anything) beforehand. Unfortunately, Tilly was hungry when she woke up, and forgot to fast. She had a large carbohydrate-based breakfast before going to the doctor's clinic.

**b** Describe the process through which Tilly's meal would have been broken down into glucose. (2 marks)

Both Tilly and Giovanni take the test over the 2-hour period. However, because Tilly hasn't fasted, she doesn't take the glucose solution. The unidentified results are shown in the graph below.




**c** Which curve belongs to each person? Does either person have diabetes? Explain your answer, using specific examples. (5 marks)

**d** Using your knowledge of the glucose homeostasis feedback loop, describe what is happening at points A, B and C on curve 1. (3 marks)

Researchers have developed a new type of treatment for type 1 diabetes that works through having a small device placed on the bottom of your foot. This device, called In-Shoe-Lin, is able to detect when blood glucose levels get too high and inject a small amount of insulin into the bloodstream through the base of your foot. However, before it can be given to people with type 1 diabetes, it needs to be rigorously tested.

**e** Describe a way of testing this treatment by listing the key points of the experimental design. It is important that this design leads to valid and conclusive results. (5 marks)

ISBN 978-1-108-88711-3

**17** Stem cells are important cells in our body as they have the ability to differentiate into many different types of cells. This offers the possibility of using them as a continuous source of cells to treat disorders such as type I diabetes.

**a** What type of stem cells would be more advantageous to treat type 1 diabetes: adult stem cells or embryonic stem cells? Explain your reasoning. (1 mark)

**b** Identify the disadvantages associated with using either type of stem cell to treat disorders. (2 marks)

**c** When an embryo undergoes gastrulation, three main layers are formed: ectoderm, mesoderm and endoderm. Which layer would be responsible for forming the cells needed to correct type 1 diabetes? (1 mark)

**18** The cell theory states that all cells (including stem cells) arise from pre-existing cells.

**a** Draw a fully labelled diagram of the cell cycle, clearly identifying the key processes that occur at each stage in the development of new cells. (6 marks)

Between each of these stages, there are checkpoints that ensure the cell is developing correctly. If any damage or errors have occurred throughout the cell cycle, the cell is marked for destruction.

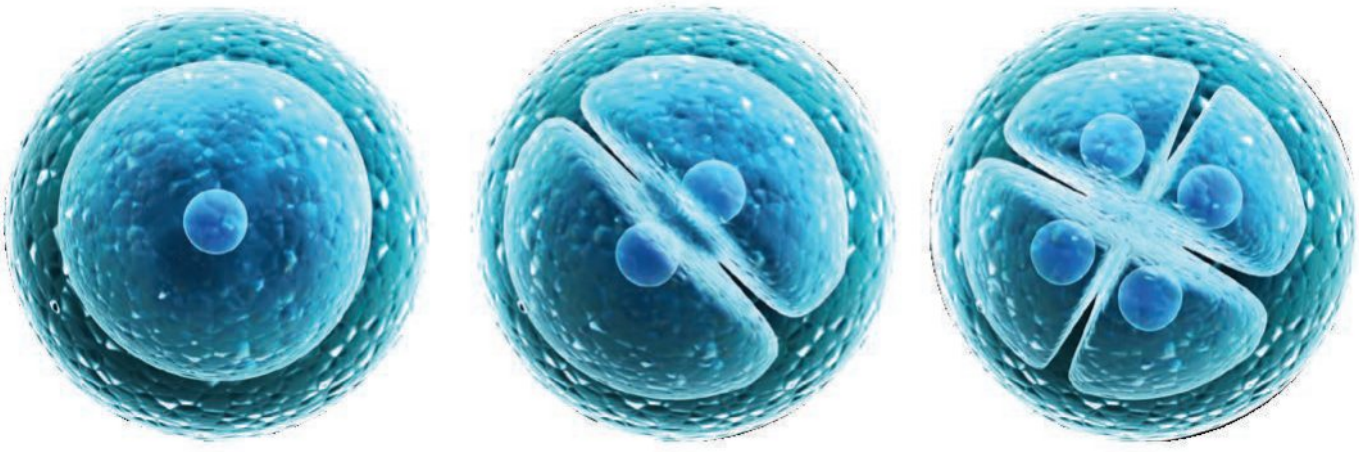
**b** What is name of this process? (1 mark)

**c** Explain the key steps within the process you identified in part **b**. (4 marks)

**d** What is the difference between intrinsic and extrinsic death signals leading to the destruction of a cell? Provide an example of what could cause each. (2 marks)

**e** A key protein involved in the cell cycle checkpoints is p53. If this protein is damaged, it can no longer perform its functions of halting the cell cycle, repairing DNA and activating programmed cell death. A consequence of this is the development of cancer.
What are some of the key characteristics of cancer cells compared to normal cells? You may use a diagram to help identify any differences. (3 marks)

**f** One of the stages of the cell cycle contains four key sub-phases. Use a diagram to show the key differences of the appearance of DNA/chromosomes in each. (4 marks)



ISBN 978-1-108-88711-3

UNIT 2

HOW DOES INHERITANCE IMPACT ON DIVERSITY?

CHAPTER 7

# REPRODUCTIVE STRATEGIES, ADAPTATIONS AND DIVERSITY

## Introduction

Biology is not just the study of individual living things; it is also the study of the population in which living things exist and of the interaction that the population has with its environment. In order to survive as a species and continue living, organisms need to reproduce and pass on their genetic information to the next generation. This chapter examines the different ways in which organisms reproduce, and the advantages and disadvantages of these strategies. It also explores how the successful survival of a species depends not only on the way in which it reproduces, but also on the adaptations it has that enhance its chance of surviving in a wide range of environments. The contributions of Aboriginal and Torres Strait Islander knowledge and perspectives to the understanding of adaptations and the interdependencies between species are also covered.

## Curriculum

**Area of Study 1 How is inheritance explained? Outcome 1**
**Area of Study 2 How do inherited adaptations impact on diversity? Outcome 2**

| Study Design | Learning intentions – at the end of this chapter I will be able to: |
|---|---|
| **(AoS 2) Reproductive strategies**<br>• Biological advantages and disadvantages of asexual reproduction<br>• The process and application of reproductive cloning technologies | **7A Asexual reproduction**<br>**7A.1** Define asexual reproduction<br>**7A.2** Summarise the different methods of naturally occurring asexual reproduction used by prokaryotes and eukaryotes, including examples of organisms using each method<br>**7A.3** Identify the advantages and disadvantages of asexual reproduction<br>**7A.4** Outline the process and application of each of the different types of reproductive cloning technologies used in plants and animals<br>**7A.5** Examine issues associated with reproductive cloning technologies |

ISBN 978-1-108-88711-3

| Study Design | Learning intentions – at the end of this chapter I will be able to: |
|---|---|
| **(AoS 1) From chromosomes to genomes**<br>• The nature of a pair of homologous chromosomes carrying the same gene loci and the distinction between autosomes and sex chromosomes<br>• Karyotypes as a visual representation that can be used to identify chromosome abnormalities<br>• The production of haploid gametes from diploid cells by meiosis, including the significance of crossing over of chromatids and independent assortment for genetic diversity<br>**(AoS 2) Reproductive strategies**<br>• Biological advantages of sexual reproduction in terms of genetic diversity of offspring | **7B Sexual reproduction and meiosis**<br>**7B.1** Define and explain sexual reproduction, including key terms and processes<br>**7B.2** Define karyotope, autosome and chromosome<br>**7B.3** Demonstrate an understanding of how a karyotype can be used to identify chromosomal abnormalities<br>**7B.4** Identify the advantages and disadvantages of sexual reproduction<br>**7B.5** Distinguish between asexual and sexual reproduction<br>**7B.6** Outline the purpose of and key steps in meiosis<br>**7B.7** Summarise the significance of the processes of crossing over, independent assortment and random fertilisation in creating variation and therefore genetic diversity<br>**7B.8** Distinguish between mitosis and meiosis<br>**7B.9** State the biological advantage for offspring that are genetically diverse |
| **(AoS 2) Adaptations and diversity**<br>• The biological importance of genetic diversity within a species or population<br>• Structural, physiological and behavioural adaptations that enhance an organism's survival and enable life to exist in a wide range of environments<br>• The contribution of Aboriginal and Torres Strait Islander peoples' knowledge and perspectives in understanding adaptations of, and interdependencies between, species in Australian ecosystems | **7C Adaptation, diversity and survival, with Indigenous perspectives**<br>**7C.1** Define structural, physiological and behavioural adaptations<br>**7C.2** Identify examples as either structural, physiological or behavioural adaptations<br>**7C.3** Describe an example of the contribution of Aboriginal and Torres Strait Islander peoples' knowledge and perspectives in understanding adaptations of species in Australian ecosystems<br>**7C.4** Describe an example of the contribution of Aboriginal and Torres Strait Islander peoples' knowledge and perspectives in understanding interdependencies between species in Australian ecosystems |

ISBN 978-1-108-88711-3

| Study Design | Learning intentions – at the end of this chapter I will be able to: |
|---|---|
| • Survival through interdependencies between species, including impact of changes to keystone species and predators and their ecological roles in structuring and maintaining the distribution, density and size of a population in an ecosystem | **7D Surviving through interdependencies, with Indigenous perspectives**<br>**7D.1** Define and identify different symbiotic relationships as parasitism, commensalism or mutualism<br>**7D.2** Define and identify different groupings of organisms as species, populations, communities or ecosystems<br>**7D.3** Define and identify producers, primary consumers, secondary consumers and tertiary consumers in a given food chain or food web<br>**7D.4** Draw a food chain and/or food web from a given scenario<br>**7D.5** Define keystone species and explain how it impacts the ecosystem around it<br>**7D.6** Given a scenario, hypothesise the potential impacts of the removal of a keystone species from that situation |

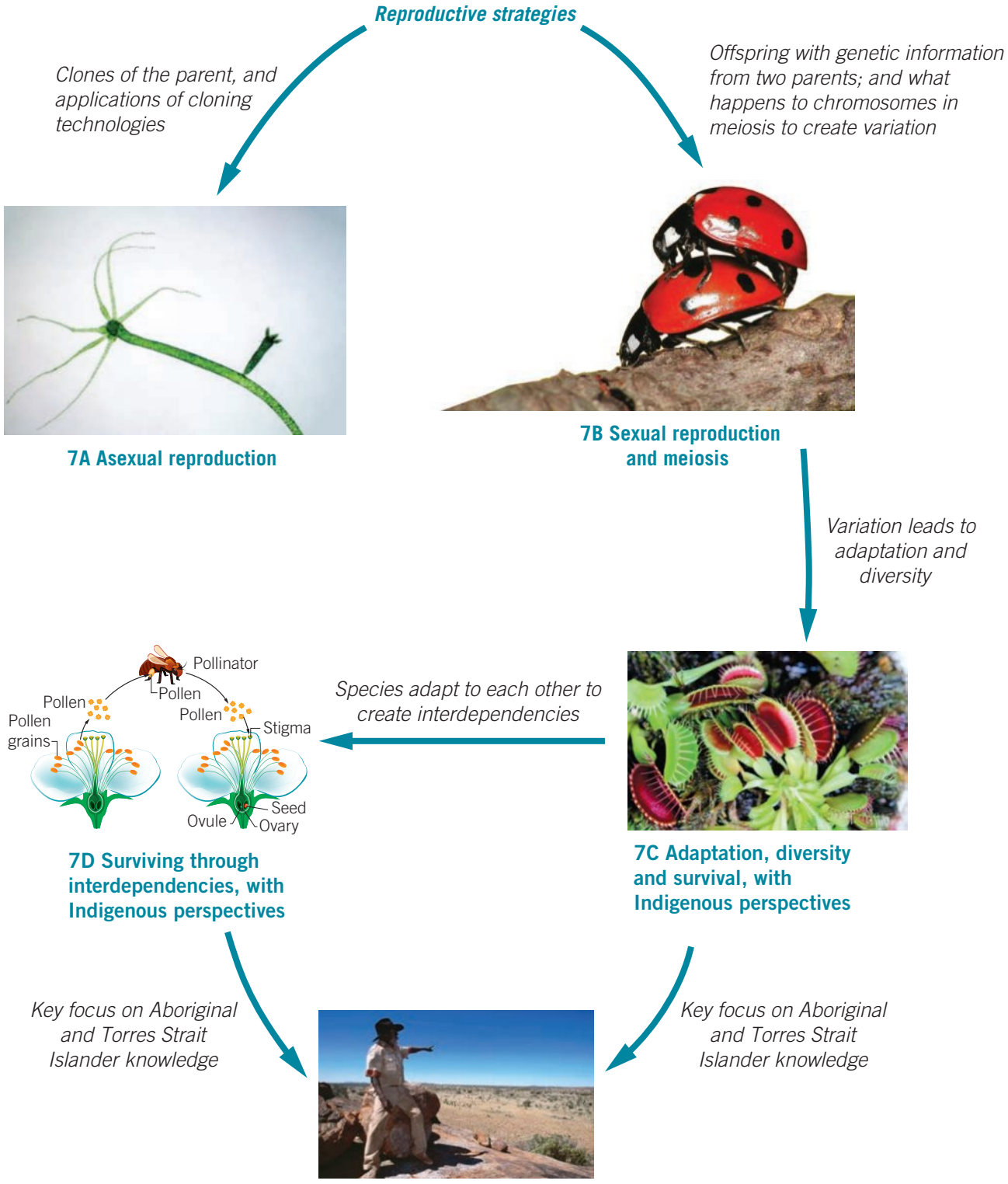


## Glossary

Adaptation
Aneuploidy
Asexual reproduction
Autosomes
Budding
Centromere
Chiasma
Chromatid
Clone
Cloning
Commensalism
Community
Consumers
Crossing over
Decomposers
Detritivores
Diploid
Ecosystem
Embryo splitting
Enucleation
Fertilisation
Fission
Food chain
Food web
Fragmentation
Gamete
Gonads
Haploid
Homologous chromosomes
Independent assortment
Indigenous
Karyotype
Keystone species
Meiosis
Micropropagation
Mutualism
Non-disjunction
Nuclear transfer
Parasitism
Parthenogenesis
Phototropism
Population
Producers
Sex chromosomes
Sexual reproduction
Somatic cell
Species
Spores
Synapsis
Trisomy
Variation
Vegetative propagation
Zygote

ISBN 978-1-108-88711-3

## Concept map




*See the Interactive Textbook for an interactive version of this concept map interlinked with all concept maps for the course, and for a quiz of prior knowledge from Years 9 & 10 science.*

ISBN 978-1-108-88711-3


# Asexual reproduction

**Study Design:**

- Biological advantages and disadvantages of asexual reproduction
- The process and application of reproductive cloning technologies

**Glossary:**

Asexual reproduction
Budding
Clone
Cloning
Embryo splitting
Enucleation
Fission
Fragmentation
Micropropagation
Nuclear transfer
Parthenogenesis
Somatic cell
Spores
Vegetative propagation

## ENGAGE

### It's all about asexual reproduction

Do you ever wonder why everything in your fruit bowl gets mouldy as soon as one item is mouldy? Or why the crown-of-thorns sea star is so difficult to control? These questions can be answered by understanding how such organisms reproduce.

**Asexual reproduction** a type of reproduction in which only one parent is required to produce offspring, which are genetically identical to the parent

**Clone** an organism or a cell that is identical to another organism or cell

**Figure 7A–1** Mould and the crown-of-thorns sea star reproduce asexually.

## EXPLAIN

### Defining asexual reproduction

**Asexual reproduction** is the production of offspring from a single parent. Offspring produced in this way are genetically identical to that parent, as they receive all the parent's genetic information. These offspring can be called **clones** of the parent.

As only one parent is needed to produce the offspring, special types of cell division are required. Prokaryotes that reproduce asexually use binary fission to create more cells, while eukaryotes that reproduce asexually use mitosis. You may recall that these processes were covered in detail in Section 3B.

**3B** THE CELL CYCLE LINK

**VIDEO 7A–1** ASEXUAL REPRODUCTION

Asexual reproduction generally occurs more often in primitive organisms; however, it can occur in both prokaryotes and eukaryotes, unicellular and multicellular organisms, fungi, plants and animals.

ISBN 978-1-108-88711-3

## Types of naturally occurring asexual reproduction

There are many types of asexual reproduction, and the method used varies between species.

**Fission**
a type of naturally occurring asexual reproduction in which the parent cell splits, forming two genetically identical cells

LINK 1C CELL TYPES
3B THE CELL CYCLE

### Fission

Some organisms that reproduce by **fission** are:

- unicellular prokaryotes, such as bacteria
- unicellular eukaryotes, such as the protozoans *Amoeba* and *Euglena*, single-celled algae, some sea anemones and some coral polyps.

Recall from Section 3B that prokaryotes produce new cells by binary fission, while eukaryotes produce new cells by mitosis. Binary fission and mitosis are both examples of fission. In fission, the parent cell splits into two, producing two genetically identical cells, called daughter cells.

- *Bacteria* are prokaryotes – they have a single circular chromosome and no membrane-bound organelles. During fission, the DNA attaches to the cell membrane and replicates. The cell then elongates, pinches into two and forms two genetically identical cells.
- *Eukaryotes*, such as protozoa, have a membrane-bound nucleus and so the process of fission takes longer and is more complex than in bacteria. After DNA replication and mitosis, the cytoplasm divides by cytokinesis, and this gives the cell time to grow before it can form two daughter cells again.

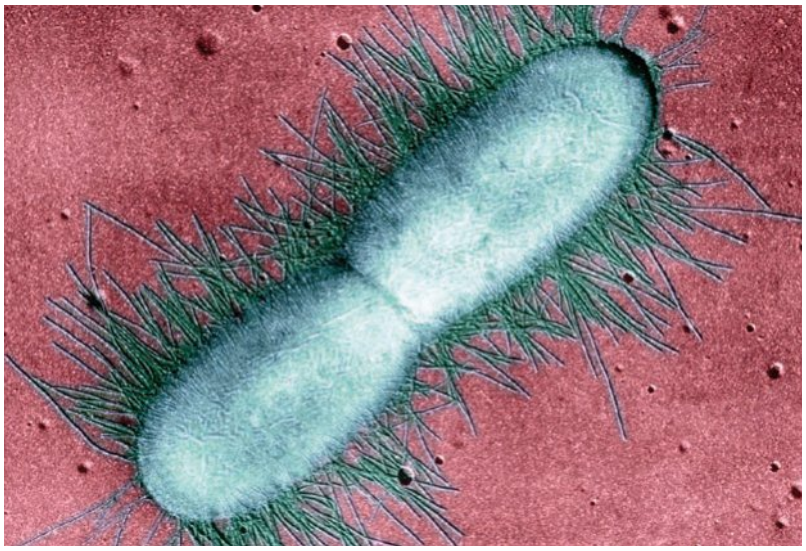


**Figure 7A–2** An *Escherichia coli (E. coli)* bacterium in the early stages of binary fission

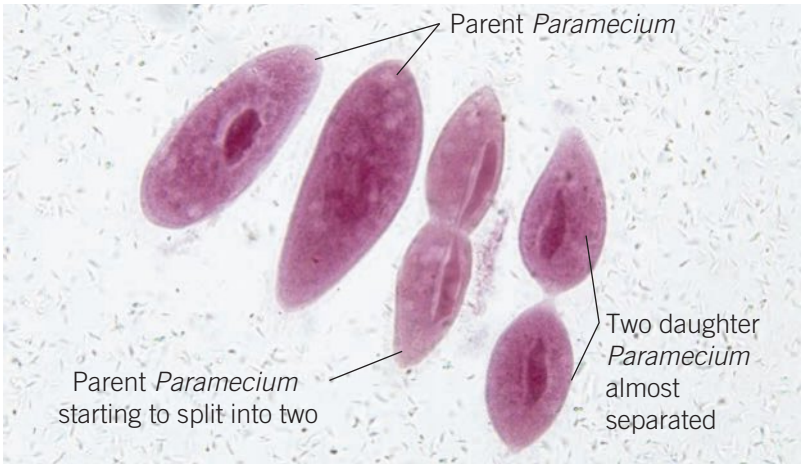



**Figure 7A–3** The protozoan *Paramecium* undergoing fission

### Fragmentation

**Fragmentation** occurs in multicellular organisms, including:

- many plants (called *vegetative propagation*)
- some animals, such as coral, sponges, echinoderms (sea stars, sea urchins), annelids (segmented worms) and flat worms.

Fragmentation is similar to fission in that the parent cell/organism splits (see Figure 7A–4 on the following page). However, fragmentation occurs only in multicellular organisms, and the daughter cells/organisms are not necessarily all the same size. When a parent cell/organism breaks into two or more fragments, each fragment regenerates the missing section and two or more daughter cells/organisms are formed. This may happen naturally, as is the case with sponges and

**Fragmentation**
a type of naturally occurring asexual reproduction in which the parent breaks into two or more fragments and each fragment then regenerates to form a new daughter organism

ISBN 978-1-108-88711-3

coral, or it may occur due to some form of damage from predators, the environment or human impact. In the case of the crown-of-thorns sea star, *Acanthaster planci*, known for destroying the coral of the Great Barrier Reef, cutting up the sea star into pieces was one of the first methods used to try to control it. Unfortunately, it is now believed that the sea star was able to regenerate from the fragments created and its numbers therefore increased rapidly, and the destruction of the reef continued.

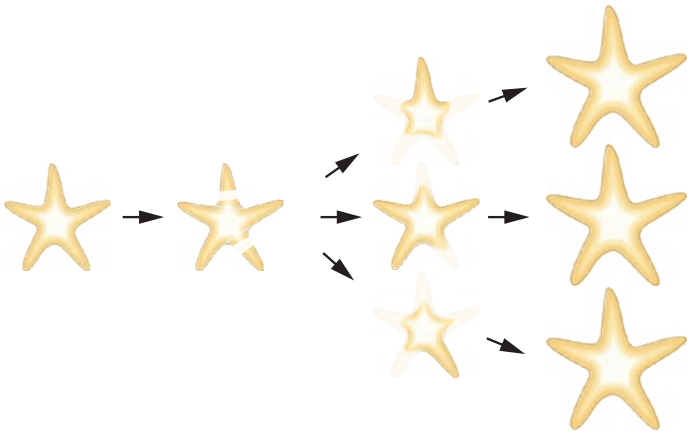


**Figure 7A–4** An example of fragmentation can be seen in sea stars: the parent sea star breaks into two or more fragments and each fragment then regenerates to form new daughter sea stars.

## Budding

**Budding**
a type of naturally occurring asexual reproduction in which a small outgrowth (bud) develops on the surface of the parent organism and eventually detaches, forming a new organism

**Budding** occurs in:

- unicellular organisms (yeast cells)
- some invertebrate multicellular organisms (*Hydra*, sponges, marine anemones, coral polyps, some flatworms, and several species of annelids).

In budding, a small outgrowth (bud) develops on the surface of the parent organism. Eventually, the bud grows into a daughter organism that separates from the parent, resulting in the formation of offspring, as shown in Figure 7A–5. In some cases, such as coral, the bud does not separate but continues to multiply.

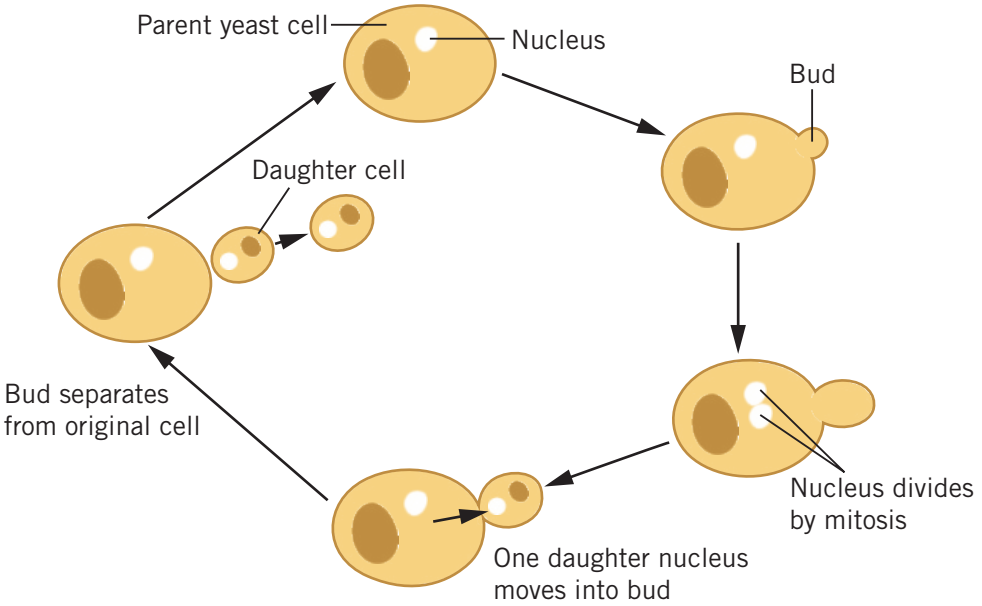



**Figure 7A–5** Yeast reproduce asexually by budding: a small bud on the surface of the parent yeast cell grows, and eventually detaches and becomes a separate organism.

ISBN 978-1-108-88711-3

## Parthenogenesis

**Parthenogenesis** occurs in:

- many invertebrate species (some ants, water fleas, stick insects, bees, aphids and termites)
- some vertebrates, such as fish, amphibians and reptiles.

During parthenogenesis, also known as 'virgin birth' (*parthenos* = virgin; *genesis* = birth), offspring are produced from unfertilised eggs. The females of the species produce egg cells that have a full complement of genetic information. Therefore, each daughter organism is genetically identical to its female parent.

**Figure 7A–6** Aphids are horticultural and agricultural insect pests in Australia and globally, adapted to suck sap from tender shoots and flowers. Parthenogenesis enables them to rapidly infest a crop shortly after germination or budding, or when plant growth restarts in spring or after rain.

## Spore formation

**Spores** are produced by:

- fungi (including moulds)
- some protists, prokaryotes, algae, ferns and mosses.

Spore formation can be asexual, involving mitosis, or sexual. In the case of bread mould, spores are formed by cell division at the tips of the reproductive hyphae. The spores are produced in large numbers and are stored in a structure called a *sporangium*. When the sporangium wall disintegrates, the spores are released and, when conditions are favourable, they germinate and form new mould organisms. This is why mould is able to spread very quickly.

**Parthenogenesis** a type of naturally occurring asexual reproduction in which offspring are produced from the unfertilised egg of a female parent

**Spores** small, lightweight capsules produced in large numbers by asexual reproduction; easily dispersed and can withstand tough environmental conditions

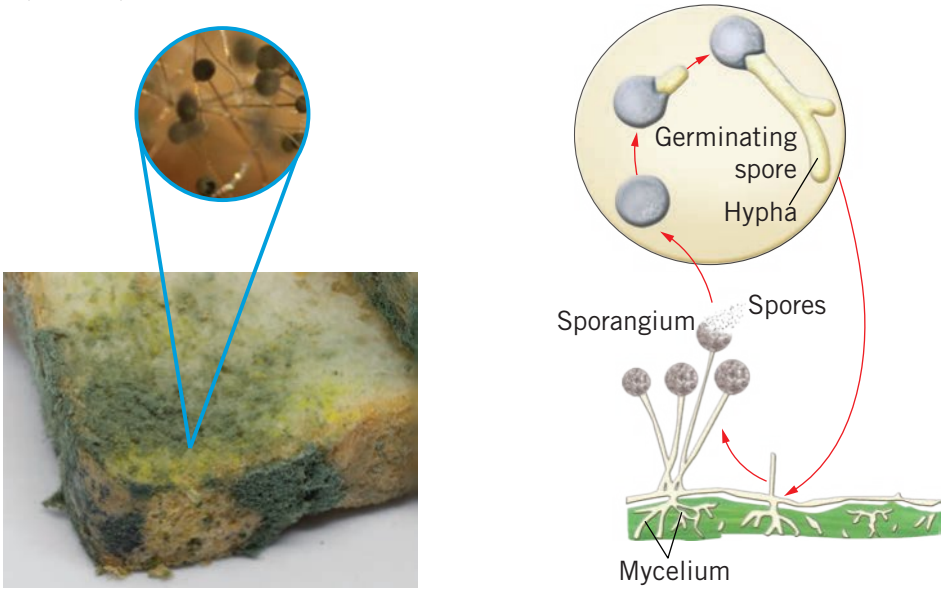



**Figure 7A–7** Spore formation: The asexual reproduction of bread mould. Left: Mould is shown growing on bread, and the inset microscope view shows hyphae and sporangia. Right: Diagram showing the asexual spore cycle: sporangia grow from the hyphae (mycelium) and release spores, which germinate to form a new mycelium to complete the cycle.

## Check-in questions – Set 1

1 Define 'asexual reproduction'.
2 Explain the relationship between asexual reproduction and the term clones.
3 Complete these sentences.
   a Prokaryotes use _____ as their means of cell division.
   b Eukaryotes use _____ as their means of cell division.
4 Coral can reproduce asexually by *budding* or by *fragmentation*. Summarise what these two terms mean.

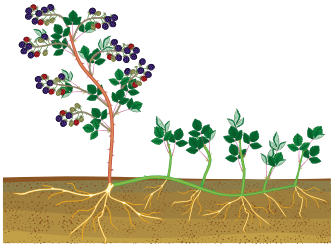
ISBN 978-1-108-88711-3

## Vegetative propagation

**Vegetative propagation** another name for asexual reproduction in plants; can occur both naturally and artificially; also called vegetative reproduction

Asexual reproduction in plants is called **vegetative propagation** and can take a number of forms. Keep in mind that most plants can also reproduce sexually. Examples of different types of naturally occurring vegetative propagation are given in Table 7A–1.

**Table 7A–1** Types of vegetative propagation

| Type | Description |
|---|---|
| Tuber  | A tuber is a swollen underground stem that can give rise to new daughter plants that arise from buds. The point where the bud germinates from the tuber is called the 'eye' of the tuber. The tuber itself is then used as a food supply during the growth of the new plant.<br>Example: potatoes |
| Rhizome  | A rhizome is a horizontal underground stem from which new buds shoot up through the surface of the soil and produce new daughter plants.<br>Examples: bamboo, ginger |
| Stolon  | Also known as runners, stolons are horizontal above-ground stems that grow out of the parent plant. At various intervals, the runners give rise to plantlets with roots that can become a whole new plant. Once the new plants are established, the runners die.<br>Example: strawberries |
| Plantlet  | As well as growing from stolons, young plants (known as plantlets) can grow from a leaf surface and then drop to the ground. If they land on fertile ground, they will grow into new plants.<br>Examples: piggyback plant, mother of thousands |
| Bulb  | A bulb is a short underground stem surrounded by many closely packed, fleshy leaves, called scales (food storage). Each bulb grows into a new plant.<br>Examples: daffodils, tulips, onions |
| Sucker  | A sucker, also called a root sprout, is a new shoot that arises from a bud on the underground root of the parent plant, which extends some distance from the parent plant.<br>Example: blackberries |

ISBN 978-1-108-88711-3

## Advantages and disadvantages of naturally occurring asexual reproduction

### *Advantages*

- Requires only one parent
  - No need for gametes (sex cells)
  - No need for fertilisation (fusion of gametes)
  - No need to find a mate
- Daughter cells/organisms are genetically identical to parent (clones)
  - Genetic traits that are best suited to that particular environment are passed on providing an advantage in a stable environment
- Efficient form of reproduction
  - Occurs at a rapid pace
  - Can colonise a new habitat quickly
  - Less energy is required
  - No need for parental care of a baby/juvenile
- Reliable form of reproduction
  - Large chance that most offspring will survive in a stable environment
  - The process is simple, so there is less chance for errors

LINK UNIT 4

### *Disadvantages*

- No (or lack of) genetic variation in the offspring
  - The species may only be well suited to one environment
  - Evolution cannot occur without variation
  - Genetic traits that may not be favourable to survival are also passed on
  - Changes to the environment, including selection pressures or disease, could wipe out the whole population
- Rapid population growth
  - Leads to overcrowding
  - Over competition for resources (light, food, space)

## Check-in questions – Set 2

WORKSHEET 7A–1 NATURALLY OCCURRING ASEXUAL REPRODUCTION

1 Define 'vegetative propagation'.
2 Complete each sentence.
  a Another name for underground stems is _____ .
  b Another name for stolons is _____ .
  c A type of plant that reproduces using runners is _____ .
  d A type of plant that reproduces using tubers is _____ .
3 Outline why an organism might carry out asexual reproduction.

ISBN 978-1-108-88711-3

## Types of artificial asexual reproduction

### Defining artificial cloning

**Cloning** the process of creating genetically identical organisms or clones; can occur naturally or artificially

You know that asexual reproduction results in offspring that are genetically identical to their parents – they are clones of the parents. The process of making clones by asexual reproduction can also occur artificially – in fact, artificial cloning has been carried out by humans for hundreds of years. Artificial **cloning** means that humans take control of the reproductive process so they can select the specific genetic information that is desired in the offspring. The cloning of organisms artificially can involve the use of reproductive cloning technologies.

**9A** GENETIC AND REPRODUCTIVE TECHNOLOGIES LINK

### Reproductive cloning technologies in plants

#### *Cuttings*

When a cutting is taken from the stem, root or leaf of a plant, a new organism identical to the parent plant can be produced. Each cutting will develop its own roots and grow into a whole new plant. However, new varieties of plants cannot be created in this way. Taking cuttings is a common method used by gardeners to create new plants, as it is much faster than growing plants from seeds. (You will learn more about this in Section 7B.)

**7B** SEXUAL REPRODUCTION AND MEIOSIS LINK

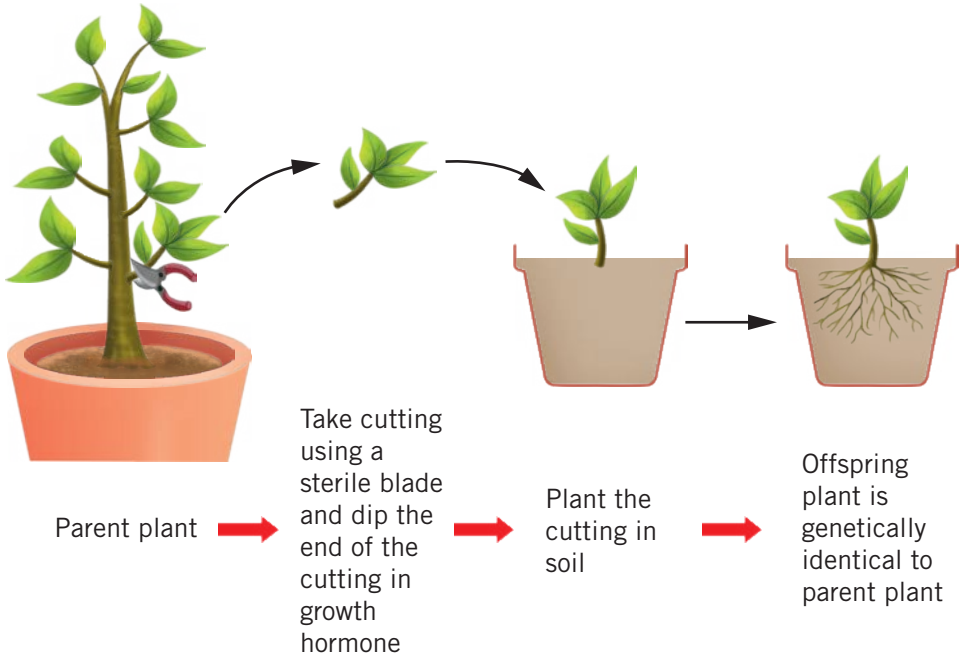



**Figure 7A–8** Many types of plants, including woody and herbaceous plants, can be propagated by cuttings, a form of artificial asexual reproduction.

**Grafting** a type of artificial asexual reproduction in which the stem tissue of one plant is joined to the root tissue of another plant so they grow together as one plant

#### *Grafting*

**Grafting** is a type of artificial asexual reproduction in which the stem of one plant (known as a *scion*) is attached to the root of another plant (known as the *stock*) in order for a new organism, identical to the scion, to be grown. For grafting to be successful, four conditions must be met:

- The scion and stock must be compatible.
- Both scion and stock must be at the right stage of development.

ISBN 978-1-108-88711-3

- Certain layers (xylem and phloem of the vascular tissue) of the scion and stock must be in contact.
- The graft union must be kept moist until the wound has healed.

LINK 4E PLANT SYSTEMS

The benefit of grafting is that both a strong root stock and a stem with all the desired characteristics can be selected for maximum chance of survival and yield. This process is very important in the horticulture industry, especially for growing citrus fruits and grape vines, as a disease-resistant rootstock is matched with a scion that produces more fruit but would normally be susceptible to root diseases and/or pests.

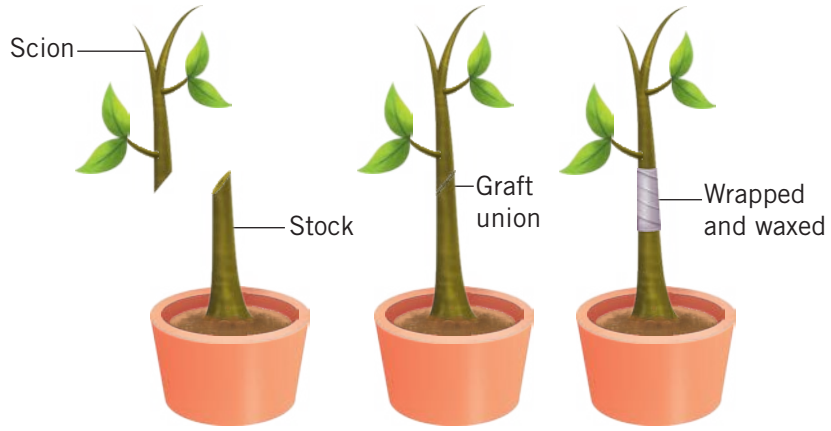



**Figure 7A–9** Grafting is a form of artificial asexual reproduction and involves the steps shown in this illustration. It is commonly used with fruit trees.

**Micropropagation** a type of artificial asexual reproduction in which large numbers of identical plants are produced rapidly by tissue culture techniques; occurs under controlled conditions

### *Tissue culture*

When large numbers of plants need to be produced rapidly, a technique known as tissue culturing, or **micropropagation**, is used. Tissue or cells taken from the parent plant are placed in a special growing medium (containing nutrients, water and growth hormones) and in certain conditions (specific temperature, humidity and so on). Over a short period of time, thousands of new plants, genetically identical to the parent plant, can be produced.

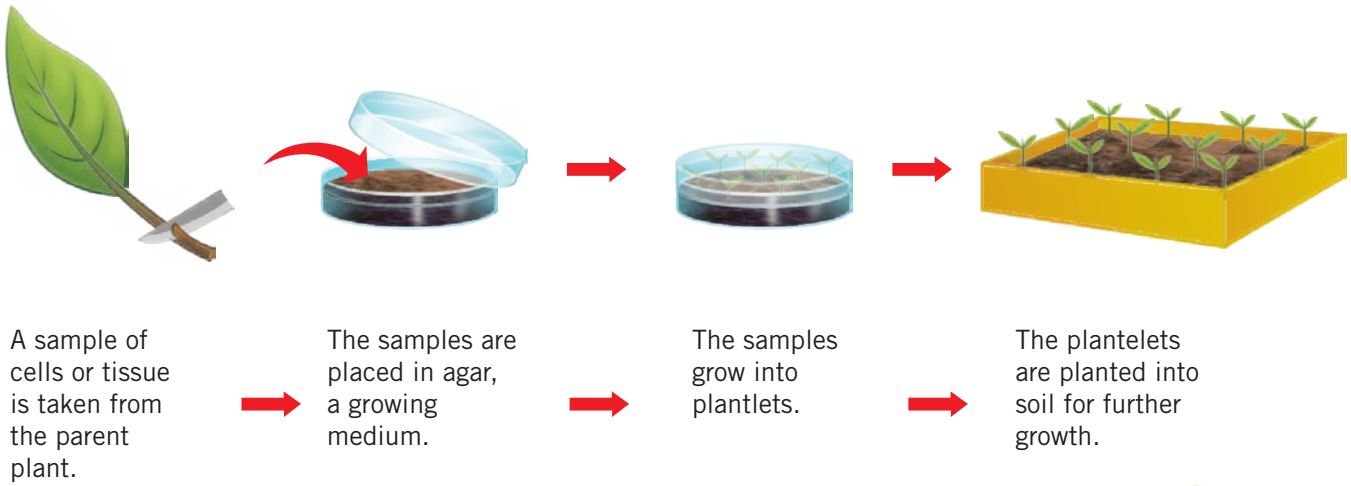



**Figure 7A–10** Tissue culture, or micropropagation, is often used to increase the populations of plants that are rare or difficult to breed, such as orchids.

ISBN 978-1-108-88711-3

**Embryo splitting** a type of artificial asexual reproduction in which offspring that are genetically identical to each other are produced by splitting the cells of an embryo early in development and implanting the cells in surrogate mothers to develop as normal

7B SEXUAL REPRODUCTION AND MEIOSIS LINK

## Reproductive cloning technologies in animals

### *Embryo splitting*

**Embryo splitting** is a process in which embryo cells (produced artificially by the fusion of a sperm nucleus and an egg nucleus) are separated. The cells are then implanted into the uterus of a surrogate mother. All the resulting offspring are genetically identical to each other, much like naturally occurring twins. The offspring are not genetically identical to their parents.

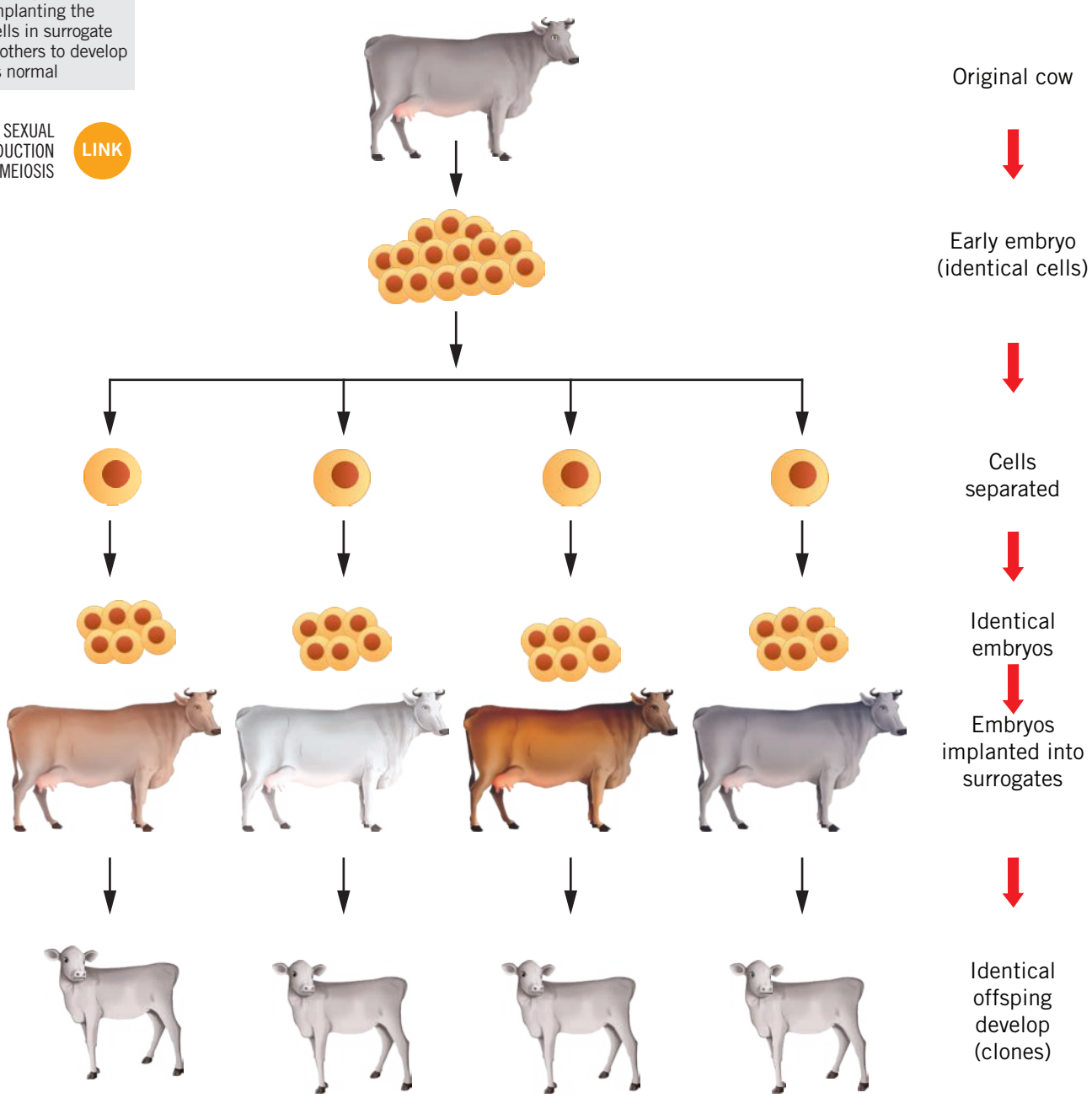



**Figure 7A–11** Mammalian embryo splitting has been used for some time for the efficient and safe reproduction of livestock.

ISBN 978-1-108-88711-3

### *Nuclear transfer*

**Nuclear transfer** is a cloning method in which offspring are produced using adult cells. The technique involves removing the nuclear DNA from a **somatic cell** of a donor (organism A) and placing the DNA in an egg cell from a different donor (organism B) that has had its nucleus removed (**enucleation**). An electric pulse is then delivered to encourage fusion of the nuclear DNA with the empty egg cell and to stimulate the egg to divide. The developing embryo is implanted into the uterus of a surrogate mother (organism C). The offspring is genetically identical to the donor of the somatic cell nucleus (organism A).

**Nuclear transfer** a type of artificial asexual reproduction in which an adult cell nucleus is fused with an egg cell that has had its nucleus removed; the resulting cell is placed in a surrogate mother to develop as normal

**Somatic cell** a body cell containing a full complement of genetic information (diploid)

**Enucleation** the process by which a cell has its nucleus removed

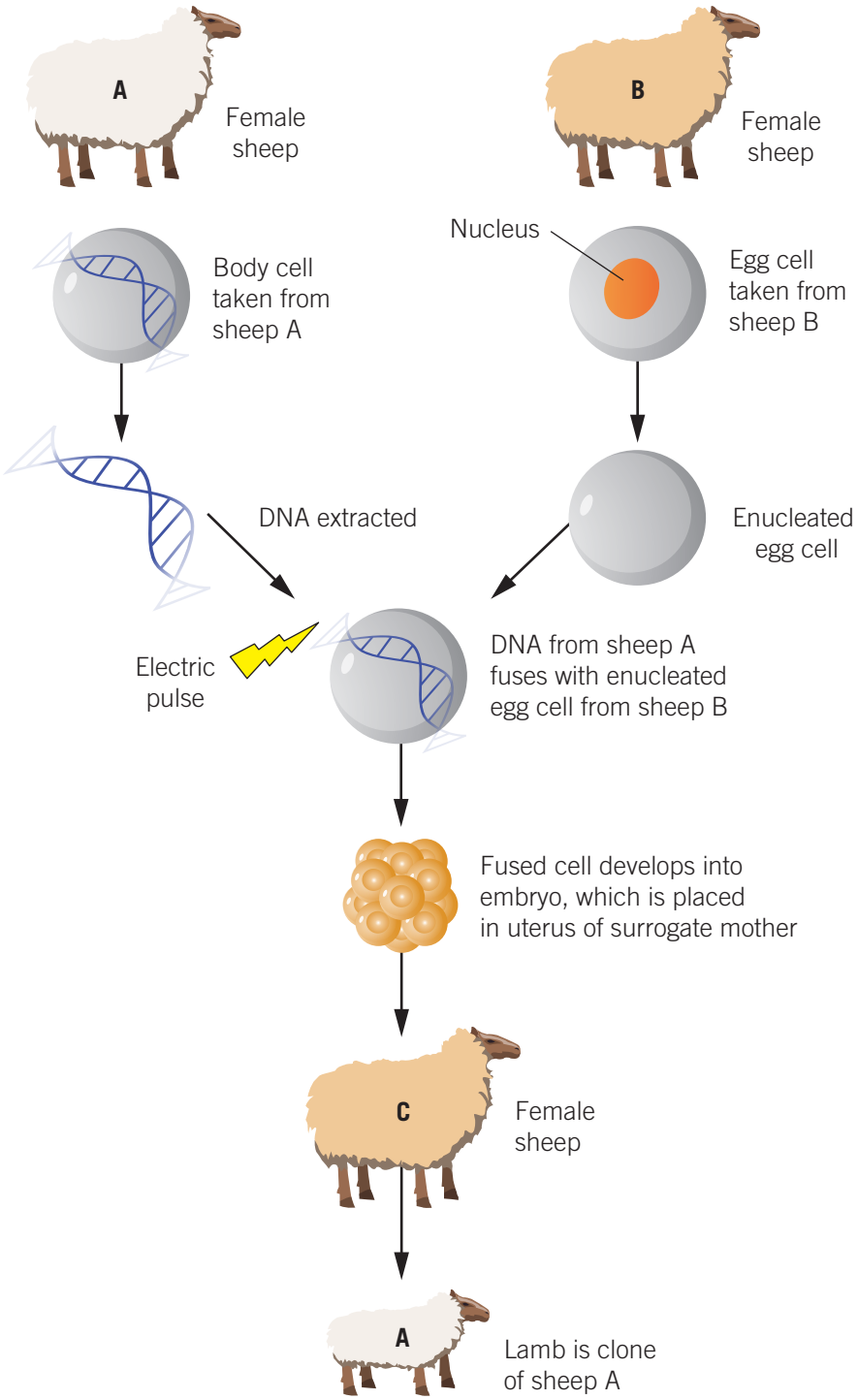



**Figure 7A–12** Nuclear transfer is an artificial cloning method used in regenerative medicine and embryonic stem cell research.

ISBN 978-1-108-88711-3

## Applications and issues of artificial asexual reproduction

### *Applications*

- Because there is greater control of the reproductive process and selection of the genetic information that is desired in the offspring, healthy and productive offspring can be produced quickly and in larger numbers.
- There is also the potential to:
  - ► replenish populations of endangered animals and restore extinct species
  - ► make stem cells
  - ► minimise the impact of the environment, by producing offspring that do not rely on particular seasons
  - ► enable scientists to clone organisms that are useful in medicine and agriculture, such as animals with a high milk production
  - ► directly provide resources for humans (medications, drug testing, clinical trials); for example, cloned animals used in drug testing will have more consistent responses than animals that are genetically different.

**3A** WHERE DO NEW CELLS COME FROM? LINK

**6A** INVESTIGATIVE DESIGN LINK

### *Issues*

- There is no genetic variation in the offspring.
  - ► The species may only be well suited to one environment.
  - ► Changes to the environment, including disease, could wipe out the whole population.
- The process is labour intensive.
- The process is extremely expensive.
- There is a high failure rate.
- Organisms often have adverse health effects, including possible premature ageing and defects in their vital organs.

**UNIT 4** LINK

**WORKSHEET 7A–2** ASEXUAL REPRODUCTION – CLONING

## Check-in questions – Set 3

1 Define ‘artificial cloning’.
2 Name two ways to artificially produce clones of plants.
3 The two reproductive technologies used in animals differ depending on the cells being used. Which technique uses which type of cell?

ISBN 978-1-108-88711-3

## 7A SKILLS

VIDEO 7A–2
SKILLS: MAKING CONNECTIONS

### Making connections

As you are using this book, you will have noticed that there are links to other chapters and sections. These links are there to help you make connections between ideas and concepts. By making these links, you are giving the information more meaning, and this increases the chance that the information will be retained in your long-term memory.

For example, in Section 1C, you learned about the structure of prokaryotic cells. Your understanding of these cells was further extended when, in Section 3B and the start of Section 7A, you learned how prokaryotic cells reproduce. Knowing about the structure and function of the components of prokaryotic cells makes it easier to learn how they reproduce. The asexual reproduction of bacteria, or binary fission, is a quick process because of the simplicity of the bacterial cell structure. This is why your teachers recommend using mind maps and concept maps as a revision tool, so you can visually link a large amount of information and this can help you learn. This is also why you will find a concept map at the beginning of each chapter (except Chapter 6) – the map ties the contents of the chapter together.

*Try this*: Using the following list of terms from this section, draw a mind map showing the links between the terms. On each link, write the connection between the words.

> asexual reproduction, binary fission, fission, mitosis, fragmentation, cloning, embryo splitting, spores, nuclear transfer, vegetative propagation, cuttings, micropropagation, tissue culture, genetically identical, parthenogenesis, budding, tubers, stolons, bulbs, runners

You may like to include definitions as well. An example has been done for you, in Figure 7A–13.

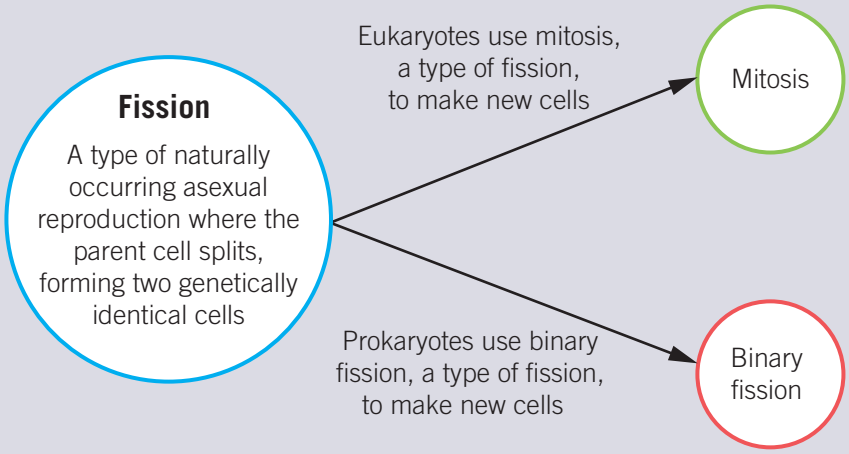



**Figure 7A–13** A mind map of fission in asexual reproduction. Mind maps allow you to link ideas so that they make more sense. Including definitions and connections between the terms creates a visual reminder of key content.

ISBN 978-1-108-88711-3

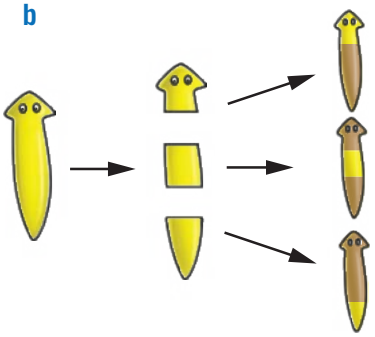
## Section 7A questions

1 a Define 'cloning'.
  b Explain what asexual reproduction is.
  c Name the different forms of naturally occurring asexual reproduction.
  d Name the different forms of artificial asexual reproduction.

2 Most simple organisms undergo asexual reproduction naturally. There are a variety of ways in which this can occur. Look at the following diagrams and explain the process shown in each case.

a

b



3 Classify and explain each of the following observations in nature.
  a Some species of whiptail lizards exist in populations that are all female.
  b The giant puffball mushroom bursts open and releases trillions of spores.
  c Dahlias look like bulbs but are in fact thickened underground stems.

4 a Outline why, for plants colonising a new area, it is beneficial to reproduce asexually.
  b Identify the disadvantages to the plant's survival by reproducing asexually.

5 Summarise how the advantages and disadvantages of artificial asexual reproduction are similar to those of naturally occurring asexual reproduction.

6 a What are naturally occurring human clones called?
  b Distinguish between the two methods used to artificially clone animals.
  c Give reasons why a livestock breeder may wish to use one of the two reproductive cloning technologies you listed for part **b**.

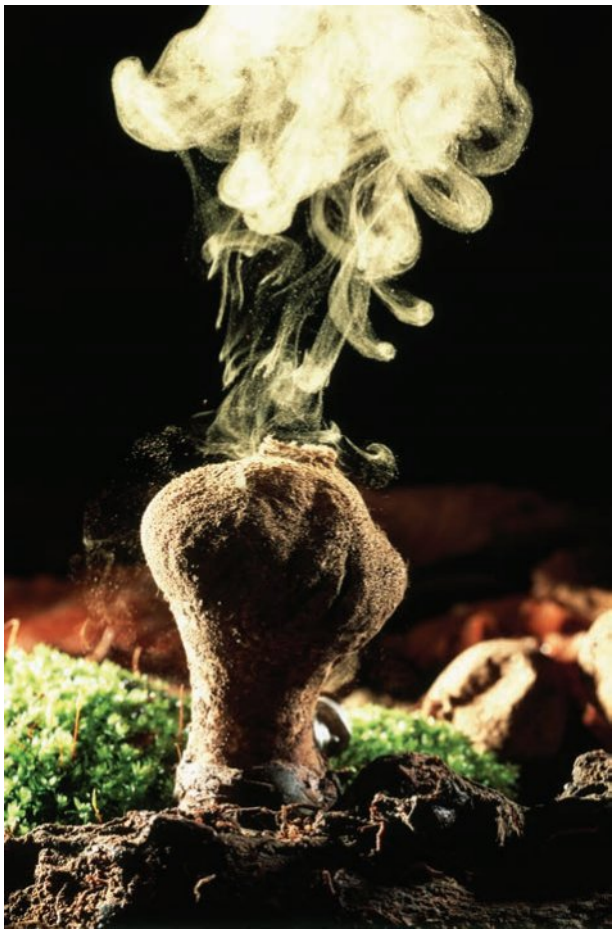


**Figure 7A–14** A puffball mushroom releasing spores

ISBN 978-1-108-88711-3


# Sexual reproduction and meiosis

**Study Design:**

- The nature of a pair of homologous chromosomes carrying the same gene loci and the distinction between autosomes and sex chromosomes
- Karyotypes as a visual representation that can be used to identify chromosome abnormalities
- The production of haploid gametes from diploid cells by meiosis, including the significance of crossing over of chromatids and independent assortment for genetic diversity
- Biological advantages of sexual reproduction in terms of genetic diversity of offspring

**Glossary:**

Aneuploidy
Autosomes
Centromere
Chiasma
Chromatid
Crossing over
Diploid
Fertilisation
Gamete
Gonads
Haploid
Homologous chromosomes
Independent assortment
Karyotype
Meiosis
Non-disjunction
Sex chromosomes
Sexual reproduction
Synapsis
Trisomy
Zygote

## ENGAGE

### The birds and the bees

In Section 7A, you saw how asexual reproduction is very efficient in terms of saving energy and time for an organism. The offspring produced are genetically identical to the parent, which makes sense if the parent species is able to successfully survive in a particular environment. So why would a species want to reproduce sexually? It is a significantly more complex process requiring a lot of energy and time. Sexual reproduction must offer some advantage that asexual reproduction cannot provide.

LINK 7A ASEXUAL REPRODUCTION

LINK UNIT 4

**Figure 7B–1** Birds reproduce sexually and often have elaborate rituals to attract a mate. Left to right: pied oystercatchers, rainbow lorikeets, a peacock.

ISBN 978-1-108-88711-3

## EXPLAIN

# Defining sexual reproduction

7A ASEXUAL REPRODUCTION LINK

VIDEO 7B–1 BIOLOGICAL ADVANTAGES OF SEXUAL REPRODUCTION

In Section 7A you saw how, in asexual reproduction, the production of offspring requires just one parent organism. Recall that offspring produced in this way are genetically identical to, or clones of, the parent organism. In this section, you will learn about **sexual reproduction**, which is a method of reproduction that relies on the fusion of the nuclei of two sex cells (e.g. egg and sperm) from two parents (typically male and female). The offspring have received genetic information from both parents, and so they are not genetically identical to either parent.

**Sexual reproduction** a type of reproduction in which two parent organisms contribute gametes, containing genetic material, to the offspring

## Revising reproductive structures

You may like to refer to the following images as you work through this section.

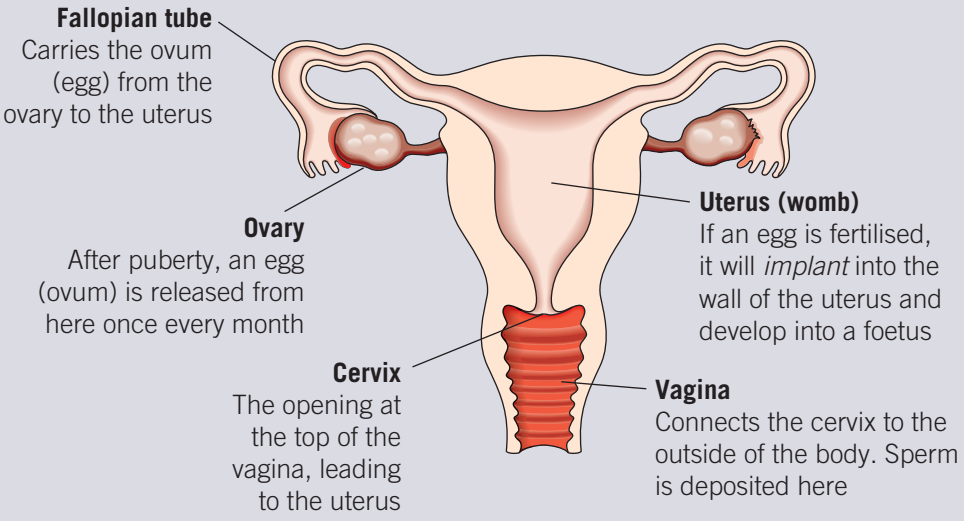



**Figure 7B–2** The female reproductive system

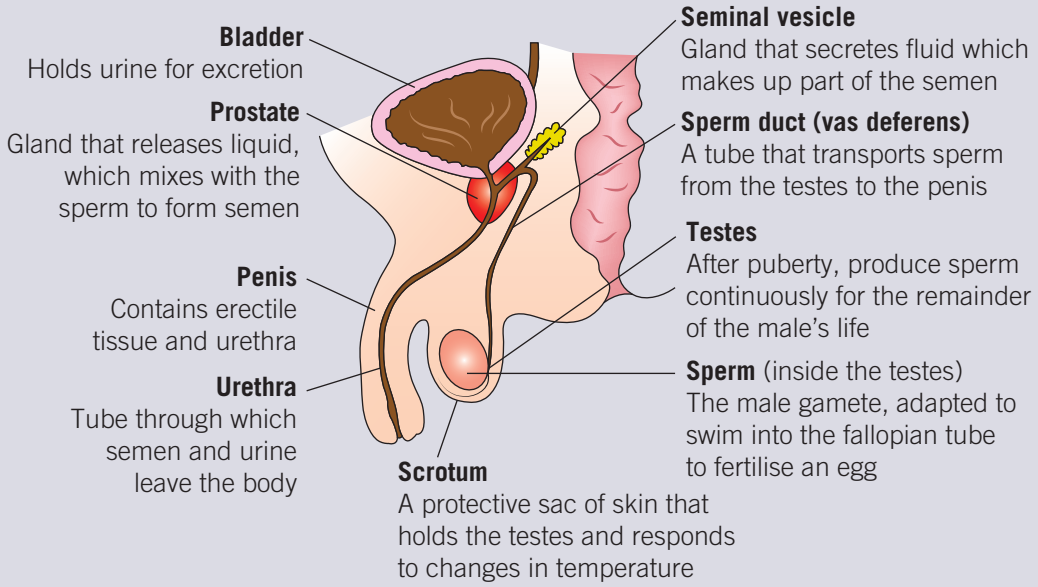



**Figure 7B–3** The male reproductive system

ISBN 978-1-108-88711-3

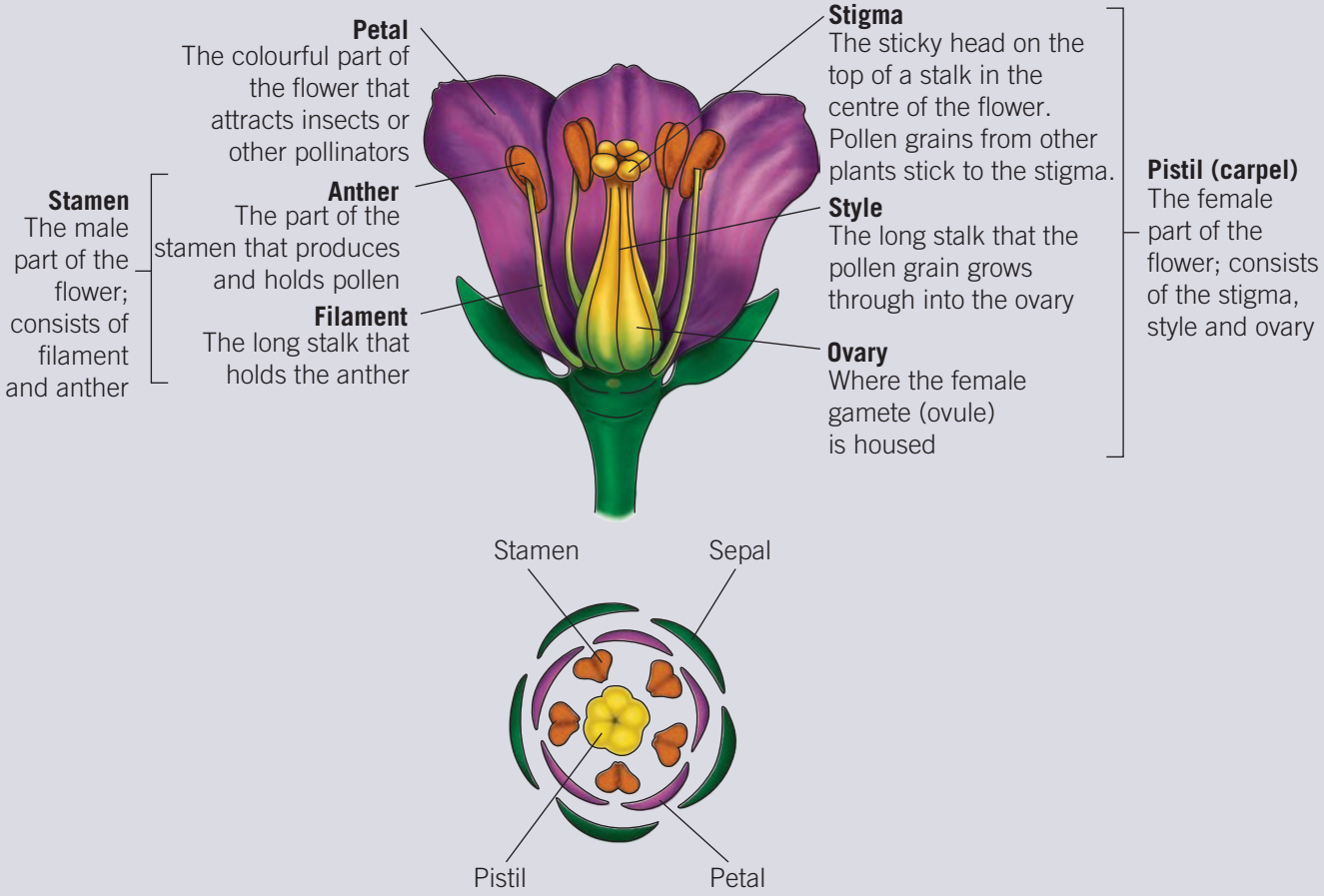



**Figure 7B–4** Top: Cross-section of a flower. Bottom: View of the flower from above

## Explaining sexual reproduction

Sexual reproduction requires two organisms of the same species, both contributing a sex cell, or **gamete**, that combine to produce a new unique offspring. You may already know that the gametes are produced in the **gonads**, or sex organs, of the male (the testes) and the female (the ovaries) by the process of **meiosis**. In animals, the male gamete is the sperm and the female gamete is the egg (ovum), while in plants the male gamete is the pollen and the female gamete is the ovum. Each gamete contains half the genetic information needed to form a new organism of the same species. In this way, when the two gametes meet, they fuse, in a process known as **fertilisation**, and form a **zygote**, which has the full set of genetic information, half from each parent. In Chapter 8, you will investigate how the genetic information inherited from each of the parents determines an organism's traits. As the zygote develops, it is creating new cells by the process of mitosis (see Chapter 3) and in this way it grows. Eventually its cells take on specialised functions and form the embryo of the organism.

**Gamete**
a haploid cell, or sex cell, involved in the creation of unique offspring in sexual reproduction; in humans, the male gamete is a sperm and the female gamete is an egg (ovum); in plants, the male gamete is a pollen grain and the female gamete is an ovum

**Gonads**
the sex organs responsible for carrying out meiosis and producing gametes; the testes in males and the ovaries in females

**Meiosis**
the process by which gonads produce haploid gametes, or sex cells, for sexual reproduction

LINK 8B INTRODUCTION TO GENETICS
3B THE CELL CYCLE

**Fertilisation**
the process by which the nucleus of an egg cell (or ovum) and the nucleus of a sperm cell fuse to form a zygote

**Zygote**
a diploid cell formed when the nuclei of an ovum and a sperm fuse during fertilisation

ISBN 978-1-108-88711-3

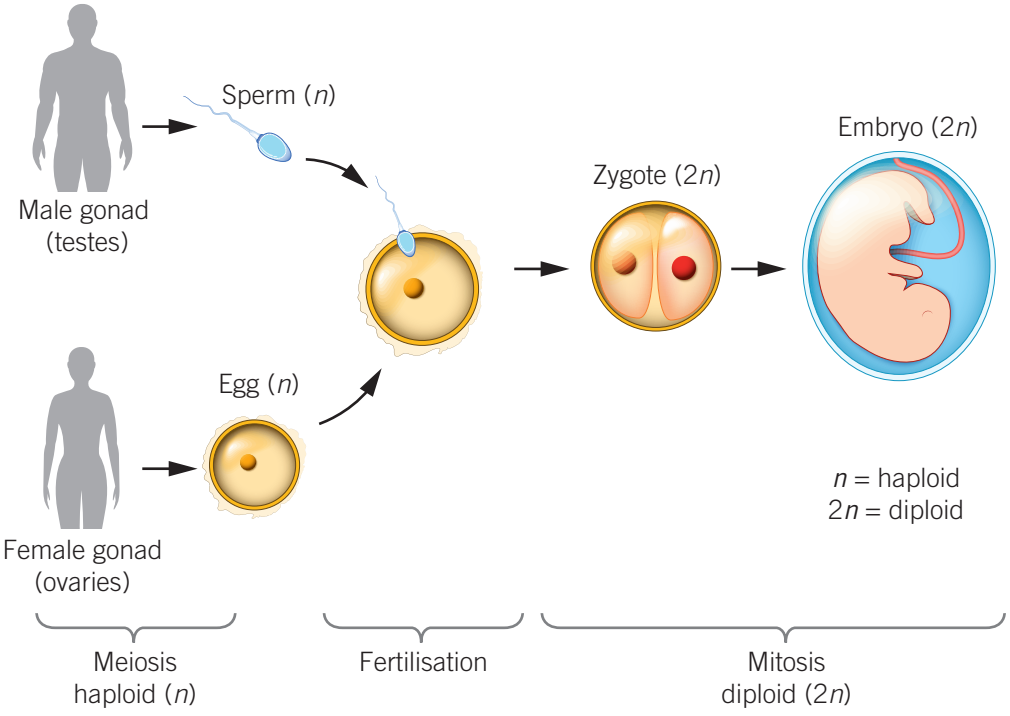



**Figure 7B–5** Sexual reproduction involves the contribution of genetic information from two parents via their gametes, which fuse during fertilisation to form a zygote.

**Haploid**
containing nuclei with only one set of chromosomes

**Diploid**
containing two complete sets of chromosomes, one set from the mother (maternal) and one set from the father (paternal); pairs of chromosomes are called homologous chromosomes

**Karyotype**
a pictorial representation of chromosomes in pairs, showing size, banding pattern, shape and number of chromosomes in an individual's somatic cell; allows for the determination of diploid number, gender and chromosomal abnormalities

**Autosomes**
chromosomes that do not determine sex; in humans, pairs 1 to 22

**Sex chromosomes**
a pair of chromosomes in a diploid cell that determine the biological gender of the offspring; in humans, pair 23 is the sex chromosomes: males have an X and a Y chromosome, while females have two X chromosomes

In Figure 7B–5, note the terms **haploid** ($n$) and **diploid** ($2n$). These terms describe the number of chromosomes in the respective cells. The letter $n$ is the symbol used to represent the number of chromosomes in one set of the organism's DNA. Notice that diploid has the symbol $2n$, which indicates that a diploid cell has twice as many chromosomes as a haploid ($n$) cell. For example, in humans, the amount of genetic information carried by the gametes, the haploid cell, is 23 single chromosomes. When the ovum and the sperm meet and fuse, the zygote formed contains 23 pairs of chromosomes, the diploid number. These numbers vary between species but are generally consistent for every individual within each species.

Geneticists use a **karyotype**, a pictorial representation of the chromosomes in the nucleus of an individual's somatic cell, to determine the diploid number of chromosomes. Figure 7B–6 shows a karyotype of a human female, where you can clearly see 23 pairs of chromosomes. Pairs 1 to 22 are called **autosomes** as they do not determine the sex of the offspring and are found in all human males and females. Pair 23, however, differs between males and females. This pair is called the **sex chromosomes** as they determine the biological gender of the offspring. Female offspring receive an X chromosome from both parents via the gametes, while male offspring receive one X chromosome from their mother and one Y chromosome from their father. The left section of Figure 7B–6 shows the image captured once the DNA in the nucleus of the cell being investigated has condensed and formed chromosomes.

ISBN 978-1-108-88711-3

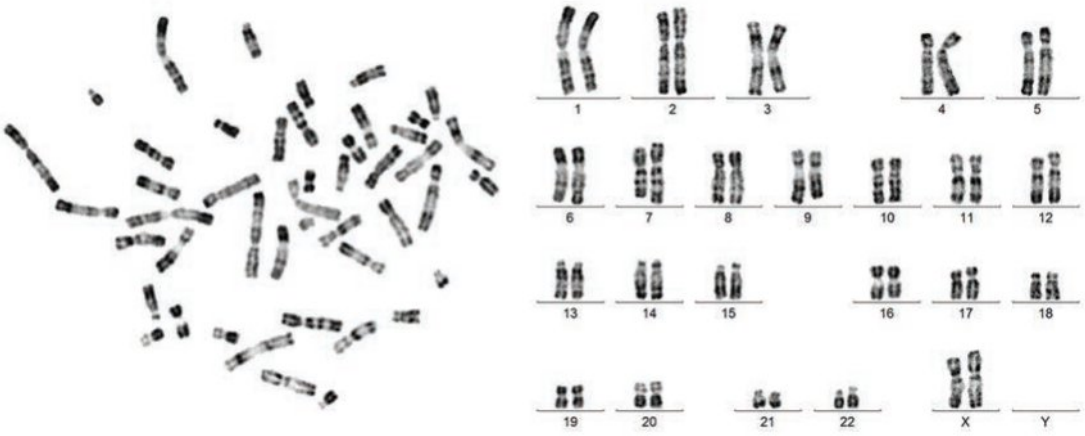



**Figure 7B–6** A karyotype of a human female, containing 22 pairs of autosomes and one pair of sex chromosomes (XX)

**Centromere** the structure in a chromosome where the two chromatids are held together; also the point of attachment of the kinetochore, which the spindle microtubules attach to

**Homologous chromosomes** chromosomes that have matching structural features (size, banding pattern, centromere location) and gene loci

When you look at the autosomes in Figure 7B–6 you can see they are organised in pairs that have the same structural features, such as size, banding pattern and **centromere** position. Chromosomes that match in this way are called **homologous chromosomes**. One copy has come from the female parent and one copy has come from the male parent, a consequence of the fusing of the male and female gametes in sexual reproduction. Homologous chromosomes also share gene loci, a concept that will be covered further in Chapter 8. As females have two copies of the X chromosome, their sex chromosomes are also considered to be homologous.

LINK 8A THE NATURE OF GENES

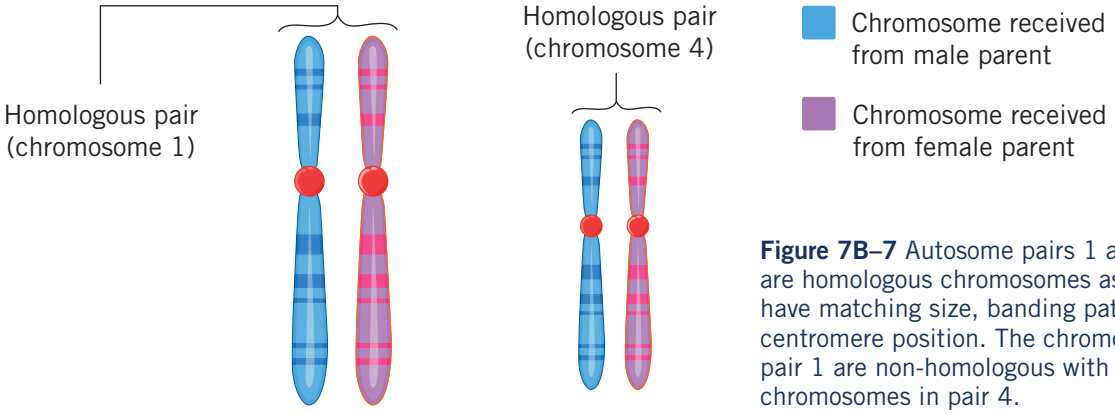



**Figure 7B–7** Autosome pairs 1 and 4. Pair 1 are homologous chromosomes as they have matching size, banding pattern and centromere position. The chromosomes in pair 1 are non-homologous with the chromosomes in pair 4.

## Advantages and disadvantages of sexual reproduction

### *Advantages*

- The offspring are not genetically identical to their parents or siblings.
  - ► Variation exists within the population.
  - ► A disease is less likely to affect all the individuals in a population as some are naturally resistant.
- Evolution can occur if the environment or conditions in the environment change and there is variation in the population, where some individuals are better adapted.

LINK UNIT 4

ISBN 978-1-108-88711-3

*Disadvantages*

- It takes more time and energy, due to:
  - production of gametes
  - the need for two parent organisms
  - the need to compete for a chance to mate
  - longer gestation periods
  - the need for parental care of the baby/juvenile.
- More can go wrong, as it is a complex process.

### Comparing asexual and sexual reproduction

**Table 7B–1** Comparing the characteristics of asexual and sexual reproduction

| Asexual reproduction | Sexual reproduction |
|---|---|
| One parent | Two parents |
| Offspring genetically identical to parent | Offspring not genetically identical to parent |
| No gametes | Gametes required |
| Time and energy efficient | Uses a lot of time and energy |
| No variation in the population | Variation in the population |
| Inherit genetic information from one parent | Inherit genetic information from both parents |
| No fertilisation | Fertilisation |

**WORKSHEET 7B–1** COMPARING ASEXUAL AND SEXUAL REPRODUCTION

## Check-in questions – Set 1

1 Define 'sexual reproduction'.
2 Distinguish between haploid and diploid in eukaryotic organisms.
3 Define the following terms: karyotype, autosome, sex chromosomes, homologous chromosomes.

**VIDEO 7B–2** MEIOSIS

## Meiosis

Meiosis is the process by which animals and plants produce gametes for sexual reproduction. This process occurs in the gonads of sexually reproducing organisms (in humans, the testes and ovaries). The process begins with a parent cell, which is diploid, and results in four 'daughter' cells (the gametes), which are haploid. Remember, the gametes must contain only half the chromosomes of a somatic cell, so that when fertilisation occurs, the resulting zygote has the full set of chromosomes or a diploid number of chromosomes.

**Chromatid** one of two strands of a double chromosome formed when a single chromosome is replicated early in to mitosis or meiosis; when two chromatids are joined at a centromere, they are called sister chromatids and are identical

In order to produce haploid gametes, meiosis involves two divisions of the nucleus, known as meiosis I and meiosis II.

- In meiosis I, the chromosomes in the homologous pair separate and are pulled to opposite poles of the cell.
- In meiosis II, the **chromatids** in the double chromosome are pulled apart, forming a single chromosome, and the haploid gametes are produced.

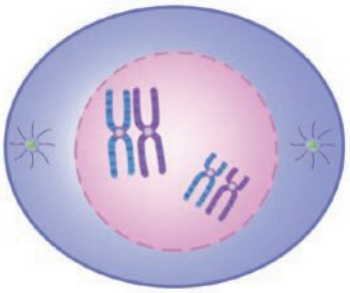
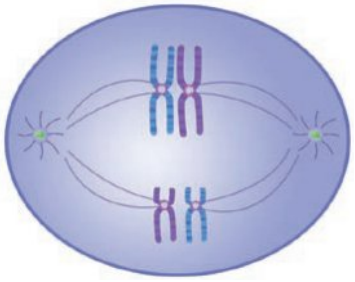
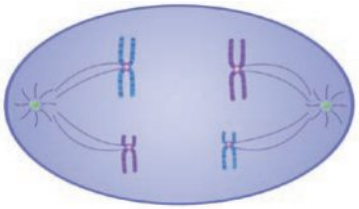
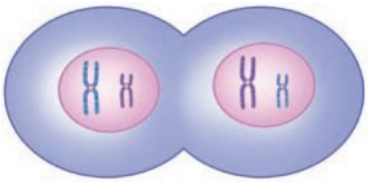
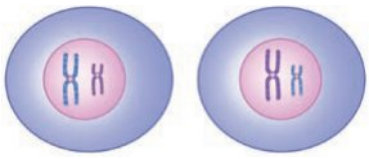
These steps are further subdivided into several stages: interphase, prophase, metaphase, anaphase, telophase and cytokinesis (not a stage of meiosis). The events that occur during these stages are very similar to mitosis, especially meiosis II, which you will see clarified in the following pages.

ISBN 978-1-108-88711-3

## The stages of meiosis

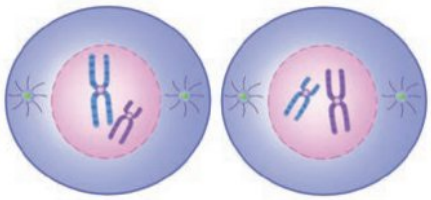
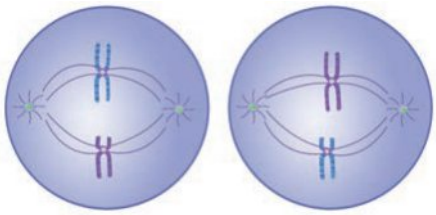
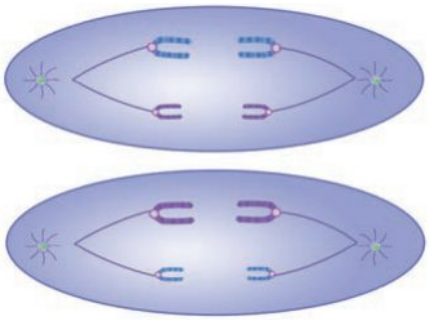
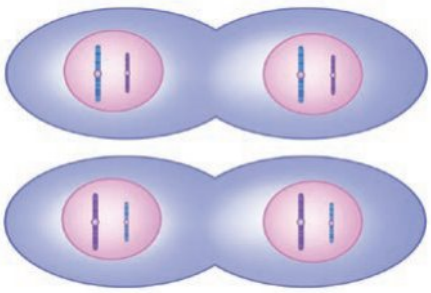
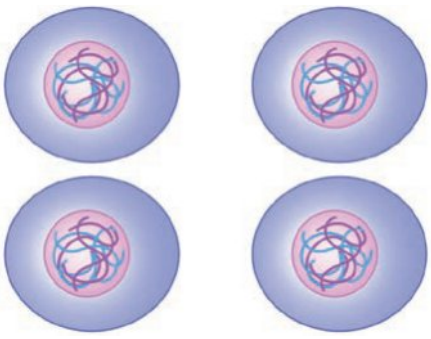
The stages of meiosis are summarised in Table 7B–2.

**Table 7B–2** Stages of meiosis

| Meiosis I | | |
|---|---|---|
| Prophase I<br>2*n* |  | • DNA winds up, chromosomes condense (two chromatids joined at a centromere)<br>• Spindle microtubules form<br>• Homologous chromosomes position themselves side by side (called *synapsis*)<br>• Nuclear membrane dissolves by the end of prophase I<br>• Crossing over may occur late in prophase I: chromosomes may become so close that there is an exchange of genetic material between them at the chiasmata (covered in greater detail on page 322) |
| Metaphase I |  | • Spindle microtubules attach to the centromere of homologous chromosomes and pull them into a line at the equator of the cell<br>• Independent assortment: the homologous chromosomes take random positions along the equator of the cell |
| Anaphase I |  | • Spindle microtubules split the homologous chromosomes into single chromosomes, which move to opposite poles of the cell<br>• The centromeres do not divide<br>• Independent assortment: the bivalents move randomly to either pole |
| Telophase I |  | • Spindle microtubules disappear<br>• The cell membrane pinches in and two separate nuclei form, with the nuclear membrane re-forming around each |
| Cytokinesis |  | • The cell cytoplasm divides, forming two haploid daughter cells |

ISBN 978-1-108-88711-3

**Table 7B–2** *Continued*

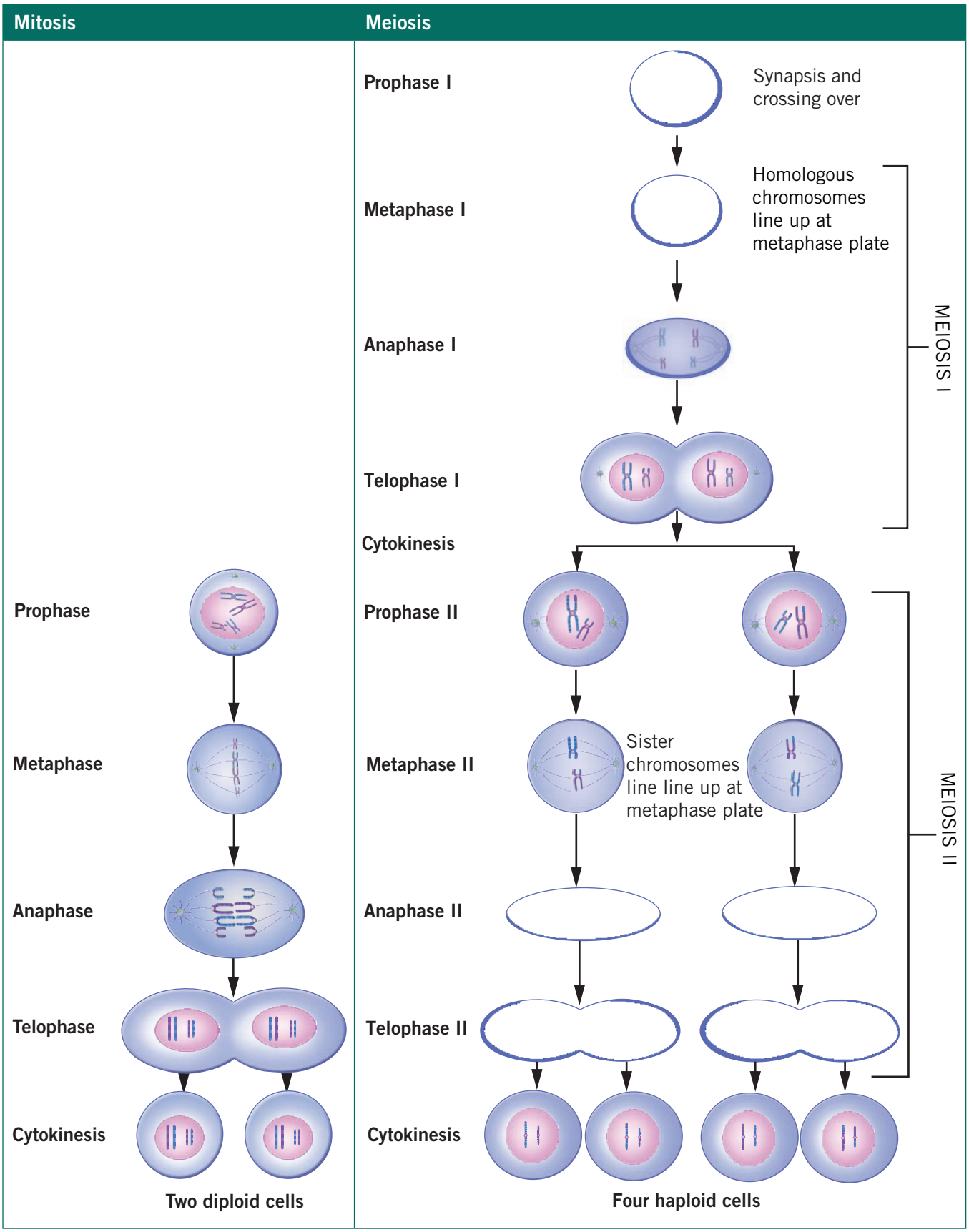
| **Meiosis II** | | |
|---|---|---|
| Prophase II |  | • Nuclear membrane dissolves<br>• Spindle microtubules re-form |
| Metaphase II |  | • Chromosomes move into the equator of the cell<br>• Spindle microtubules attach to each chromatid via the centromere |
| Anaphase II |  | • Sister chromatids are pulled to opposite poles of the cell<br>• The centromere is divided |
| Telophase II |  | • The nuclear membrane re-forms, the spindle microtubules disappear<br>• At the end of telophase II, the chromosomes de-condense and are no longer visible |
| Cytokinesis<br>$4 \times n$ |  | • Both cells pinch in half to produce four haploid cells, each containing half the genetic information of the parent cell<br>• One member of a chromosome pair is present in each gamete |

ISBN 978-1-108-88711-3

## Mitosis versus meiosis

A summary and comparison of the processes of mitosis (making copies of somatic cells) and meiosis (making gametes) is given in Table 7B–3.

**Table 7B–3** Mitosis versus meiosis, see the Interactive Textbook where you can zoom in to see chromosome detail




ISBN 978-1-108-88711-3

WORKSHEET 7B–2 COMPARING MITOSIS AND MEIOSIS

## Check-in questions – Set 2

1 Outline the purpose of meiosis.
2 Distinguish between meiosis I and meiosis II.
3 Summarise the processes in meiosis I and II by listing two key aspects of each stage. Try to select features of each stage that distinguish it from the other stages.

# Creating genetic diversity

## The importance of genetic diversity

UNIT 4 LINK

The advantage of sexual reproduction and meiosis is that they create genetic variation or diversity in the offspring. Variation is necessary for populations of organisms so some individuals are better adapted and to survive changes in the environment, including selection pressures such as disease or climate change, allowing for evolution to occur.

There are three main sources of this genetic variation:
- crossing over (in prophase I)
- independent assortment (in metaphase I)
- random fusion of gametes from the two parents (fertilisation).

**Synapsis** pairing of homologous chromosomes during prophase I of meiosis

**Chiasma** the point of contact between non-sister chromatids in a homologous pair of chromosomes; the point at which crossing over may occur

**Crossing over** exchange of genetic material between non-sister chromatids in a homologous pair of chromosomes during prophase I of meiosis; occurs at the chiasmata and results in recombinant chromosomes, increasing variation between gametes

## Crossing over

Recall that, in prophase I, homologous chromosomes position themselves side by side, a process called **synapsis**. The non-sister chromatids of the homologous chromosomes are in contact with each other at points called *chiasmata* (singular: **chiasma**). This is the physical point at which **crossing over** may occur. The non-sister chromatids of a homologous pair of chromosomes get so close that some of the genetic material from the maternal chromosome swaps with some of the genetic material from the paternal chromosome. This results in the chromosomes being recombined in a new combination of genetic material, leading to more variation between the gametes.

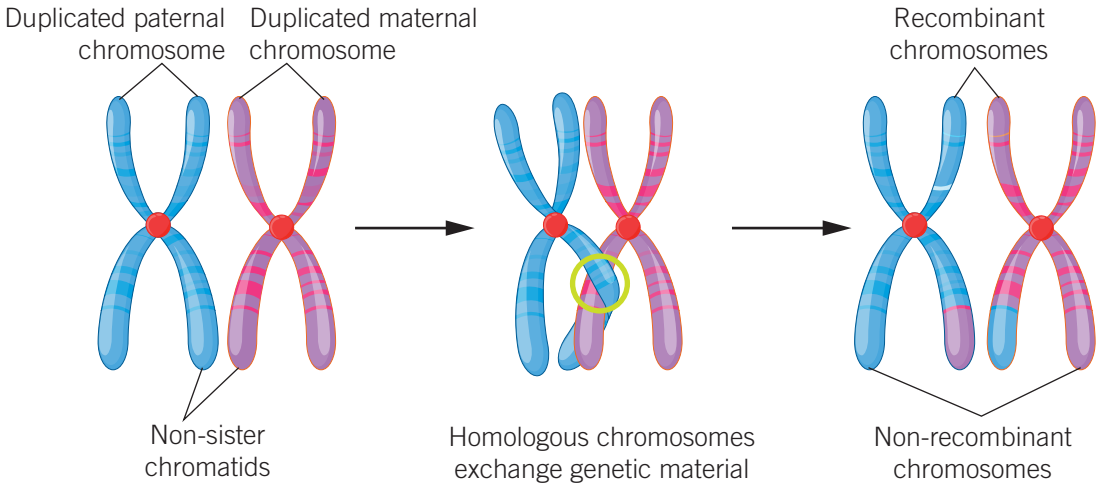



**Figure 7B–8** Crossing over during prophase I results in the formation of recombinant chromosomes with a new combination of genetic material. The green circle indicates the position of the chiasma.

ISBN 978-1-108-88711-3

## Independent assortment

In metaphase I, homologous chromosomes line up in the centre of the cell. The arrangement of the homologous pairs is random: the maternal chromosome may be on the left and the paternal chromosome on the right, or vice versa. This random orientation of the homologous pairs during metaphase I is called **independent assortment**. As this random assortment occurs for each homologous pair independently of the other pairs, the number of possible gamete combinations depends on the number of homologous pairs that the species has. In humans, the number of possible gamete combinations can be represented by $2^n$ (where $n$ represents one complete set of chromosomes in that organism) or $2^{23}$ (8 388 608) possible combinations in humans.

**Independent assortment** the random arrangement of pairs of homologous chromosomes during meiosis, resulting in the random combination of alleles into gametes

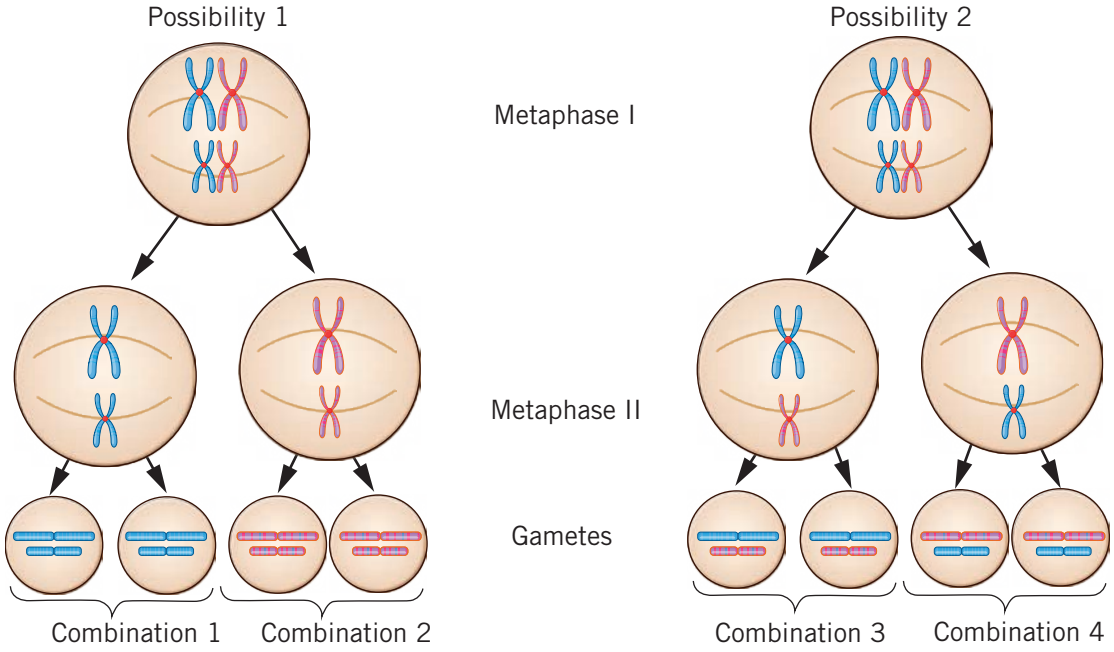



**Figure 7B–9** Independent assortment during metaphase I results in many possible gamete combinations.

## Random fertilisation

Fertilisation, or the fusion of gametes from two parent organisms, is another way in which variation is increased in species that reproduce sexually. As you know, the fusion of haploid gametes forms a diploid zygote, and crossing over and independent assortment lead to greater variation between gametes, so it makes sense that random fertilisation can produce a large number of possible genetically unique zygotes.

## Check-in questions – Set 3

1 How can organisms create variation during sexual reproduction and meiosis?
2 Explain why genetic variation, or diversity, among offspring is advantageous to the survival of a species.

ISBN 978-1-108-88711-3

## Meiosis going wrong

UNIT 4 LINK

**Non-disjunction** in meiosis occurs when chromosomes fail to separate during anaphase. This failure to separate can occur during anaphase I or anaphase II and results in daughter cells or gametes forming with an incorrect number of chromosomes (**aneuploidy**). You can see in Figure 7B–10 that if the:

- homologous chromosomes fail to separate during meiosis I, all four daughter cells are affected
- sister chromatids fail to separate in one of the cells during meiosis II, two of the four daughter cells are affected.

**Non-disjunction** when chromosomes fail to separate normally during anaphase

**Aneuploidy** when cells contain one more or one less chromosome than normal

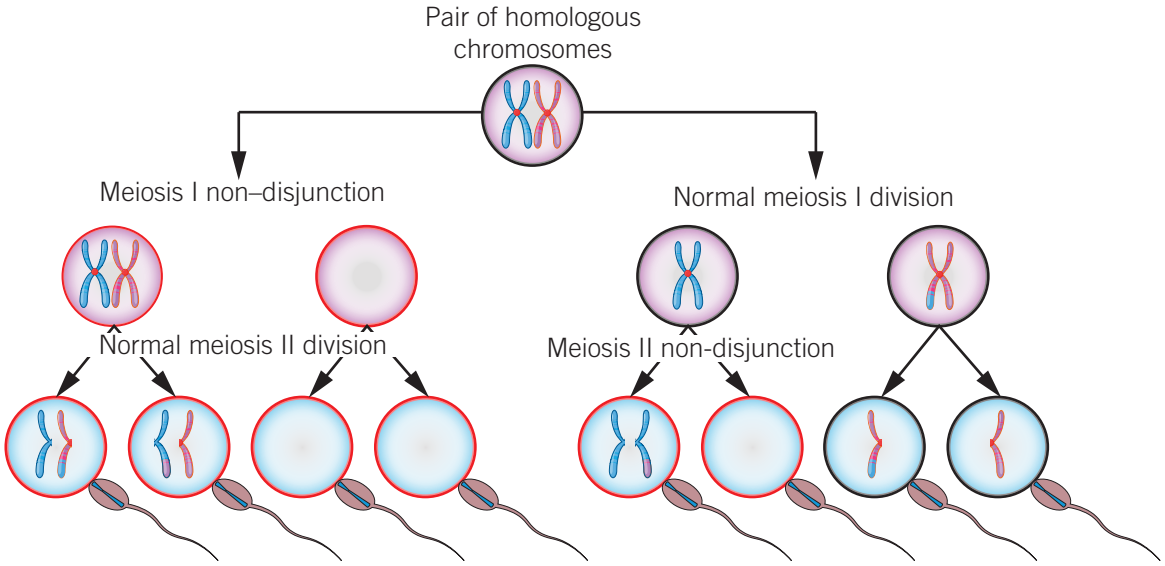



**Figure 7B–10** Non-disjunction is when chromosomes do not separate as they should during meiosis I or meiosis II. The affected cells are circled in red.

3B THE CELL CYCLE LINK

If a gamete produced during non-disjunction, with an incorrect number of chromosomes, combines with a normal gamete during the process of fertilisation, the resulting zygote will have a chromosomal abnormality. As the zygote undergoes mitosis to grow, all the daughter cells produced will also carry the chromosomal abnormality. Some examples of syndromes caused by chromosomal abnormalities are:

- Down syndrome (three copies of chromosome 21)
- Edwards syndrome (three copies of chromosome 18)
- Klinefelter syndrome (XXY)
- Turner syndrome (XO).

9A GENETIC AND REPRODUCTIVE TECHNOLOGIES LINK

To identify whether a cell contains a chromosomal abnormality, a prenatal karyotype can be used. Foetal cells are obtained from the mother by amniocentesis or chorionic villus sampling, a photograph is taken when the chromosomes have condensed, and they are then stained and arranged according to their structure. For example, an individiual with Down syndrome has three copies of chromosome 21. This is called **trisomy** and is a consequence of non-disjunction in one of the parent's gametes, where instead of containing a single copy of chromosome 21, the gamete contains two copies.

**Trisomy** a condition in which there is an extra copy of a chromosome in a somatic cell

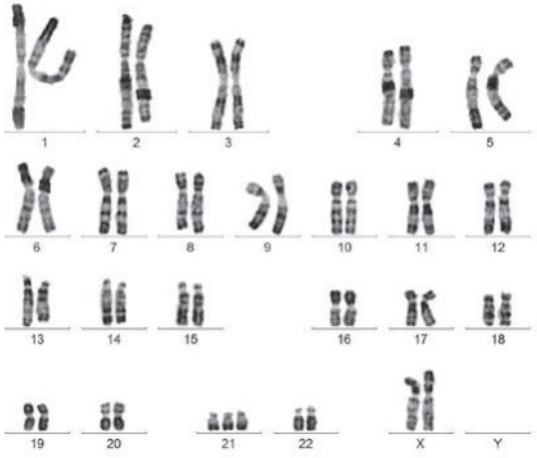



**Figure 7B–11** Down syndrome is the consequence of non-disjunction occurring in a parental gamete. It is characterised by three copies of chromosome 21, which is determined using a karyotype.

ISBN 978-1-108-88711-3

## 7B SKILLS

VIDEO 7B–3
SKILLS: INTERPRETING DIAGRAMS

**Interpreting diagrams given for asexual and sexual reproduction**

In this chapter, you have read about asexual and sexual reproduction and examples of organisms that reproduce in these ways. However, there are some organisms that reproduce both sexually and asexually. So how do you know which type of reproduction is being referred to in an assessment situation? Simply by knowing the key characteristics of asexual and sexual reproduction and the differences between them. Table 7B–1 (on page 318) summarises what to look for: Is there one parent or two? Are gametes or fertilisation involved? Males and females? Consider Figure 7B–12, the reproduction of bread mould using spore formation. See if you can identify any of the characteristics of asexual and sexual reproduction using Table 7B–1 to help you.

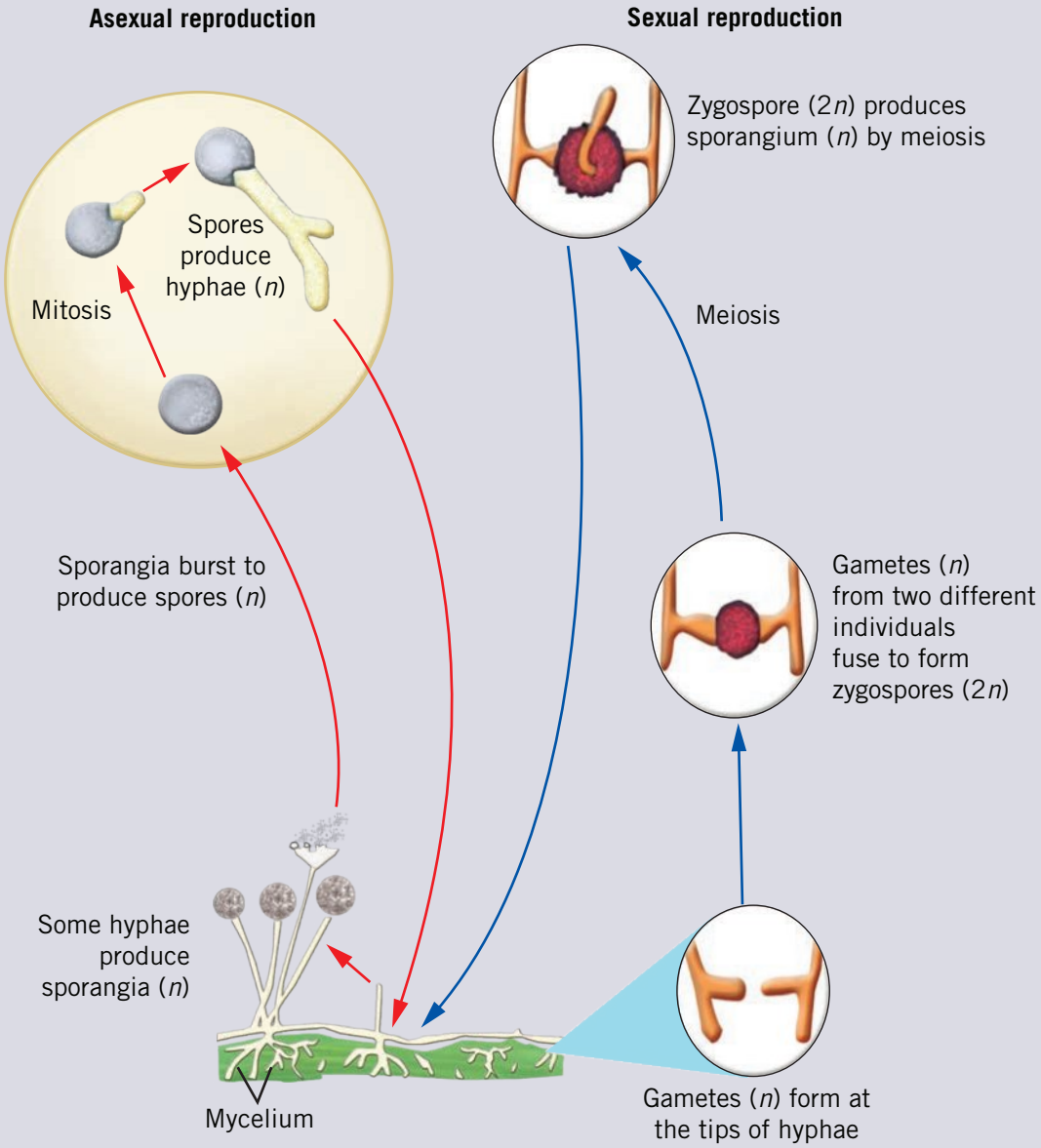



**Figure 7B–12** Some organisms are able to reproduce sexually and asexually, so it is important to be able to identify the key characteristics of each. Asexual reproduction in a mould is shown on the left (from Figure 7A–7) and sexual reproduction is on the right.

ISBN 978-1-108-88711-3

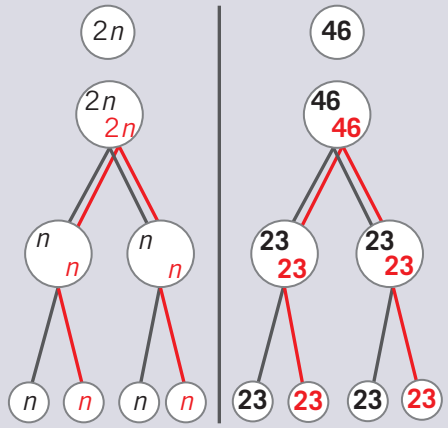
VIDEO 7B–4
SKILLS: NUMBERS OF CHROMOSOMES AT DIFFERENT STAGES

### Numbers of chromosomes at different stages

To assess your understanding of meiosis, and how it is different from mitosis, assessors can ask about the numbers of chromosomes at the different stages.

Remember, meiosis begins with a diploid parent cell, consists of two divisions and produces four daughter cells, gametes (see Table 7B–4). Let's work through the key changes in chromosome number.

**Table 7B–4** The change in chromosome number during interphase and meiosis

| Stage | Description | Illustration | Example (humans) |
|---|---|---|---|
| Start | Diploid cell |  | |
| Interphase | DNA replicated<br>Chromosomes initially possess sister chromatids | | |
| Meiosis I (Anaphase I) | Separation of the homologous pairs<br>Halving the chromosome number | | |
| Meiosis II (Anaphase II) | Separation of the sister chromatids<br>Cells are haploid | | |



VIDEO 7B–5
SKILLS: ORDERING AND DRAWING STAGES

### Ordering and drawing stages

In Biology you may be asked to order or draw parts of biological processes that occur in stages. Mitosis and meiosis are examples of processes where these types of questions are common.

Tips for ordering diagrams:

- Begin by identifying the process if possible.
- Determine whether there are any diagrams that you already know occur before or after other diagrams.
- Consider whether the diagrams you are ordering show cells that are diploid or haploid, have homologous chromosomes, show the DNA has been replicated, and so on.
- Make sure you know the stages well. Using memory tools may help. For example, **M**etaphase is when the chromosomes **M**eet in the middle and **A**naphase is when they move **A**way from each other. Or perhaps you know the IPMATC acronym for the six phases of cell division: **I**nterphase, **P**rophase, **M**etaphase, **A**naphase, **T**elophase, **C**ytokinesis.

Consider this example:

> *Question*: Cells divide by the process of meiosis to produce gametes. Using the letters under each cell in Figure 7B–13, write the cells in order from the earliest stage in meiosis through to the latest.

ISBN 978-1-108-88711-3

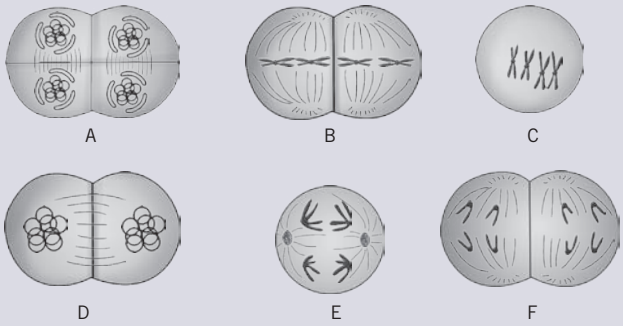



**Figure 7B–13** Sample question where ordering images allows assessors to determine whether you understand the stages in a process

*Answer*: C, E, D, B, F, A.

Remember, one cell becomes four gametes during meiosis, and therefore C/E will be first, B/D/F second and A last. Prophase comes before anaphase, so C must come before E. Metaphase comes before anaphase, so B must be before F. But what about D? D shows two cells with the cytoplasm divided, so cytokinesis has occurred. But is it the first or second time? Two cells are formed after the first cytokinesis and four cells after the second cytokinesis, and therefore D comes before B.

Tips for drawing diagrams:

- Determine whether you are drawing one stage or all stages of the process.
- Be sure to include labels in your diagrams: label the stage, spindle microtubules, homologous chromosomes, chromatids, and so on. There is no need to label every diagram with everything. For example, the first-time spindle microtubules appear, they should be labelled, the first time a homologous pair of chromosomes is present, it should be labelled.
- Biological diagrams are always drawn in 2D, so there is no need for 3D effects like shading. You can see in Figure 7B–13 how simple lines and black and white images are clear and easiest to understand.
- You may like to begin by drawing the outline of the cell for each stage you are to draw. Then you can add the nuclear membrane, centrioles, spindle microtubules, paired chromatids with centromeres, and so on.
- You will not be expected to draw more than two pairs of chromosomes.
- Consider whether the cell you are drawing is diploid or haploid.
- Study Table 7B–2 (on pages 319–20).
- Practise, practise, practise!

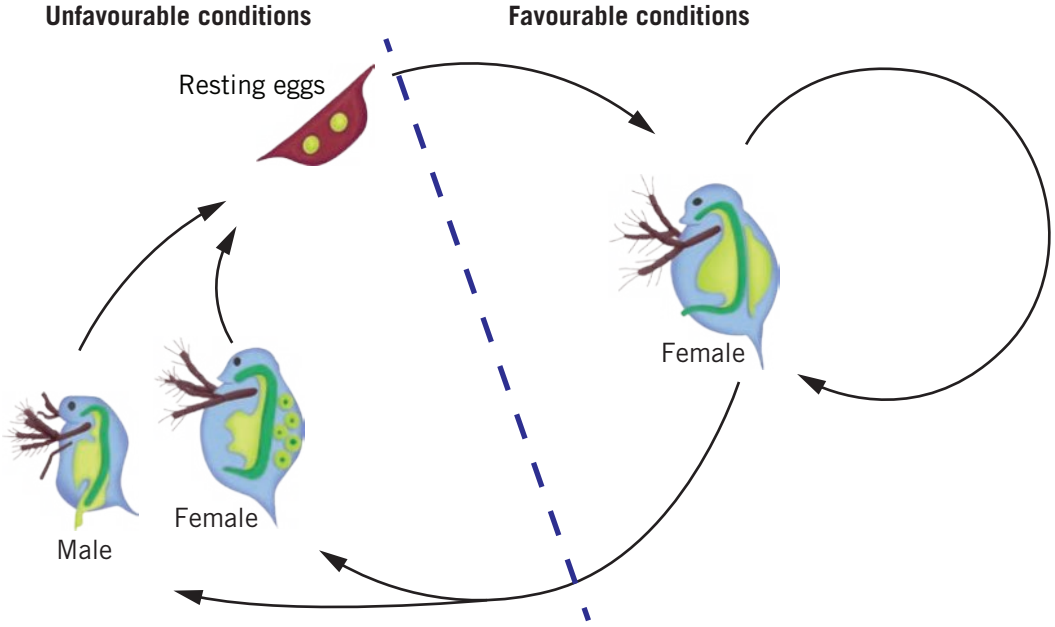
## Section 7B questions

1 For the following questions, name the stage of meiosis that matches the key event listed and draw a simple diagram to illustrate what the stage looks like.
   - **a** Homologous chromosomes are aligned at the equator of the cell and their position determines independent assortment.
   - **b** Synapsis of the homologous chromosomes occurs and crossing over results.
   - **c** Chromatids separate and move to opposite poles.

2 Koalas have a diploid number of 16. When meiosis occurs, there are changes in chromosome number. How many chromosomes are there at the end of each of the following stages of the cell cycle?
   - **a** Interphase
   - **b** Anaphase I
   - **c** Anaphase II

ISBN 978-1-108-88711-3

3 Describe a fundamental difference between the first and second divisions of meiosis.
4 Distinguish between a somatic cell and a gamete.
5 Give reasons why the offspring of sexual reproduction are not identical.
6 The figure below shows a simplified diagram of the life cycle of the water flea, *Daphnia*. Note that one cycle occurs during favourable conditions, and the other cycle occurs in unfavourable conditions.




In favourable conditions, all the individuals in the population are females.
a Is this cycle of reproduction asexual or sexual?
b What is the name of this type of reproduction?
c What is the name of the cell division involved in this type of reproduction?
In unfavourable conditions, for example when food is scarce, male and female *Daphnia* are present in greater numbers.
d Is this cycle of reproduction asexual or sexual?
e Give reasons why this type of reproduction occurs in unfavourable conditions.
f Which females show the greatest variation or diversity: those found in favourable or unfavourable conditions? Explain your answer.

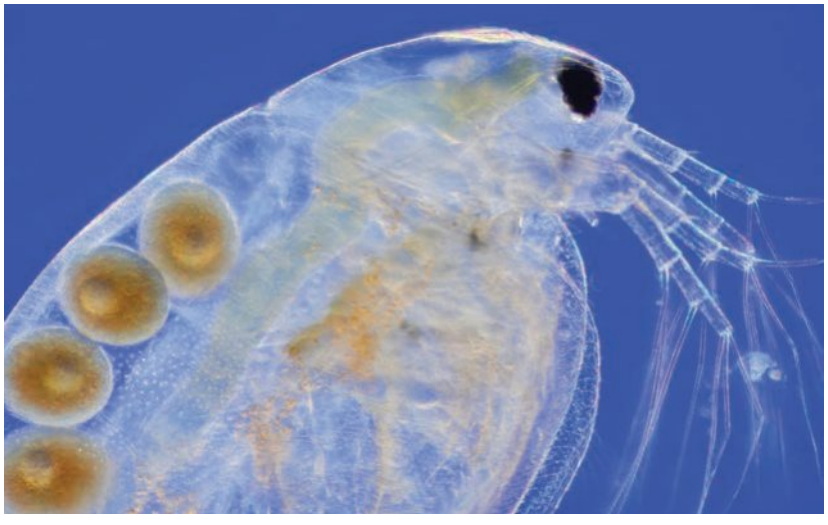
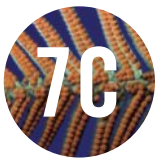


**Figure 7B–14** Light micrograph of a water flea

ISBN 978-1-108-88711-3




# Adaptation, diversity and survival, with Indigenous perspectives

**Study Design:**
- The biological importance of genetic diversity within a species or population
- Structural, physiological and behavioural adaptations that enhance an organism's survival and enable life to exist in a wide range of environments
- The contribution of Aboriginal and Torres Strait Islander peoples' knowledge and perspectives in understanding adaptations of, and interdependencies between, species in Australian ecosystems.

**Glossary:**
Adaptation
Indigenous
Phototropism
Variation

## ENGAGE

### Desert adaptions

As humans, we tend to make our surroundings suit us. We build or buy houses that we like and have everything we need. To make them even more comfortable, we decorate them, furnish them and install a number of accessories to make everything just the way we want it.

LINK 2D ROLE OF CHLOROPLASTS AND MITOCHONDRIA

However, other organisms don't have this luxury. In fact, some creatures have to inhabit incredibly harsh environments. For example, you learned in Section 2D that plants need water to survive and conduct photosynthesis. Considering this, imagine being a cactus that has to grow and live in the desert, a climate known for its lack of water, such as the one shown in the Namib Desert in Figure 7C–1.

So how do cacti manage to do this? If you compare a cactus to many other plants, the first thing that you might notice is that a cactus has spines, not leaves. This difference in shape reduces the surface area that is exposed, which reduces the amount of water that escapes the cactus to the environment through transpiration. As an additional benefit, the spines also deter animal predators that may be looking for a source of water.

**Figure 7C–1** A cactus surviving in the barren landscape of the Namib Desert, in Namibia, Africa

LINK 4E PLANT SYSTEMS

ISBN 978-1-108-88711-3

EXPLAIN

## Introduction to adaptations

1C CELL TYPES LINK

VIDEO 7C–1 ADAPTATION, DIVERSITY AND SURVIVAL

In Chapter 1, you learned about the characteristics that are necessary for life. While many of these processes may seem basic, it is important to remember that a huge number of different life forms live in a wide range of environments around the world. This section looks at the **adaptations** of organisms that help them survive and flourish in their habitats. You will read about the three main types of adaptation – behavioural, structural and physiological – and explore a number of examples in depth.

**Adaptation**
a change that makes an organism better suited to its environment

## Behavioural adaptations

Behavioural adaptations are the actions or activities of an organism that enable it to survive in its environment. They are the things that animals or plants *do* that help them to survive.

**Figure 7C–2** Greylag geese fly very large distances, looking for warmer climates in which to spend the winter months.

You will have heard about birds migrating between summer and winter climates (Figure 7C–2). This is an example of a behavioural adaptation. Birds migrate for various reasons: to find appropriate mating/nesting locations, to go where there are better food sources, or simply to avoid the cold by going to warmer areas.

Hibernation is another behavioural adaptation that you are probably familiar with. Animals that hibernate (including bears, squirrels and some possums) stay inactive and are able to reduce their body temperature, greatly slowing down their metabolism. In this way, they are able to survive through the months when food sources are scarce.

**Figure 7C–3** A Venus fly trap waits for its next meal. When an insect lands and moves on the red surface, the trap closes around the prey.

Although it is less obvious, plants have also developed behavioural adaptations to help them survive. The Venus fly trap (Figure 7C–3) gets nutrition through consuming insects. It does this by luring them into its open 'trap' and then snapping it shut. However, this requires energy and so it would be inefficient to close the trap every time something landed on it. To avoid this potential problem, the Venus fly trap only closes if the object that has landed in the trap moves a couple of times, which indicates that it is alive and most likely an insect.

ISBN 978-1-108-88711-3

You may have noticed that, in this example, as well as the behavioural adaptation of the trap closing, there is another type of adaptation: the structures within the trap are able to detect movement – this is an example of a structural adaptation.

## Structural adaptations

Structural adaptations are the physical features or parts of an animal or plant that help it survive in its environment. Structural adaptations are the easiest to recognise. Some examples that you may be aware of are:

- a giraffe's long neck – helps it reach food on tall trees
- bright feathers on a peacock – help it attract mates
- thorns on rose bushes – help protect the plant from being eaten
- long eyelashes on a camel – help prevent sand from getting in its eyes.

**Figure 7C–4** Thorns are an example of a structural adaptation that helps plants survive, by protecting them from animals that may otherwise eat them. Bright feathers on a peacock are an adaption that help them attract mates.

It is important to realise that animals and plants are not making a conscious decision to develop these adaptations to help them survive better. Instead, in every population, there exist individuals that are different. These differences are caused by small changes in the DNA sequence, which results in physical changes. In biology, we call this **variation**. Occasionally this variation leads to an individual being better suited to the environment, such as those mentioned in the bullet points above. Individuals that are better suited to the environment are more likely to survive to reproductive age and so pass on the genes for this different physical trait to their offspring. Over time, this trait becomes increasingly common, until it is the standard, rather than the exception. This process is known as *natural selection* and you will learn more about it in Unit 4.

**Variation** differences that exist within a species

LINK UNIT 4

## Check-in questions – Set 1

1 How does a behavioural adaptation differ from a structural adaptation?
2 What kind of adaptation are migration and hibernation examples of?

ISBN 978-1-108-88711-3

## Physiological adaptations

A physiological adaptation is any internal or cellular feature that helps an organism survive in its environment. As these adaptations are harder to visualise, some examples will help to highlight the types of physiological adaptations that are possible.

**Figure 7C–5** Snake venom is an example of a physiological adaptation in an animal. This is the Mozambique spitting cobra – you can see the venom being shot out towards a target, most likely its next meal.

The production of chemicals in the body that provide a survival advantage can be a form of physiological adaptation. An example is the production of venom by snakes (Figure 7C–5). Snake venom can have many functions, but it is most commonly associated with killing or immobilising prey. In this way, snakes that produce a more effective venom can capture food more easily and thus are more likely to survive in their environment.

**2D** ROLE OF CHLOROPLASTS AND MITOCHONDRIA LINK

**Phototropism** the process by which the growth and orientation of an organism occurs in response to a light stimulus

Plants also have physiological adaptations that involve the use of chemicals. As you learned in Section 2D, plants require energy from sunlight to carry out photosynthesis. Therefore, it is crucial that they are able to always find sunlight. They have developed a mechanism to do this, called **phototropism**, which means they are able to alter the direction in which they grow, in response to sunlight. If a plant grows towards the sunlight, it is called positive phototropism. Phototropism occurs because of a plant hormone called auxin, which causes the cells that are furthest away from the light source to elongate. This results in the movement (bending) of the plant towards the light, and higher rates of photosynthesis.

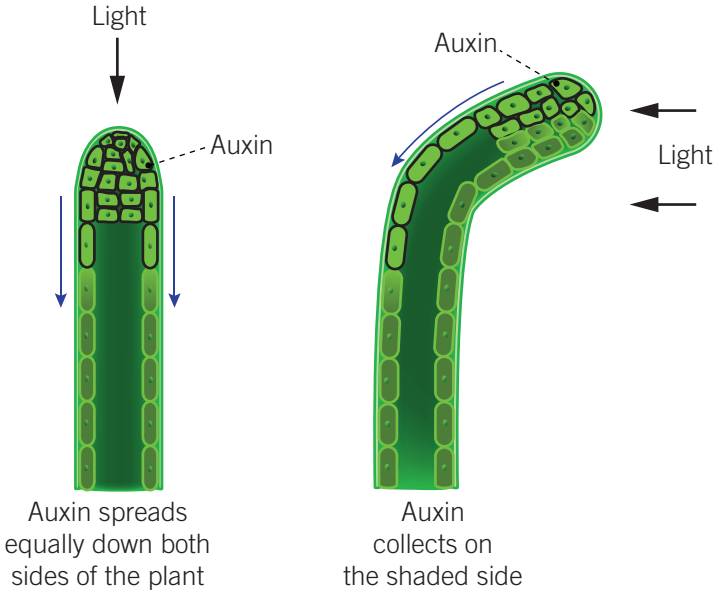



**Figure 7C–6** The plant growth hormone, auxin, spreads evenly when a shoot is exposed to direct sunlight evenly. However, when the sunlight is mostly from one side, auxin collects on the shaded side ('dark side'). The cells on that side grow more and that side elongates, compared to the side exposed to the light, causing the shoot to bend towards the light as it grows.

ISBN 978-1-108-88711-3

Another physiological adaptation occurs in the condition known as sickle cell anaemia. In a person who has this condition, the shape of the red blood cells is altered from the normal 'doughnut' shape to that of a sickle (Figure 7C–7). This shape makes the red blood cells less effective at carrying oxygen around the body. If you think this doesn't seem like something that would make an animal better suited to its environment and more likely to survive, you are correct. However, in certain parts of the world where malaria is present, it is actually advantageous to have sickle-shaped red blood cells. It has been shown that the malaria parasite is unable to infect these cells. Although sickle cell anaemia results in a number of health complications, these are preferable to becoming infected with malaria, which can often be fatal in countries where medical services aren't easily available.

Sickle cell anaemia is an example of how the success of an adaptation depends on the environment in which it occurs. An adaptation that is highly suited to one environment or set of conditions may not be at all useful in a different environment.

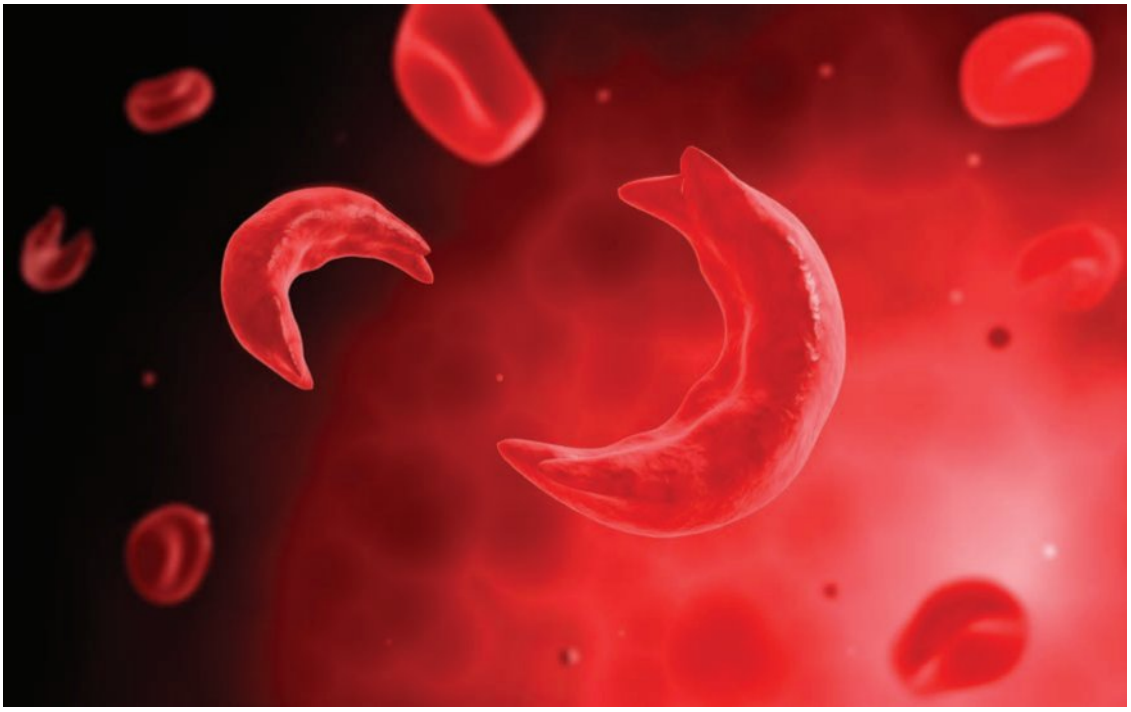


**Figure 7C–7** The difference in shape of sickled red blood cells (centre of image) compared to the normal doughnut-shaped red blood cells (seen in the background)

## Check-in questions – Set 2

1 Would sickle cell anaemia be a physiological adaptation in a region without malaria? Explain.
2 What is the name of the plant hormone involved in phototropism? What physiological benefit does this provide the plant?

**Figure 7C–8** Malaria is transmitted by the bite of infected mosquitoes, and is most common in tropical and subtropical regions

ISBN 978-1-108-88711-3

**Indigenous** the original or earliest known inhabitants of an area; also referred to as First Peoples or First Nations

1A LIVING OR NON-LIVING LINK

## Aboriginal and Torres Strait Islander knowledge and perspectives in understanding adaptations

While modern scientific studies have helped us better understand how organisms adapt to their environment, much of this knowledge has existed within **Indigenous** cultures for a very long time.

Aboriginal and Torres Strait Islander peoples' knowledge and perspectives in understanding adaptations of species come from a variety of cultures, some of which date back over 60 000 years. This understanding is based on observations of their environment, both abiotic and biotic factors, and experience of what is needed by humans, plants and animals to survive in Australian environments.

Today, knowledge of plant and animal adaptations to habitat and season is still essential for finding food and materials in Australian environments. Knowing likely places and times to hunt kangaroos, collect bogong moths and gather certain fruits are essential for survival, and Aboriginal and Torres Strait Islander peoples completed this for thousands of years. In the context of life on Earth, this makes them very successful.

**Figure 7C–9** An Aboriginal elder on Cave Hill, Pitjantjatjara Community, Central Australia, pointing out features of the landscape

This knowledge of the adaptations of plants and animals has not just been used for hunting and gathering. In recent decades, researchers have found, through sources such as Aboriginal and Torres Strait Islanders oral histories, archaeological evidence and early colonists' records, that Aboriginal and Torres Strait Islander peoples used their knowledge to manage the land, till the soil, sow seeds and harvest crops. They managed, and continue to manage, the land, encouraging animals to populate certain areas where they may be hunted sustainably, constructing weirs and traps on waters to sustainably harvest eels, fish and other aquatic life, and using fire to create beneficial ecosystems.

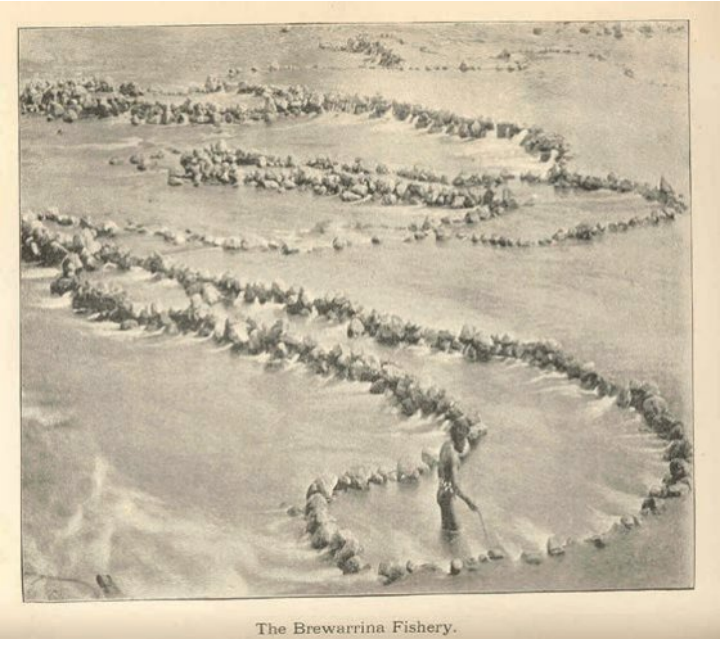



**Figure 7C–10** The Brewarrina fish traps on the Barwon River in New South Wales are an example of Aboriginal Australian aquaculture. They are a series of dry-stone weirs and ponds arranged across the river to create fish traps, where fish were herded into the ponds and the openings quickly shut with a few rocks. The walls of the traps are different heights, allowing them to be used at different water levels. According to the Dreaming an ancestral being called Baiame, threw his net across the Barwon, creating their design. The place is extremely significant to the Aboriginal peoples of Western and Northern NSW for whom it is imbued with spiritual, cultural, traditional and symbolic meanings.

ISBN 978-1-108-88711-3

It is now understood that Aboriginal and Torres Strait Islanders were aware of the adaptations of plants to certain soil conditions and used this knowledge to carry out a form of agriculture:

> Dr Beth Gott, a renowned ethnobotanist from the School of Biological Sciences at Monash University, has established a garden at the university with examples of plants eaten and used by Aboriginals before colonisation. In 'Ecology of Root Use by the Aborigines of Southern Australia', Gott explains that the effect of the systematic and repetitive tilling process aerated the soil, loosened it for seed germination and root penetration, and incorporated ash and compost material with the plants. She said that it 'bore sufficient resemblance to agriculture/horticulture to be regarded as a sort of natural gardening'.
>
> *Bruce Pascoe: Dark Emu, Magabala Books, 2018*

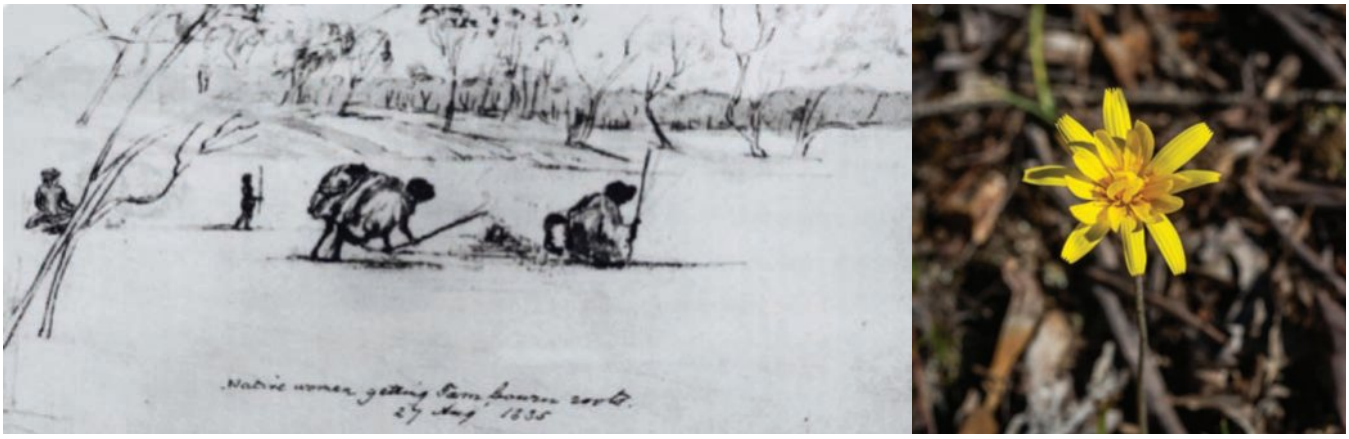


**Figure 7C–11** Left: Yam diggers at Indented Head, Victoria, 1835. Yams were a staple of Aboriginal diet. The area was cleared of other vegetation, with the help of burning, to encourage the yams to grow and to make it easier to harvest them. The yield of such yam gardens was very high. Right: The yam daisy or murnong, *Microseris lanceolate*

As well as their knowledge of adaptations of plant and animal species, the physical and physiological adaptations of Aboriginal and Torres Strait Islander peoples to the Australian environment enabled them to not just survive, but prosper sustainably on their own land, which was managed in traditional ways.

> For example, the journals and documents of European colonisers mentioned that First Australians often had exceptional abilities in jumping, running and stamina, while their eyesight, reflexes, throwing accuracy, and spatial awareness made them sought-after as trackers, guides and hunters. The pearling and whaling industries sought them out for these abilities too, while today they are valued in professional sports.
>
> *ACARA Teacher Background information*

It is worth recognising that some traditional ways have not been practised since colonisation by the British, while others live on. The knowledge and perspectives of understanding ecosytems and how to maintain them still exist, and are summed up by the term 'caring for Country'. This will be discussed further in Section 7D.

LINK **7D** SURVIVING THROUGH INTERDEPENDENCIES, WITH INDIGENOUS PERSPECTIVES

ISBN 978-1-108-88711-3

## Aboriginal and Torres Strait Islander calendars of seasons

A broad example of the understanding of adaptations can be seen in the Aboriginal peoples' calendars of the seasons. These are based not only on weather or celestial observations, as in the Western understanding of seasons, but also on knowledge of plants' and animals' adaptations to wet and dry periods, to temperature and wind, and the availability of food. A specific example of a seasonal calendar is the Gulumoerrgin (Larrakia) seasons calendar, created by members of the Larrakia language group, from the Darwin region in the Northern Territory, working with the Commonwealth Scientific and Industrial Research Organisation, CSIRO (Figure 7C–12).


**Figure 7C–12** The Gulumoerrgin (Larrakia) seasons calendar, which is based on knowledge of natural events and stages annually in the life of plants and animals, which in turn is based on their adaptations to abiotic factors. (Source: CSIRO Indigenous knowledge and environmental management)

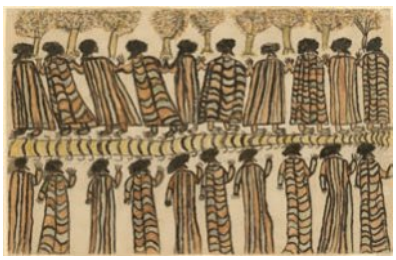
## Examples of applications of structural adaptations in plants and animals

1C CELL TYPES LINK

The adaptations for survival of many living organisms provide countless applications for human materials, devices, processes and technologies. Many of these have been invented by humans after observing all kinds of living things – bacteria, fungi, plants and animals. This has been done successfully in many ancient and modern human cultures. Aboriginal and Torres Strait Islander peoples are no exception, having invented and developed tools, weapons, costumes and materials from structural adaptations observed in other organisms. Specific examples are summarised in Table 7C–1.

ISBN 978-1-108-88711-3

**Table 7C–1** Examples of Aboriginal and Torres Strait Islander peoples' knowledge and application of adaptations of species

| | |
|---|---|
|  | **Water-holding frog** *(Ranoidea platycephala)*<br>Lives in temporary creeks, pools and swamps in arid and semi-arid regions, and is adapted to survive long dry periods by storing water under its skin. When the water dries up, the frog burrows into the soil or sand and secretes mucus around itself. The mucus dries into a waterproof cocoon, enabling the frog to aestivate (remain dormant) until the next rainfall, which may be months or even years away. Traditional owners teach the life-saving method of finding the frogs in extreme droughts by observing markings left on the surface or by tapping the ground with a spear. Squeezing the frog releases the water, which can be drunk. |
|  | **Lawyer-cane plant** *(Calamus)*<br>Also known as 'wait-a-while', is a climbing palm found in Queensland. It has rings of small hooks or spines along its strong, flexible vine-like leaf stems, which attach it to other plants as it grows, an adaptation enabling it to reach light in crowded rainforests. The hooks are a hazard, catching on skin and having to be carefully removed (hence 'wait-a-while'), but they have many applications. The Jirrbal people insert long stems into tree hollows to hook out edible grubs, and also use them like a wire saw to cut meat or soft timber, to harvest insects. The Kuku-Yalanji people use them as fishing hooks, particularly for prawns. |
|  <br>  | **Stingray**<br>Has a strong sharp barb at the end of its tail, an adaptation to defend against predators. The barb has backwards-pointing 'teeth', making it hard to remove once it pierces flesh. Many Aboriginal and Torres Strait Islander peoples used the barbs as spear tips, as a fighting weapon and for hunting and spearing fish. Some, such as the Yanyuwa people, made copies of the stingray barb from wood or bone. |
|  | **Possum fur**<br>Adapted to provide a warm, water-resistant covering to enable survival in extreme cold and wet. Its ability to hold an insulating layer of dry air close to the skin even in rainy conditions was well known to Aboriginal peoples in south-eastern Australia (present day Victoria and New South Wales) who made possum skin cloaks like those depicted here in the painting *Figures in possum skin cloaks* by William Barak, a traditional elder of the Wurundjeri of the Woiwurrung language group. |

ISBN 978-1-108-88711-3

## Check-in questions – Set 3

1 Apart from the weather and the movement of the stars, what other natural features usually mark the seasons in Aboriginal and Torres Strait Islander peoples' cultures?
2 The barbs of stingrays were used in some Aboriginal and Torres Strait Islander peoples' spears, but what knowledge of this adaptation in stingrays is used indirectly?
3 What adaptation in possums is used by Aboriginal peoples in colder, wetter environments?
4 An adaptation in the lawyer-cane plant is used by some Aboriginal and Torres Strait Islander peoples. What is the adaptation and what benefit does it give the plant?

**WORKSHEET 7C–1** INDIGENOUS KNOWLEDGE AND PERSPECTIVES IN UNDERSTANDING ADAPTATIONS

See the Interactive Textbook for this worksheet, which provides an information research activity to find other examples of Aboriginal and Torres Strait Islanders knowledge of species' adaptations for survival, with curated links.

In your report on the activity, you should identify which Aboriginal and Torres Strait Islander peoples provided the knowledge and perspectives, out of respect for their intellectual property.

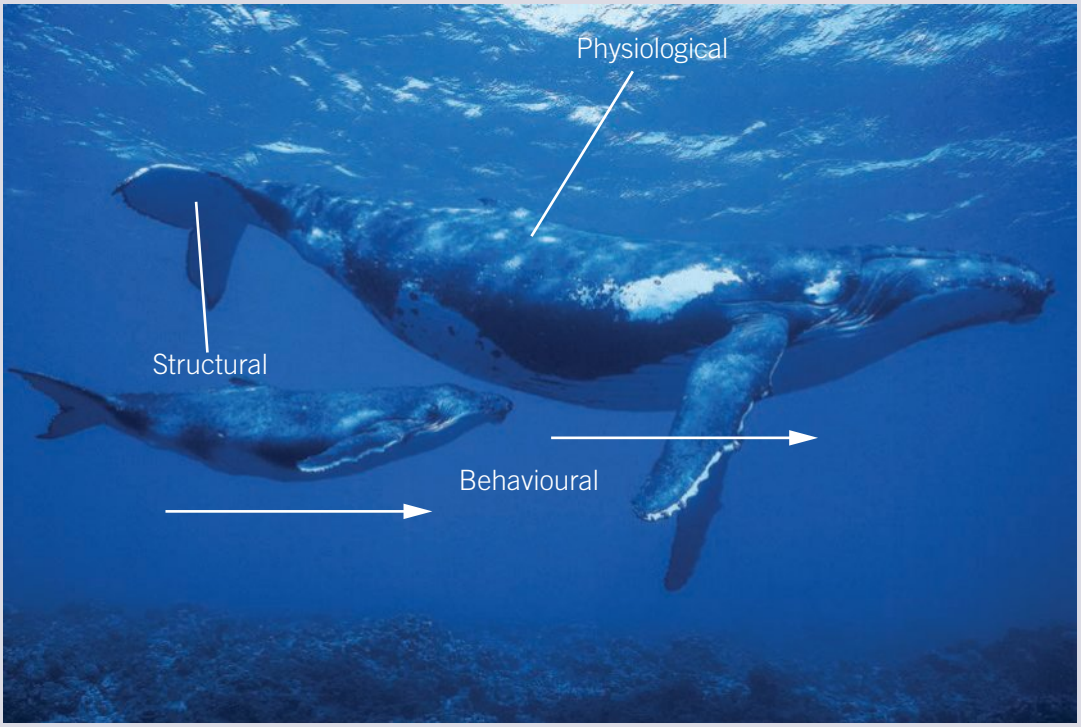
**VIDEO 7C–2** SKILLS: IDENTIFYING ADAPTATIONS

## 7C SKILLS

**Identifying adaptations**

In this section, you learned about three types of adaptations that develop over time in organisms: behavioural, structural and physiological. It is important that you are able to identify adaptations in organisms and to classify the type of adaptation. Consider this example:

> *Question*: Using the image below, identify one structural, one physiological and one behavioural adaptation that the humpback whale has developed to make it better suited to living in the ocean.




ISBN 978-1-108-88711-3

*Answer:*

- *Structural*: The whale has a large, horizontal tail, which helps it achieve a strong up and down propulsion. This is very helpful when swimming large distances.
- *Physiological*: Instead of being covered in hair, which would create drag when swimming, the whale has blubber under the skin to provide warmth and buoyancy.
- *Behavioural*: Whales undertake long migration journeys, sometimes up to 5000 km, in search of warmer waters, for both feeding and breeding.

What other examples can you think of? In a question like this, you might consider drawing a line to the image to connect the feature that you are discussing with your point (as shown in the image on the previous page). This helps clarify what you are talking about to an examiner.

## Section 7C questions

1 Define 'adaptation'.
2 Compare behavioural, structural and physiological adaptations.
3 Explain, using an example, why an adaptation is only as good as the environment it is in.
4 What is necessary in a population for structural adaptations to occur?
5 What is the process by which structural adaptations become more common in a population over a period of time is called?
6 List three specific examples of adaptations in plants or animals known to Aboriginal and/or Torres Strait Islander peoples. State what advantage for survival the adaptation provided to the organism and what advantage for survival it gave to the people who applied their knowledge of it.
7 Assuming that global warming continues, polar bears will need to adjust to life with less ice and more water. Name one behavioural, structural and physiological adaptation that could see polar bears better suited to this new environment.

**Figure 7C–13** A polar bear and cub swimming through melted sea ice

ISBN 978-1-108-88711-3


# Surviving through interdependencies, with Indigenous perspectives

**Study Design:**

- Survival through interdependencies between species, including impact of changes to keystone species and predators and their ecological roles in structuring and maintaining the distribution, density and size of a population in an ecosystem
- The contribution of Aboriginal and Torres Strait Islander peoples' knowledge and perspectives in understanding adaptations of, and interdependencies between, species in Australian ecosystems

**Glossary:**

Commensalism
Community
Consumers
Decomposers
Detritivores
Ecosystem
Food chain
Food web
Keystone species
Mutualism
Parasitism
Population
Producers
Species

## ENGAGE

### Interdependency of species

In the previous section, you read about how animals (or plants) become better adapted over many generations to their environment and surroundings. Individuals within a species that are better adapted survive longer and subsequently can reproduce more, passing on their alleles (which determine characteristics). While adaptation is helpful, no organisms on Earth live in isolation. Instead, they are all part of populations, communities and larger ecosystems. Indeed, many of the adaptations that you can think of relate to the fact that an organism lives surrounded by many other different organisms. For example, animals might have large ears to be able to hear approaching predators, or plants may have thorns to protect them from being eaten. However, survival isn't just about avoiding the other animals in an ecosystem. Almost all organisms are dependent on other organisms within their environment for their survival. This concept, called the interdependency of species, is the focus of this section.

**Figure 7D–1** A rabbit's large ears allow it to detect predators (left), and thorns help protect a rose against predators (right).

## EXPLAIN

### Symbiosis

**Parasitism**
a symbiotic relationship between two species, where one species benefits at the expense of the other

**Commensalism**
a symbiotic relationship between two species, where one species benefits and the other one isn't affected

**Mutualism**
a symbiotic relationship between two species, where both species benefit from the interaction

In some cases, dependency exists between just two species, in a process called *symbiosis*. There are three types of symbiosis, and each is defined by which of the organisms benefits from the interaction:

- **parasitism** – one species benefits at the expense of the other (the other is usually harmed as a result)
- **commensalism** – one species benefits and the other one isn't affected
- **mutualism** – both species benefit from the interaction.

You can get a better understanding of what these terms mean by summarising them in a table, showing whether the impact on each species involved in the relationship is positive, negative or neutral. Some examples are shown in Table 7D–1.

ISBN 978-1-108-88711-3

**Table 7D–1** Symbiotic relationships in nature

| Relationship | Species 1 | Species 2 | Example |
|---|---|---|---|
| Parasitism |  |  | Fleas (species 1) on a dog (species 2)<br>Fleas bite the skin of dogs, in order to consume their blood for nutrients. This harms the dog, creating great discomfort and causing them to itch.<br>  |
| Commensalism |  |  | Remora fish (species 1) on a shark (species 2)<br>The remora fish attaches to the shark in order to eat leftover food scraps, as well as to be transported around. The shark is not harmed in this process, but doesn't receive any benefits either<br>  |
| Mutualism |  |  | Clownfish (species 1) in a sea anemone (species 2)<br>The clownfish feeds on algae and small creatures that could harm the sea anemone. At the same time, the poisonous tentacles of the sea anemone protects the clownfish from potential predators.<br>  |

## Living together

Organisms tend to exist in larger groupings than those in the simple symbiotic examples above. With humans, for example, it is easy to identify small and large groups, such as families, communities and nationalities. Each of these groups is progressively larger and incorporates more people. Similarly, in ecology there are levels, or hierarchies, that are important to understand. These include:

- **species** – a group of organisms that are capable of interbreeding to produce fertile offspring
- **population** – a group of organisms of the same species that are living in the same location at the same time (e.g. kangaroos living in the Grampians)
- **community** – a number of different populations existing in the same location and interacting with each other at the same time (e.g. kangaroos, koalas, eucalyptus trees and possums living in the Grampians)
- **ecosystem** – the combination of all organisms and their habitat.

**Species**
a group of organisms that are capable of interbreeding to produce fertile offspring

**Population**
a group of organisms of the same species that are living in the same location at the same time

**Community**
a number of different populations existing in the same location at the same time and interacting with each other

**Ecosystem**
the combination of all organisms and their habitat

## Check-in questions – Set 1

1 Define the following key terms: mutualism, commensalism, parasitism.
2 Using a different example to the one provided in this section, compare the differences between a species, a population, a community and an ecosystem.

ISBN 978-1-108-88711-3

VIDEO 7D–1 FOOD CHAINS AND FOOD WEBS

## Food chains and food webs

The easiest way to think about how organisms depend on other organisms for survival is in terms of what they eat. Another way is to consider the reason that organisms eat, which is to obtain energy. This way, we can also look at how energy is transferred between organisms.

1C CELL TYPES LINK

As you learned in Section 1C, plants and some types of bacteria use the energy from the Sun to make their nutrients. By doing this, these plants and bacteria make their own chemical energy. Organisms that do this are called *autotrophs* (*auto* = self, *troph* = food). This is the starting point for all the energy that passes through an ecosystem. In terms of a food chain, autotrophs are called **producers**.

**Producers** organisms that convert sunlight into their own chemical energy; autotrophs

**Consumers** organisms that feed on other organisms to obtain the energy/nutrients they require; heterotrophs

When an organism can't produce its own nutrients, it must obtain them by ingesting other organisms. This type of organism is called a *heterotroph* (*heteros* = other, *troph* = food). The first class of heterotrophs obtain their nutrients by feeding on plants, and are called *herbivores*. As these organisms need to obtain their energy by eating another organism, they are referred to as **consumers**. Animals that obtain their energy through ingesting producers are known as *primary consumers*, as they are the first step in the food chain after the photosynthetic organisms. Another class of consumers is those that don't eat plants, but instead eat other animals. These are known as *carnivores* and, in a food chain, are called *secondary consumers*.

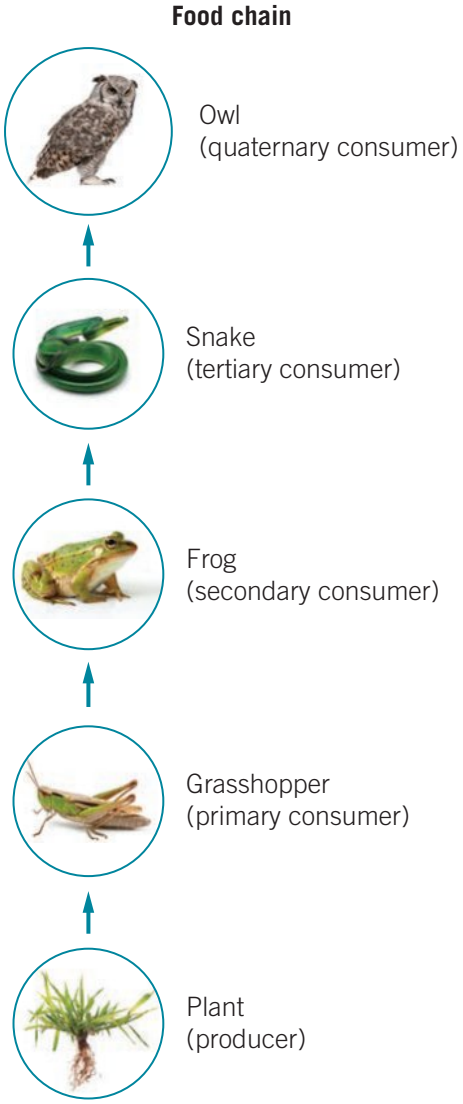
There are other classes of heterotrophs that differ from these consumers in a significant way. While the ones discussed above feed on living organisms, some organisms obtain their nutrients from dead plant and animal material. Two main types that you should know are **detritivores** and **decomposers**. Both feed on the organic material obtained from dead organisms. The difference between them is their mode of 'digestion'. Detritivores ingest the material and break it down internally, whereas decomposers secrete enzymes to break down the organic material externally and then ingest the compounds that remain.

**Detritivores** organisms that obtain nutrients by ingesting dead plant and animal material

**Decomposers** organisms that obtain nutrients by secreting enzymes to break down the dead plant and animal material

**Food chain** a linear network of links (energy transfer) from producers through to consumers

These interactions can be displayed in a simplified way, as a **food chain**. A food chain shows a linear movement of energy from producers through to consumers, as shown in Figure 7D–2. Note that, in food chains, the arrow points towards the organism that is the consumer (e.g. the owl eats the snake, and so the arrow goes from snake to owl).




PPS

**Figure 7D–2** A basic food chain showing a plant (producer) and various levels of consumers

ISBN 978-1-108-88711-3

However, as you will learn in the next part of this section, the interactions in an ecosystem are more complex than can be portrayed in a food chain. Organisms often interact with many other organisms, including those at the levels below them in the food chain and sometimes even those at the same level. To be able to visualise this level of detail, we must represent it through the use of a **food web**. An example of a food web is shown in Figure 7D–3.

**Food web** an interconnection between different food chains and organisms at the same or different levels

## Check-in questions – Set 2

1 Use the food web shown in Figure 7D–3 to answer the following questions.
   - **a** How many producers are there?
   - **b** What role does the rabbit play in the food web?
   - **c** What is an example of a secondary consumer in the food web?

## Keystone species

VIDEO 7D–2 KEYSTONE SPECIES

Food chains and food webs are too simple to capture the full complexity of what is happening in an ecosystem and how all the interactions impact on the survival of the organisms. Interestingly, there are many examples of species having a much larger impact in an ecosystem than you would expect, based on their size or numbers. A species like this is referred to as a **keystone species**.

**Keystone species** a species that has a much larger impact in an ecosystem than expected based on its size or numbers

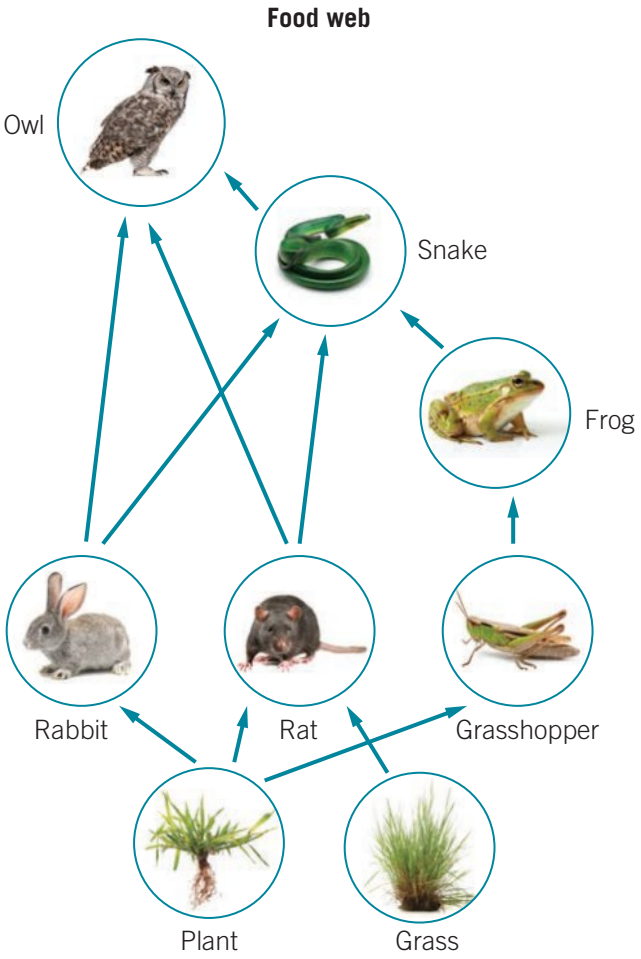



**Figure 7D–3** A food web showing how organisms can have multiple feeding pathways in an ecosystem, rather than just the linear model displayed in a food chain

Understanding where the term 'keystone' comes from can help you understand the importance of these organisms in biology. A keystone, as you can see in Figure 7D–4, is a wedge-shaped rock at the very top of a stone archway. The keystone is incredibly important to the structure – if it is removed, the entire arch will collapse. In biology, a keystone species has the same importance: if you remove it, or even just reduce its numbers, this could create many changes that could see the entire system (ecosystem) collapse.

**Figure 7D–4** In construction, a keystone is a wedge-shaped stone at the top of an arch that holds the whole structure together. Here, you can see the keystone in an archway in a 12th century fortress in Israel.

ISBN 978-1-108-88711-3

To fully appreciate this concept, we'll examine a real-life example that happened in the Yellowstone National Park in the United States. But first, let's look at a food chain that existed within this park (Figure 7D-5).

**Figure 7D–5** A basic food chain that existed in Yellowstone National Park, showing elk eating the trees and being hunted by the wolves

By around the 1930s, hunting had effectively reduced the number of wolves to zero. If you think about the food chain above, what effect(s) do you think wiping out the wolves would have had? Your initial response might be to think that, without wolves being around, nothing would eat the elk and so elk numbers would increase. This is true, but it was only the start of the changes that occurred.

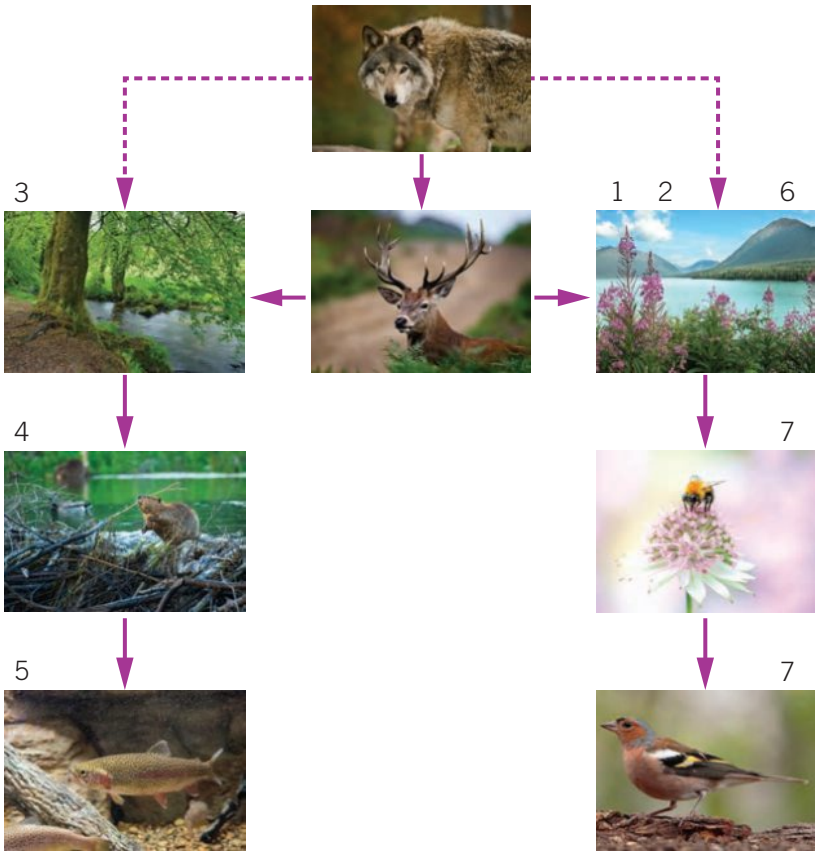



**Figure 7D–6** A diagram showing that in Yellowstone National Park the wolf has impacts on a huge number of other plant and animal species, both directly (solid arrow) and indirectly (dashed arrow). Mainly through its direct role as a predator of the elk, the wolf has indirect 'downstream' effects on the health and livelihood of trees, flowers, aquatic species, birds, insects and smaller animals. This is why the wolf is called a keystone species.

In fact, the absence of wolves created a huge flow-on effect, including the following:

1. More elk meant that more plants were being eaten.
2. Not only were the elk eating more grass, but they weren't worried about being hunted by wolves. This meant that they weren't constantly on the move, and instead stayed in one location for much longer and ate the grass in that location until it was almost depleted.
3. Plant species such as aspen and riverside willows declined in numbers.
4. Riverside willows were used by beavers to make dams, so the decline in the willows meant that beaver numbers also declined.
5. The lack of beaver dams had a negative impact on aquatic plant and animal life.
6. Many flower species were negatively affected by the elk spending more time near the river.
7. The lack of flowers caused a decrease in insect species, as well as the songbirds that fed on the insects.

ISBN 978-1-108-88711-3

Interestingly, these effects were most eviden 1990s, when the wolves were reintroduced i Yellowstone National Park. Through this sir change, which resulted in the elk's natural predator being present in the ecosystem, all the changes were slowly reversed. Indeed, there were even other impacts that had previously gone unnoticed. A summary of these effects is shown in Figure 7D–6.

This example highlights the impact that a predator, especially a high-level one, can have on an ecosystem. By hunting and feeding on the organisms below it in the food chain, a predator can keep the entire system in balance.

Keystone species don't have to be predators. Indeed, organisms almost at the opposite end of the food chain spectrum can be considered keystone species. One such example, which you may have seen discussed before, is bees.

Your first thought might be that if bee numbers continue to decline and potentially reach extinction, the worst outcome would be that you will no longer be able to buy honey to put on your toast. However, the consequences could actually be catastrophic.

LINK **7B** SEXUAL REPRODUCTION AND MEIOSIS

Why are bees crucial to Earth's ecosystems? The answer lies in their role as pollinators (Figure 7D–7). As pollinators, bees enable plants, crops and flowers to reproduce and grow. Considering what you have learned already in this section, you may realise that this interaction doesn't just impact on the plants.

DOC **WORKSHEET 7D–1** ECOSYSTEMS AND THE INTERDEPENDENCIES WITHIN THEM

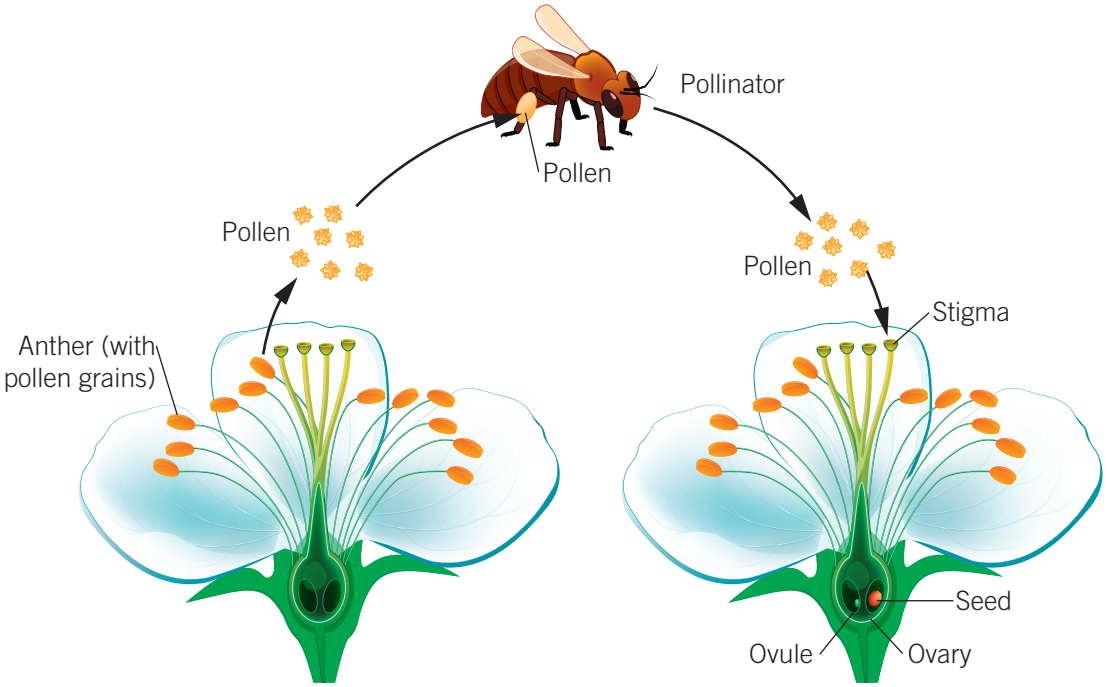



**Figure 7D–7** Bees play an important role in ecosystems by acting as a pollinator. They take the pollen from the male part of the flower (anther) and transfer it to the female part of different flowers (stigma).

ISBN 978-1-108-88711-3

## Aboriginal and Torres Strait Islander knowledge and perspectives in understanding interdependencies of species

Up until this point, we have discussed ecosystems and the interdependency of organisms using various examples of plants and animals. It is important to remember that humans are just another animal that coexists in these environments, although we do not always do so harmoniously. However, there is no better evidence of how humans can learn, understand and participate in an interdependent ecosystem than that of Aboriginal and Torres Strait Islander peoples.

### Caring for Country

Aboriginal and Torres Strait Islander peoples regard themselves as part of nature and the environment, not above animals and plants, as many in Western culture often think of themselves. The traditional world view of integration with biotic and abiotic factors of the environment, in a deep understanding of ecosystems and their place in them, encourages sustainable use of environmental resources for the benefit of the people. Seeing oneself as part of the ecosystem is key. This is the essence of 'caring for Country'.

An example of Aboriginal and Torres Strait Islander peoples' sustainable use is the harvesting of turtles and dugongs. Large numbers have been hunted for thousands of years, without decline, even after colonisation. Aboriginal and Torres Strait Islander peoples who hunt them are aware of their interdependence and reliance upon them. To ensure sustainability of supply, they impose cultural controls on where and how they hunt them, as well as who can hunt them. There are rules on how they are killed, processed, distributed and shared within the community. When hunting dugongs, young male dugongs are preferred, whereas pregnant females and those with calves are left alone. These rules are shared among the community.

### Mutual benefit in interdependence

Aboriginal and Torres Strait Islander peoples who hunt dugongs see themselves as part of the ecosystem and dependent on the dugongs. This is an example of a predator–prey relationship.

**Figure 7D–8** Aboriginal rangers work with Landcare to track the endangered black-footed rock wallaby at Ernabella in the Anangu Pitjantjatjara Yankunytjatjara Lands, South Australia.

In the case of some other species, the relationship is more complex. If you looked at the relationship between Aboriginal and Torres Strait Islander peoples and their hunting of kangaroos, this predator–prey relationship might appear to have no benefit for the kangaroos. However, research has shown that, in one area of Western Australia, hunting of kangaroos by the Martu people coupled with their managed burning of the bush results in higher populations of kangaroos than in similar areas where hunting occurs but no burning – even if the

ISBN 978-1-108-88711-3

hunting in the burned areas is heavier. In other words, managed burning of the vegetation counters the effect of hunting. The reason appears to be that the flush of new growth after a burn provides more grass and supresses plants that kangaroos don't eat. In fact, Aboriginal firestick farming promotes the spread of grassland. Kangaroos, grass and humans are interdependent, meaning their ecological relationship is mutually beneficial. This is shown in Figures 7D–9 and 7D–10.

**Figure 7D–9** An Aboriginal girl in Arnhem Land, Monica, using a firestick to burn dry grass before the wet season, when lightning strikes in wind could cause much more serious fires. A similar method, called firestick farming, is used in other parts of Australia to 'cool burn' patches of bush, which will encourage new grass growth, which in turn will attract kangaroos. Fire is the most-used traditional tool for land management by Aboriginal Australians.

**Figure 7D–10** Kangaroo numbers have been shown to be greater where traditional burning is used to promote the growth of new grass, despite the effects of hunting.

This beneficial effect of burning also applies to populations of sand monitor lizards, which don't graze on grass. For these lizards, the beneficial effect may come from the burning resulting in a diverse patchwork of vegetation leading to greater diversity of insect and small mammal food for the lizards.

Bilbies benefit from firestick farming, as it provides fresh plant growth in burned areas, which they prefer. Firestick farming also prevents more serious fires, which would burn all the vegetation cover that bilbies rely on to hide from predators, particularly feral cats. Some Aboriginal people formerly used bilbies as food and have been involved in conservation efforts since the bilbies' numbers have declined. The Kaytetye people in the Northern Territory benefit from bilbies, because bilbies have a keen sense of hearing and like to eat witchetty grubs, which they can hear chewing on roots in the ground. The sound of bilbies scratching at the soil alerts the people to the fact that fully grown grubs are moving to the surface, and are therefore easier to harvest for the Kaytetye people.

**Figure 7D–11** A bilby in central Australia

ISBN 978-1-108-88711-3

**Figure 7D–12** Bush tomato plant (*Solanum centrale*)

## Other examples

Bush tomatoes (*Solanum centrale*) have been used by Central Desert people for thousands of years. The people show interdependency with bush tomatoes, which benefit from firestick farming and from its seeds being spread. It is most common in places where people camp regularly.

The Yuin people of the south coast of New South Wales had a remarkable interdependence with killer whales. These predators would drive large whales into shallow water in the harbour at Eden, where they would be killed and harvested by the Yuin, who would then give the tongue to the killer whales as a reward. The Yuin believed that the interaction established between the Yuin people and the killer whales was a result of a ceremony on the shores where a man would limp between two lit fires. This appearance of a man being old and frail by the killer whales was believed to be the instigator for the pity the whales took on him and their herding of the larger whales to the bay, where they would then be hunted.

> The Yuin set up this interaction with the killer whales with a ceremony where a man would light two fires on the beach and pretend to limp between them as if he were old and frail. The Yuin believed that this encouraged the whales to take pity on the man and bring the bigger whales to the bay for his use.
>
> *Bruce Pascoe: Dark Emu, Magabala Books, 2018*

**Figure 7D–13** A killer whale, also known as an orca

**WORKSHEET 7D–2** INVESTIGATING INDIGENOUS KNOWLEDGE FOR THE INTERDEPENDENCE BETWEEN SPECIES

## Check-in questions – Set 3

1 What is the most widely used tool of Aboriginal and Torres Strait Islander peoples in managing traditional lands?
2 In what kinds of ways does firestick farming benefit some plants and animals?

ISBN 978-1-108-88711-3

## 7D SKILLS

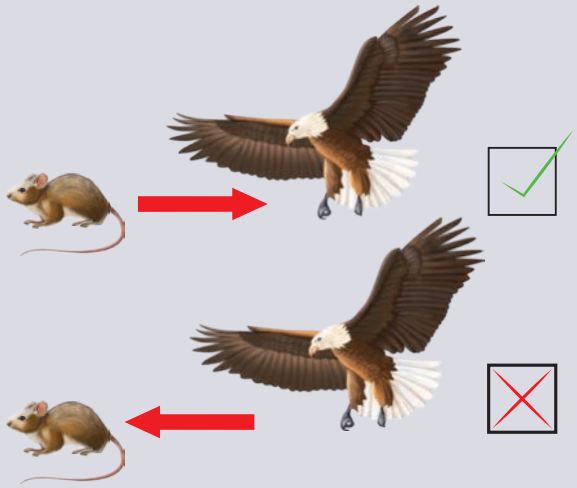
VIDEO 7D–3
SKILLS: DRAWING FOOD CHAINS/FOOD WEBS

**Drawing food chains and food webs**

In this section, you learned about how organisms are interconnected within an ecosystem. When discussing these relationships from a food source perspective, one way of representing them is through a food chain or a food web. If you are required to draw one, there are some key things to remember.

***Arrows***

An arrow indicates a relationship between two organisms. Conventionally, the arrow goes from the organism being consumed to the organism that is feeding on it. An example of this is shown below, where the hawk eats the mouse. You can see both the right way (top) and the wrong way (bottom) of drawing it.



***Food chain or food web?***

When deciding how to illustrate relationships between organisms, it is important to choose the style of diagram that is appropriate to the situation. Remember that food chains are linear, whereas food webs can show multiple interactions for a single organism. Consider the example ecosystem described in the following paragraph:

> 'The desert has a very dynamic ecosystem. There are a number of plants, which provide nutrition for insects and certain rabbit species. There are lizards, which feed on insects. Snakes that will eat lizards and rabbits. Large birds that also hunt lizards and rabbits, as well as snakes.'

Try drawing this as a food chain and as a food web. Which do you think gives you a more complete overview of the ecosystem described?

You should find that the food web is a better option in this case, as many of the organisms have multiple, overlapping food sources. For example, lizards are eaten by both snakes and large birds, where the large birds also eat rabbits. These multiple relationships would be impossible to illustrate in a linear food chain.

***Changes to a food web***

In this section, you also learned about the concept of keystone species and how their removal from an ecosystem can have a large impact. It is not uncommon to be asked to analyse what might happen if there is a change to an ecosystem, such as a new species

ISBN 978-1-108-88711-3

being introduced, the abundance of a species changing or a species becoming extinct. When answering a question like this, there are a few common outcomes that you should consider:

- *Food sources:* how does the change affect the food sources of the other organisms in the food web? If a food source becomes more plentiful, the numbers of the organisms that eat it may increase. If a food source disappears (e.g. becomes extinct), then the numbers of the organisms that feed off that source will also decrease, which may have a rolling effect throughout the ecosystem.
- *Habitat:* how does the change affect where certain organisms in that ecosystem live? As an example, imagine a species is introduced that feeds off a certain type of tree until there is very little left. Imagine that squirrels were using those trees as their home. You could see that this may lead to a decrease in squirrel numbers. The decrease in squirrel numbers would also affect everything else in the food web that fed off the squirrels.

There are often many outcomes to a single change, and it is important to try and think of as many of these as possible and the consequences that arise from this.

## Section 7D questions

1 You are sitting in your garden when you observe a snail eating the leaves of a plant. All of a sudden, a magpie swoops in and gobbles up the snail. In this scenario, which organism is the secondary consumer?

2 What is an interaction between two species, where both organisms benefit, referred to?

3 A North American woodland food chain is shown on the right.
   - **a** Identify the producer, a primary consumer and a secondary consumer in this food chain.
   - **b** It is found that a single species of butterfly exists in both green and yellow forms. What is a difference like this in a population referred to as?
   - **c** Over time, it is observed that the green butterflies become more common than the yellow butterflies. Why might this be?
   - **d** What type of adaptation forms part of the answer to part **c**?

4 **a** What is a keystone species?
   - **b** Name a keystone species found in Yellowstone National Park.
   - **c** Explain how riverside plants and trees were affected by wolves becoming extinct in the park.

5 What is the difference between a community and a population?

6 Kangaroos are hunted for food by the Martu people in Western Australia. Describe a way in which kangaroos benefit nevertheless from Martu traditional practices.

7 Bush tomatoes are a popular food for many Aboriginal peoples. In what way does this benefit the bush tomato?

ISBN 978-1-108-88711-3

# Chapter 7 review

## Summary

Create your own set of summary notes for this chapter on paper or in a digital document. A model summary is provided in the Teacher Resources, which can be used to compare with yours.

## Checklist

In the Interactive Textbook, the success criteria are linked from the review questions and will be automatically ticked when answers are correct. Alternatively, print or photocopy this page and tick the boxes when you have answered the corresponding questions correctly.

'ITB' in the linked questions columns means there is a question on this success criterion in the Interactive Textbook.

| Success criteria – I am now able to: | | Linked question |
|---|---|---|
| **7A.1** | Define asexual reproduction | 1☐, 6☐, 11☐, 13☐ |
| **7A.2** | Summarise the different methods of naturally occurring asexual reproduction used by prokaryotes and eukaryotes, including examples of organisms using each method | 2☐, 15☐ |
| **7A.3** | Identify the advantages and disadvantages of asexual reproduction | 14☐ |
| **7A.4** | Outline the process and application of each of the different types of reproductive cloning technologies used in plants and animals | 12☐, 13☐, 17☐ |
| **7A.5** | Examine issues associated with reproductive cloning technologies | 13☐ |
| **7B.1** | Define and explain sexual reproduction, including key terms and processes | 4☐, 15☐, 16☐, 17☐, 18☐ |
| **7B.2** | Define the terms karyotype, autosomes and sex chromosomes | 19☐ |
| **7B.3** | Demonstrate an understanding of how a karyotype can be used to identify chromosomal abnormalities | 19☐ |
| **7B.4** | Identify the advantages and disadvantages of sexual reproduction | 14☐ |
| **7B.5** | Distinguish between asexual and sexual reproduction | 15☐, 17☐ |
| **7B.6** | Outline the purpose of and key steps in meiosis | 5☐, 16☐ |
| **7B.7** | Summarise the significance of the processes of crossing over, independent assortment and random fertilisation in creating variation and therefore genetic diversity | 3☐, 16☐ |
| **7B.8** | Distinguish between mitosis and meiosis | 6☐, 11☐ |
| **7B.9** | State the biological advantage for offspring that are genetically diverse | 16☐ |
| **7C.1** | Define structural, physiological and behavioural adaptations | 8☐ |
| **7C.2** | Identify examples as either structural, physiological or behavioural adaptations | 7☐, 22☐ |
| **7C.3** | Describe an example of the contribution of Aboriginal and Torres Strait Islander peoples' knowledge and perspectives in understanding adaptations of species in Australian ecosystems | 20☐ |

ISBN 978-1-108-88711-3

| Success criteria – I am now able to: | | Linked question |
|---|---|---|
| **7C.4** | Describe an example of the contribution of Aboriginal and Torres Strait Islander peoples' knowledge and perspectives in understanding interdependencies between species in Australian ecosystems | ITB☐ |
| **7D.1** | Define and identify different symbiotic relationships as parasitism, commensalism or mutualism | ITB☐ |
| **7D.2** | Define and identify different groupings of organisms as species, populations, communities or ecosystems | ITB☐ |
| **7D.3** | Define and identify producers, primary consumers, secondary consumers and tertiary consumers in a given food chain or food web | 10☐ |
| **7D.4** | Draw a food chain and/or food web from a given scenario | 24☐ |
| **7D.5** | Define 'keystone species' and explain how it impacts the ecosystem around it | ITB☐ |
| **7D.6** | Given a scenario, hypothesise the potential impacts of the removal of a keystone species from that situation | 23☐ |
| **7D.7** | Describe an example of the contribution of Aboriginal and Torres Strait Islander peoples' knowledge and perspectives in understanding interdependencies between species in Australian ecosystems | ITB☐ |

## Multiple-choice questions

**1** Asexual reproduction requires
- **A** two parents to produce offspring.
- **B** one parent to produce offspring.
- **C** two clones to produce offspring.
- **D** a variety of parents to produce offspring.

**2** If an organism is injured and loses a section, but that section develops into a new organism, it has reproduced by
- **A** binary fission.
- **B** budding.
- **C** fragmentation.
- **D** propagation.

**3** Chiasmata can only be observed during
- **A** independent assortment.
- **B** crossing over.
- **C** anaphase II.
- **D** meiosis II.

**4** The Tasmanian devil has a chromosome number of $2n = 14$. This means
- **A** the diploid number is 28 chromosomes per cell.
- **B** the species has 14 pairs of chromosomes per cell.
- **C** each cell has 7 homologous pairs.
- **D** a gamete from this species has 7 chromosomes.

**5** At the end of telophase I of meiosis, the number of chromosomes in each daughter cell is
- **A** diploid, and each chromosome is composed of two chromatids.
- **B** haploid, and each chromosome is composed of one chromatid.
- **C** diploid, and each chromosome is composed of one chromatid.
- **D** haploid, and each chromosomes is composed of two chromatids.

ISBN 978-1-108-88711-3

**6** When kangaroos reproduce, the gametes of two parents fuse to form a zygote. After mitosis occurs and the organism grows, the offspring will
- **A** have some genetic similarities to each of the parents.
- **B** be identical to its brothers and sisters.
- **C** be identical to its parents.
- **D** have genetic similarity to just one parent.

**7** Bears hibernating in winter is an example of
- **A** evolution.
- **B** a structural adaptation.
- **C** a physiological adaptation.
- **D** a behavioural adaptation.

**8** A physiological adaptation is best defined as the
- **A** actions or activities of an organism that help it survive.
- **B** physical features of an organism that help it survive.
- **C** internal or cellular features of an organism that help it survive.
- **D** qualities of an organism that make it more likely to reproduce.

**9** While walking through the bush, you look up into the gum trees and observe five koalas and seven kookaburras. What term best describes what you are looking at?
- **A** species
- **B** population
- **C** community
- **D** symbiosis

**10** In Question 9, what organism in the scenario is most likely to act as the producer?
- **A** you (i.e human)
- **B** gum tree
- **C** koala
- **D** kookaburra

## Short-answer questions

**11** Plants are eukaryotic organisms.
- **a** Name the type of cell division that occurs when eukaryotic cells reproduce asexually. (1 mark)
- **b** Name the stages involved in this type of cell division. (1 mark)
- **c** Give reasons why mitosis and meiosis aren't the same despite having similar steps. (2 marks)

**12** State which organisms are the clones of each other when using the techniques embryo splitting and nuclear transfer. (2 marks)

**13 a** Cloning is considered a type of asexual reproduction. Outline the reasons why this is the case. (2 marks)
- **b** Artificial cloning, or using reproductive cloning technology, is also a type of asexual reproduction. However, in animals, it cannot work without the process of meiosis occurring at some point. Explain this by referring to the process of the two types of reproductive cloning technology and the role of meiosis in each. (2 marks)
- **c** Embryo splitting is a reproductive technology that has been used in agriculture for many years. Suggest reasons why a farmer would not consider using such a technique. (1 mark)

**14 a** Name two advantages for an organism if it reproduces asexually. Explain your answer. (2 marks)
- **b** Name two disadvantages for an organism if it reproduces sexually. Explain your answer. (2 marks)

**15** Consider each of the following statements and then classify them as examples of either sexual or asexual reproduction. Explain your choice for each.
- **a** A small section of spider plant drops off the main plant, lands on the ground and begins to grow when the conditions are right. (1 mark)
- **b** Pollen from a male avocado flower fertilises sex cells in the female avocado flower. (1 mark)
- **c** The male and female trout release their gametes into the nest the female has built with her tail. (1 mark)
- **d** A sponge is cut in half and grows into two sponges. (1 mark)

ISBN 978-1-108-88711-3

**16** Consider the images below.

Image A

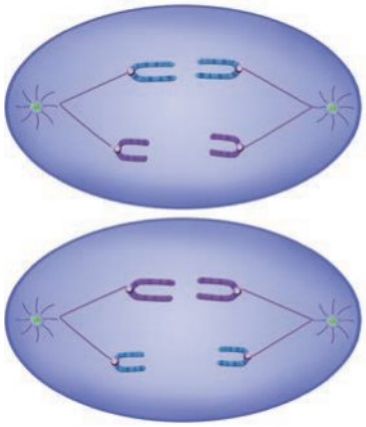
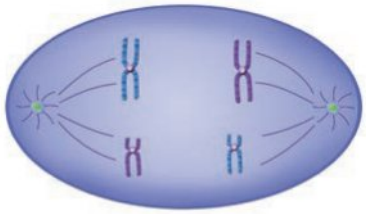


Image B



**a** Name the stages of meiosis shown in image A and image B. (2 marks)

**b** What is the main difference between the stage shown in image A and the stage shown in image B? (2 marks)

**c** There are two ways in which meiosis contributes to the genetic diversity of offspring. Select one way and outline how it contributes to genetic diversity. (2 marks)

**d** Why is it advantageous for a species to have genetic diversity among its individuals? (1 mark)

**17** A Biology teacher saved tomato seeds from a deliciously sweet tomato she had eaten. She planted the seeds in her vegetable garden and some time later the tomato plant bore fruit.

**a** Sadly, the tomatoes that grew were not as sweet as the ones she originally tasted. Explain why this could be the case. (1 mark)

**b** Tomato plants can be reproduced so that the tomatoes from the new plants will taste just as sweet as the original plants. Outline one method that could be used to produce tomato plants in this way. (2 marks)

**c** Explain why the method you have suggested will produce tomatoes that taste just as sweet as the original plants. (1 mark)

**18** The table shows the number of chromosomes in each somatic cell of different organisms.

| Species | Number of chromosomes in each somatic cell | Species | Number of chromosomes in each somatic cell |
|---|---|---|---|
| Earthworm | 36 | Crayfish | 200 |
| Goat | 60 | Potato | 44 |
| Human | 46 | Rice | 24 |

**a** Every organism listed has an even number of chromosomes in its somatic cells. Suggest why this is the case. (2 marks)

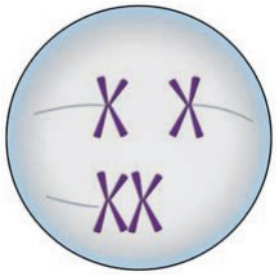
**b** How many chromosomes will each earthworm gamete contain? (1 mark)

**c** Somatic cells divide by mitosis. Why is the ability of somatic cells to divide important? (1 mark)

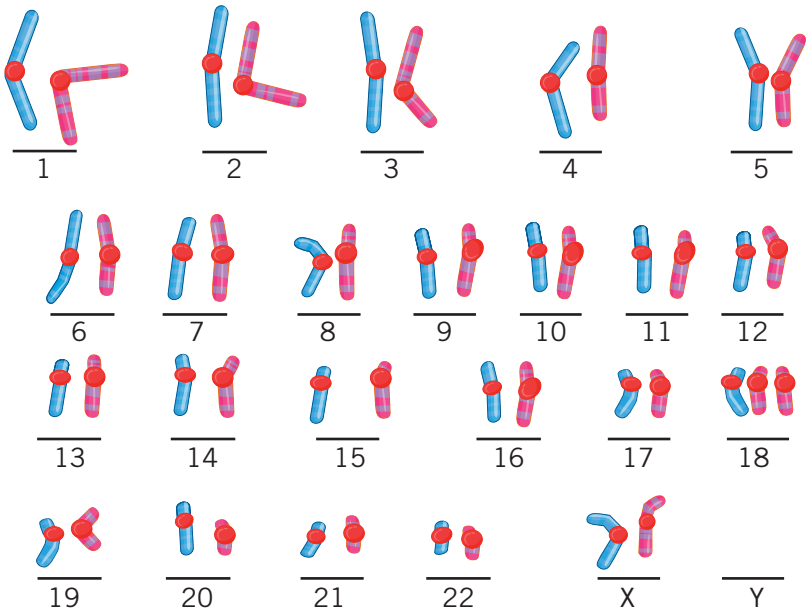
**d** When a somatic cell of a rice plant divides, how many chromosomes will each of the new cells contain? (1 mark)

ISBN 978-1-108-88711-3

**19 a** Meiosis can sometimes go wrong. Identify the name for what has gone wrong in the diagram shown at right. (1 mark)




*Use the diagram below to answer parts* **b** *and* **c**.




**b** What is the biological gender of this person? Explain how you came to your answer. (2 marks)

**c** What is the name of the syndrome this person suffers from? (1 mark)

**d** What is the name of this type of visual representation of chromosomes, and what is it useful for? (2 marks)

**20** Describe an adaptation of a plant or animal and the survival advantage that adaptation gives the organism. Explain how this adaptation may have been applied by Aboriginal and Torres Strait Islander peoples and describe the advantage for survival it gives them. (3 marks)

**21** Describe a specific example of interdependence between species known to Aboriginal and Torres Strait Islander peoples, indicating the benefits for each species. (3 marks)

**22** You buy a pot plant and put it in your kitchen, near the window, where it is just slightly in the shade for most of the day. Over time, you notice that the plant is starting to grow towards the sunlight coming through the window.

**a** What is the word equation for photosynthesis? (1 mark)

**b** What is the process by which the plant transports water from its roots? (1 mark)

**c** Name the process that causes the plant to grow towards the sunlight. (1 mark)

**d** The answer to part **c** is an example of what form of adaptation? (1 mark)

**23** Bees are a keystone species. State the major role that bees play in an ecosystem that earns them this title, and explain three consequences of bees becoming extinct. (4 marks)

**24** While sitting in the garden thinking about the role that bees play in the ecosystem, you notice a number of other organisms around you. Draw a food chain or food web that illustrates the things you might observe in a garden habitat. Ensure you include no fewer than four organisms and include at least one producer, primary consumer and secondary consumer. (4 marks)

ISBN 978-1-108-88711-3

UNIT 2

HOW DOES INHERITANCE IMPACT ON DIVERSITY?

CHAPTER 8

# INHERITANCE

## Introduction

Have you ever wondered why your physical features resemble those of your parents? Or why you have different-coloured eyes or a different blood type from your parents? In the mid-19th century, an Austrian monk named Gregor Mendel was investigating the inheritance and genetics of sweet pea plants by studying the transmission of particular traits (stem height, seed colour and shape) over generations. His early work revealed that genes come in pairs (one from each parent) and established the mathematical pattern of inheritance that is still used today, even though the importance of his work was not recognised until after his death.

With the discovery of DNA in the 20th century, much of Mendel's work could be explained by the inheritance of genes or, more specifically, forms of genes (called alleles), by offspring from their parents. Recent research and technologies now make it possible to screen for the presence or absence of particular gene products and proteins, and even to manipulate genes.

This chapter explores the structure of DNA and its transmission between generations. It also demonstrates how Punnett squares are used to predict the inheritance of traits, and how pedigrees are used to track this over multiple generations in a family.

## Curriculum

**Area of Study 1 Outcome 1**
**How is inheritance explained?**

| Study Design | Learning intentions – at the end of this chapter I will be able to: |
|---|---|
| **From chromosomes to genomes**<br>• The distinction between genes, alleles and a genome<br>• The nature of a pair of homologous chromosomes carrying the same gene loci and the distinction between autosomes and sex chromosomes<br>• Variability of chromosomes in terms of size and number in different organisms | **8A The nature of genes**<br>**8A.1** Define gene, allele and genome<br>**8A.2** Apply the terms gene and allele in the correct context within a question<br>**8A.3** Draw and annotate a pair of homologous chromosomes<br>**8A.4** Explain how chromosomes vary between species |

ISBN 978-1-108-88711-3

| Study Design | Learning intentions – at the end of this chapter I will be able to: |
|---|---|
| **Genotypes and phenotypes**<br>• The use of symbols in the writing of genotypes for the alleles present at a particular gene locus<br>• The expression of dominant and recessive phenotypes, including codominance and incomplete dominance<br>• Proportionate influences of genetic material, and environmental and epigenetic factors, on phenotypes | **8B Introduction to genetics**<br>**8B.1** Define genotype and phenotype<br>**8B.2** Distinguish between genotype and phenotype<br>**8B.3** Identify the difference between dominant and recessive phenotypes<br>**8B.4** Define homozygous and heterozygous<br>**8B.5** Classify genotypes as homozygous or heterozygous<br>**8B.6** Write genotypes for individuals using correct allele combinations for dominant and recessive phenotypes<br>**8B.7** Define epigenetic factors<br>**8B.8** Explain how epigenetic factors affect phenotypes<br>**8B.9** Give examples of environmental factors that affect phenotypes |
| **Patterns of inheritance**<br>• Predicted genetic outcomes for a monohybrid cross and a monohybrid test cross<br><br>**Genotypes and phenotypes**<br>• The expression of dominant and recessive phenotypes, including codominance and incomplete dominance | **8C Monohybrid crosses**<br>**8C.1** Define monohybrid cross and test cross<br>**8C.2** Draw Punnett squares for single gene traits<br>**8C.3** Predict chance of individuals acquiring traits from the genotype and/or phenotypes of the parents<br>**8C.4** Complete a monohybrid test cross<br>**8C.5** Know the ratio expected from different monohybrid test crosses<br>**8C.6** Distinguish between codominance and incompletely dominance<br>**8C.7** Explain how codominance and incomplete dominance are different to dominant and recessive phenotypes<br>**8C.8** Write genotypes for codominant and incompletely dominant and sex-linked traits<br>**8C.9** Define and draw Punnett squares for sex-linked inheritance<br>**8C.10** Outline the relationship between monogenic, polygenic, continuous variation and discontinuous variation |
| **Patterns of inheritance**<br>• Predicted genetic outcomes for two genes that are either linked or assort independently | **8D Dihybrid crosses**<br>**8D.1** Define dihybrid crosses<br>**8D.2** Compare the difference between linked genes with those that independently assort<br>**8D.3** Know the phenotypic ratio for a dihybrid cross between two heterozygous individuals<br>**8D.4** Know the phenotypic ratio for a dihybrid test cross for genes that independently assort<br>**8D.5** Know the phenotypic ratio for a dihybrid test cross for genes that are linked and close together<br>**8D.6** Know the phenotypic ratio for a dihybrid test cross for genes that are linked and far apart |

ISBN 978-1-108-88711-3

| Study Design | Learning intentions – at the end of this chapter I will be able to: |
|---|---|
| • Pedigree charts and patterns of inheritance, including autosomal and sex-linked inheritance | **8E Pedigrees**<br>**8E.1** Identify and represent males and females in pedigrees<br>**8E.2** Identify and represent different relationships using a pedigree<br>**8E.3** Correctly refer to and name affected and unaffected individuals in a pedigree<br>**8E.4** Identify autosomal dominant traits using a pedigree<br>**8E.5** Identify autosomal recessive traits using a pedigree<br>**8E.6** Identify X-linked dominant traits using a pedigree<br>**8E.7** Identify X-linked recessive traits using a pedigree<br>**8E.8** Identify Y-linked traits using a pedigree<br>**8E.9** Use correct genetic terminology to answer pedigree based questions |

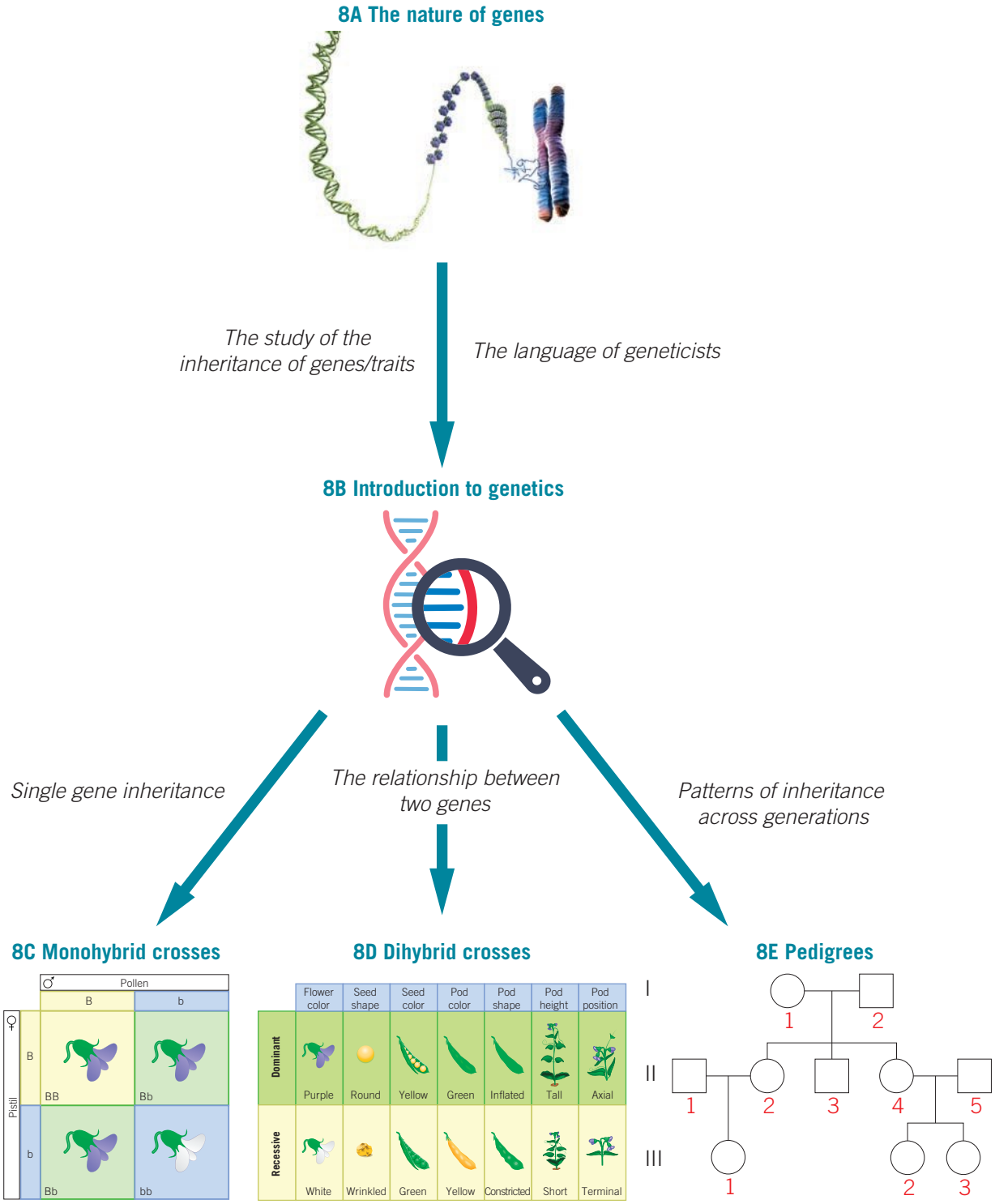


## Glossary

Allele
Alternative splicing
Carrier
Codominant
Complete dominance
Continuous variation
Crossing over
Dihybrid cross
Discontinuous variation
Dominant
Epigenetics
First filial generation ($F_1$)
Gene
Genetics
Gene locus
Genome
Genomics
Genotype
Hemizygous
Heterozygous
Homologous chromosomes
Homozygous
Incomplete dominance
Independent assortment
Inheritance
Linked genes
Monohybrid cross
Multiple alleles
Non-sister chromatids
Parental class
Parental generation
Pedigree chart
Phenotype
Polygenic trait
Proteomics
Punnett square
Recessive
Recombinant class
Segregation
Sex-linked gene
Sister chromatids
Somatic cell
Test cross
Unlinked genes
Vestigial
X-linked
Y-linked

ISBN 978-1-108-88711-3

## Concept map




*See the Interactive Textbook for an interactive version of this concept map interlinked with all concept maps for the course, and for a quiz of prior knowledge from Years 9 & 10 science.*

ISBN 978-1-108-88711-3


# The nature of genes

**Study Design:**

- The distinction between genes, alleles and a genome
- The nature of a pair of homologous chromosomes carrying the same gene loci and the distinction between autosomes and sex chromosomes
- Variability of chromosomes in terms of size and number in different organisms

**Glossary:**

Allele
Alternative splicing
Gene locus
Gene
Genetics
Genome
Genomics
Homologous chromosomes
Inheritance
Non-sister chromatids
Proteomics
Sister chromatids
Somatic cell

## ENGAGE

### Does having more DNA make you smarter or more advanced?

Did you know that an onion has six times more deoxyribonucleic acid (DNA) than a human? Or that an amoeba's total DNA is around 200 times more than a human's? These two organisms aren't very intelligent or complex, so why do they have more DNA than we do?

1A LIVING OR NON-LIVING LINK

7B ASEXUAL REPRODUCTION AND MEIOSIS LINK

As you will remember from Chapter 1, all living organisms contain DNA, some of which codes for proteins. All DNA can be passed on from parents to offspring during meiosis in plants and animals, as you learned in Chapter 7. Alterations, such as addition or duplications of sections of DNA, can occur, and this increased amount of DNA can then be passed onto offspring without affecting their survival. You'll learn more about this when studying protein synthesis in Unit 3. If this were to occur in the regions of DNA that code for proteins, it could create a new protein or trait, making the individual more or less suited to their environment.

UNIT 3 LINK

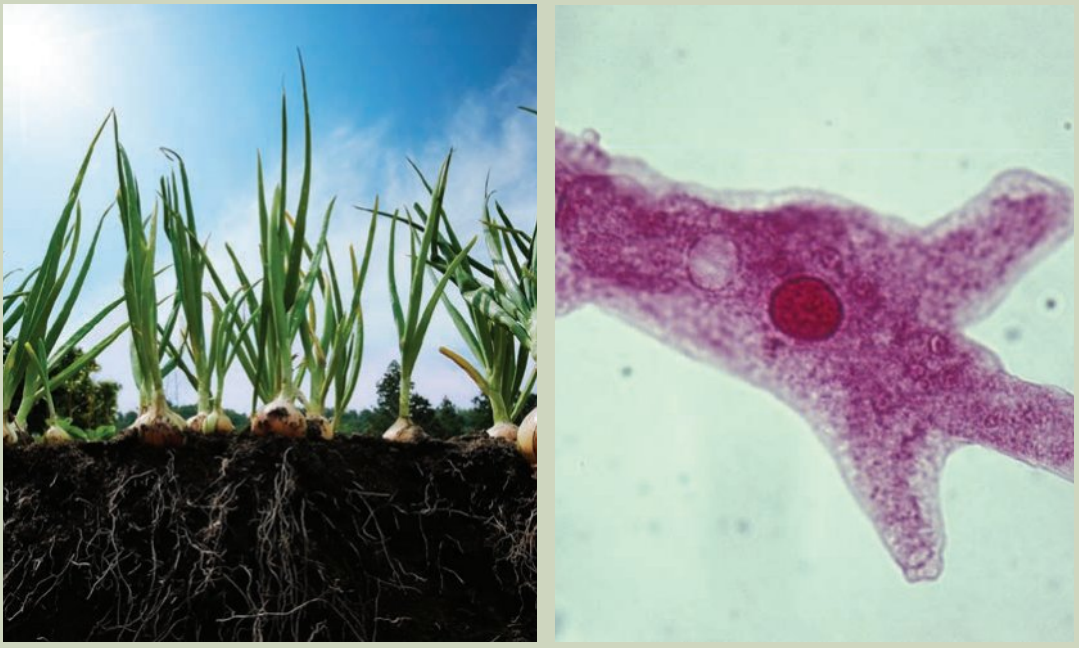


**Figure 8A–1** An onion and an amoeba, both living, each contain more DNA than humans.

ISBN 978-1-108-88711-3

EXPLAIN

## The importance of DNA

DNA is the fundamental macromolecule that is passed from pre-existing cells to new cells. In the same way, offspring inherit their DNA from their parent(s). This chapter focuses on **genetics**, the study of **inheritance**, with particular emphasis on plants and animals. This area of biology has become even more important in the past few decades for the breeding of plants and animals, conservation of species, human health and prevention of disease.

In plant and animal cells, DNA is wound tightly around proteins, called histones, forming chromosomes, as you learned in Chapter 3. These organisms inherit one copy of a particular chromosome from each parent. Each pair of chromosomes, or homologous pair, carries the same types of **genes**, which are sections of DNA that code for a polypeptide (protein). For example, in humans, the gene for the protein insulin is located on chromosome number 11. The insulin gene can be found at this location, called its **gene locus**, on every chromosome 11 in all humans. Copies of the same gene are found at the corresponding locus of each member of a pair of homologous chromosomes. As you will remember, this protein is essential in helping to keep blood glucose levels within a specific narrow range, and so maintaining the correct base sequence of DNA in this gene is crucial to the protein's function.

However, the sequence of DNA bases that code for a gene may not always be exactly the same. These slightly different forms of the gene are referred to as **alleles**. Alleles arise by mutation, which can occur during the replication of DNA, in the 'synthesis' or 'S' phase during interphase in the cell cycle. Mutations may also occur spontaneously or be caused by environmental factors, known as *mutagens*. Ultimately, mutations cause the nucleotide sequence to differ from the normal gene by a few nucelotides or even a single nucleotide. In the case of the insulin gene, the consequence of a mutation is the production of an altered version of insulin that can no longer help maintain stable blood glucose levels. If this mutation occurs in a germline cell (a cell in the ovaries or testes) prior to entering meiosis, the mutation can be passed onto the daughter cell, which is a gamete (egg or sperm, in humans).

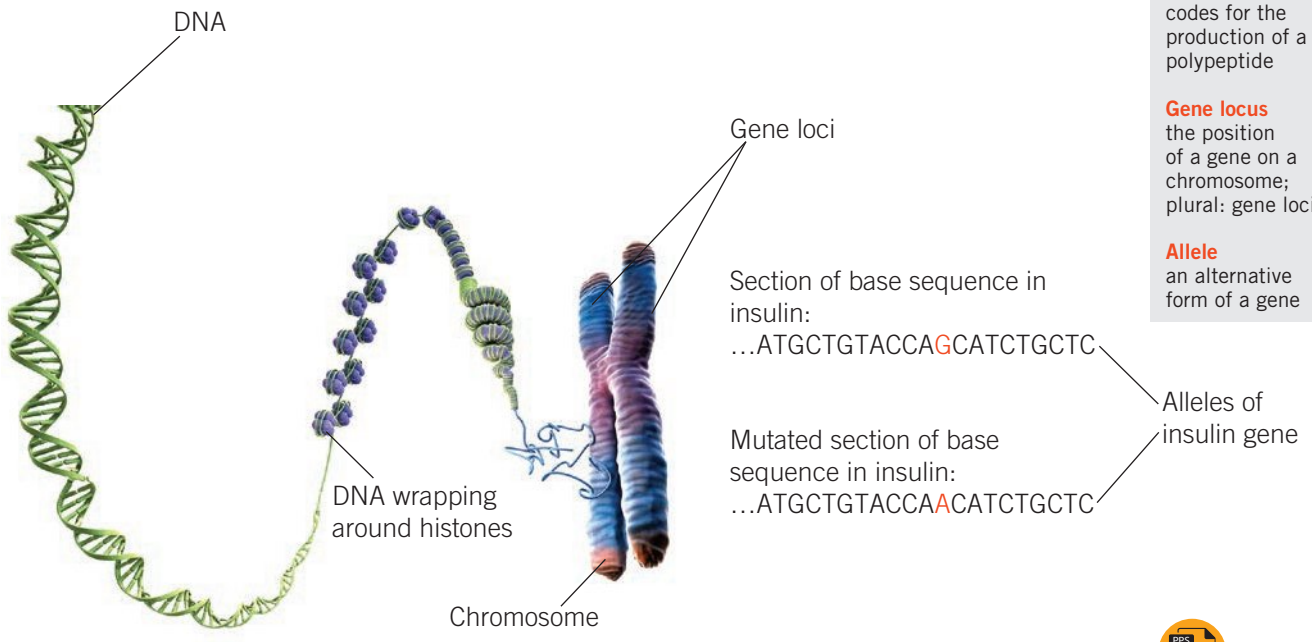



**Figure 8A–2** The relationship between DNA, chromosome formation, gene loci, genes and alleles

VIDEO 8A–1 DNA, CHROMOSOMES AND KARYOTYPES

LINK 3A WHERE DO NEW CELLS COME FROM?

LINK 5B HOMEOSTASIS IN ANIMALS

**Genetics** the study of inheritance

**Inheritance** how genetic material is passed on from one generation to the next

LINK 3B THE CELL CYCLE

LINK 7B SEXUAL REPRODUCTION AND MEIOSIS

**Gene** a sequence of DNA that codes for the production of a polypeptide

**Gene locus** the position of a gene on a chromosome; plural: gene loci

**Allele** an alternative form of a gene

ISBN 978-1-108-88711-3

UNITS 3&4 LINK

**Genome** the complete set of genetic material in an organism/cell at a given time

**Alternative splicing** when a single gene codes for more than one protein

It is estimated that humans have a **genome** of approximately 2.9 billion base pairs wrapped up into 46 chromosomes. This equates to 20 000–25 000 genes but significantly more proteins. An amoeba, on the other hand, is a unicellular eukaryote with a genome size of 6.7 billion base pairs in over 500 chromosomes. Table 8A–1 provides a comparison of the size of the genome of different species. Why do eukaryotic organisms have more proteins than genes, and why do some seemingly basic organisms, like amoebas and onions, have more DNA than complex organisms like humans? This is due to **alternative splicing** and mutations, both of which will be explored in further detail in Units 3 and 4.

**Table 8A–1** Comparing genome size, and gene and chromosome numbers of different species

| Organism | Genome size (base pairs) | Estimated number of genes | Number of chromosomes |
|---|---|---|---|
| *Homo sapiens* (human) | 2 900 000 000 | 20 000–25 000 | 46 |
| *Amoeba dubia* (amoeba) | 670 000 000 000 | unconfirmed | 500 |
| *Allium cepa* (onion) | 18 000 000 000 | unconfirmed | 16 |
| *Canis familiaris* (dog) | 2 400 000 000 | 19 000 | 78 |
| *Drosophila melanogaster* (fruit fly) | 120 000 000 | 13 600 | 8 |
| *Escherichia coli* (bacterium) | 4 100 000 | 2000–3000 | 1 (circular) |

**Genomics** the study of the genome and the relationships between genes

This data has been generated by comparative **genomics**, which compares the genomes of different species. They are compared digitally by lining up the genomes and looking for areas of similarity between them. Comparing genomes in this way provides additional information about the evolutionary relationships between species, allowing biologists to compare individual genes with those of species that have already had their genomes mapped, such as *Drosophila melanogaster*.

**Figure 8A–3** The genome of *Drosophila melanogaster* (fruit fly) was one of the first to be completely mapped by geneticists.

In addition to this, the various functions of different genes, their gene loci and even regions of DNA that do not code for proteins, can be investigated.

In 1990, the Human Genome Project was launched with the global goal of mapping the entire genome within 15 years. In 2003, two years ahead of schedule, this was completed. The study revealed that all humans share most of their DNA base sequences, although every individual is genetically unique (except for identical twins). Although the project is complete, many things are still unknown, such as the function of most genes and the role of regions of DNA that do not code for proteins.

ISBN 978-1-108-88711-3

Comparative genomics has also paved the way for studies comparing a gene's products: proteins. Research such as this has revealed that most proteins do not act alone. Proteins tend to act in metabolic pathways, with the activation of one protein affecting the functioning of another protein, which affects another protein, and so on. As shown in Figure 8A–5, receptors on the cell membrane are made of protein, and when a molecule, such as a protein hormone, binds to these receptors, the protein receptor is activated. This in turn activates an enzyme (type of protein), thus activating other proteins within the cell.


**Figure 8A–4** The Human Genome Project was one of the most ambitious scientific projects ever undertaken, and offered a major opportunity for medical advances.

LINK 1B PLASMA MEMBRANE
LINK 4C THE ENDOCRINE SYSTEM: CHEMICAL CONTROL

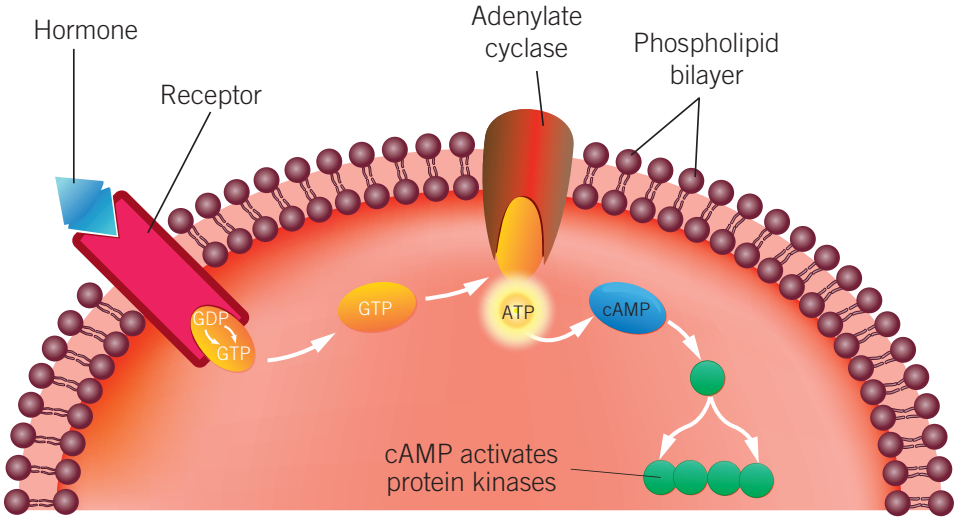



**Figure 8A–5** The mechanism of hormone action, showing how the activation of one protein can affect other proteins within the cell.

The study of the interaction between proteins and their functions in an organism is called **proteomics**.

**Proteomics** the study of proteins and their function

## Check-in questions – Set 1

1 Define the following terms: gene, allele, genome.
2 The following are examples of body features controlled by genes for which there are alleles. In a table with two columns, decide which are genes and which are alleles.
earlobes, flat nose, wrinkly peas, attached earlobes, length of beans, black hair, hair colour, nose shape, texture of peas, long beans
3 Is the following statement true or false?
'In eukaryotes, there are more genes than proteins.'
4 Outline the difference between genomics and proteomics.

ISBN 978-1-108-88711-3

# Chromosomes in eukaryotes

## Inheriting chromosomes

7B SEXUAL REPRODUCTION AND MEIOSIS LINK

**Somatic cell** a body cell containing a full complement of genetic information (diploid)

Recall from Section 7B that all eukaryotic body cells (called **somatic cells**) have two sets of chromosomes. One set has come from each parent, creating a homologous pair in the early stages (prophase I and metaphase I) of meiosis. These cells are referred to as being *diploid*, which is represented as $2n$, where $n$ is the number of chromosomes in one set of the organism's chromosomes. Therefore, in humans, who have 46 chromosomes in their somatic cells, the diploid number, or $2n$, is 46, which means that $n$ is 23.

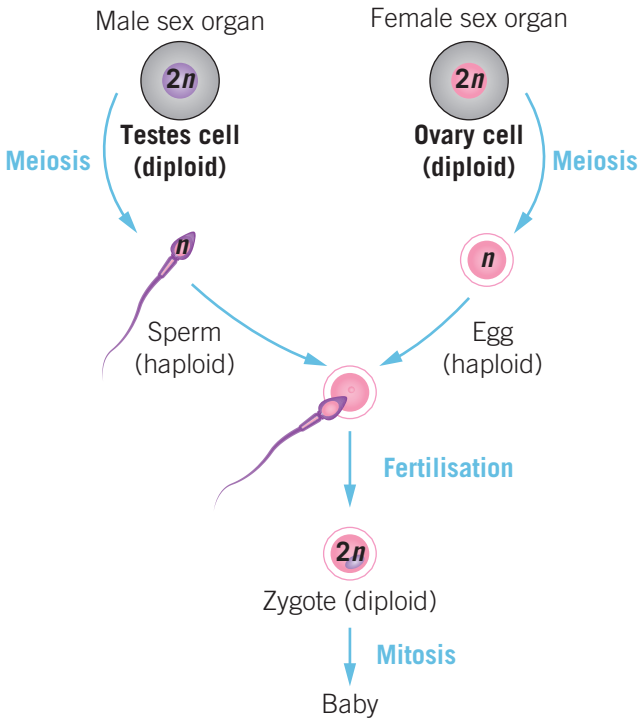



**Figure 8A–6** Meiosis and fusion of gametes (during fertilisation) keep the number of chromosomes constant from one generation to the next.

Additionally, recall that the daughter cells produced from meiosis contain half the number of chromosomes (one set) compared to the parent cell. These cells are referred to as being *haploid* and are represented by $n$. This should confirm for you the reason why meiosis is crucial for an organism: it ensures that each parent's gamete only passes on exactly one (no more and no less) complete set of chromosomes to the offspring. This is shown in Figure 8A–6.

**Homologous chromosomes** chromosomes that have matching structural features (size, banding pattern, centromere location) and gene loci, one from each parent

## The nature of homologous chromosomes

Chromosomes are made up of segments of DNA, which, as you have already learned, are called *genes*. These genes code for many different proteins. Within a species, **homologous chromosomes** contain the same sequence of genes at the same gene loci.

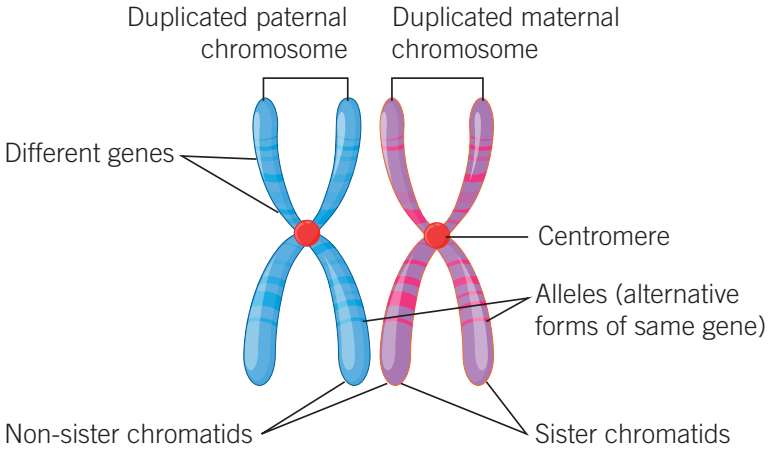



**Figure 8A–7** Homologous chromosomes are paired along their length (synapsis) and have the same length, banding pattern and centromere position.

ISBN 978-1-108-88711-3

However, the alleles for these genes are not necessarily the same for each chromosome in the pair. Note, however, that the two **sister chromatids** on a double chromosome both have the same gene sequence, and therefore allele, as this has resulted from DNA replication in the S phase of interphase. In contrast, the **non-sister chromatids** in the homologous pair can have different variations of genes (alleles) as they come from different parents.

**Sister chromatids** a pair of chromatids (single arms of a double chromosome) from the same parent as a result of DNA replication

**Non-sister chromatids** a pair of chromatids, one from the maternal chromosome and one from the paternal chromosome

Recall that a karyotype is a pictorial representation of the chromosomes in the nucleus of an individual's somatic cell. As an example, the human karyotype has 22 pairs of autosomes and two sex chromosomes. If you zoom in on one of these pairs, chromosome 11 (Figure 8A–8), you will find this chromosome includes the haemoglobin beta gene. This gene is responsible for coding for the haemoglobin protein in red blood cells, which carry oxygen around the body. A five-base section of this gene is shown in the right of the figure. Notice that, in the homologous pair, one of these chromosomes contains the base sequence ACTTC for the normal allele, while the other contains the base sequence ACATC for the mutated sickle cell allele. This mutated allele results in misshapen (sickled) red blood cells. However, as you will learn in Section 8C, this is a recessive disease, meaning that both copies of the mutated allele need to be present for an individual to suffer from sickle cell anaemia. So the individual in this image would be referred to as a *carrier*.

LINK 7B SEXUAL REPRODUCTION AND MEIOSIS

LINK 8C MONOHYBRID CROSSES

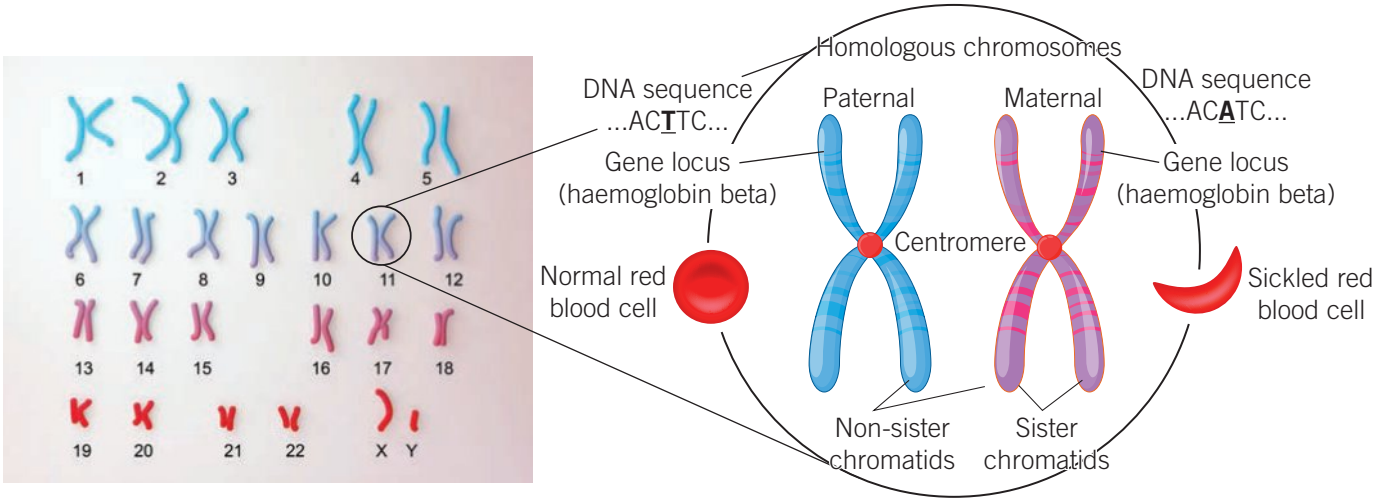



**Figure 8A–8** The gene locus of the haemoglobin beta gene, the gene responsible for coding of the haemoglobin protein in red blood cells. A mutation results in sickle cell anaemia only when an individual has two copies of the mutation.

## NOTE

What is 'normal'? In this chapter, the word is used in its genetic or medical sense, meaning characteristic of the majority of a population. It is not a value judgement.

## Check-in questions – Set 2

WORKSHEET 8A–1 THE DISTINCTION BETWEEN DNA, GENES AND CHROMOSOMES

1 Are the following statements true or false?
   - **a** Chromosomes in a homologous pair always have the same genes.
   - **b** Chromosomes in a homologous pair always have the same alleles.
   - **c** Sister chromatids always have the same genes.
   - **d** Sister chromatids always have the same alleles.
   - **e** Non-sister chromatids always have the same genes.
   - **f** Non-sister chromatids always have the same alleles.
   - **g** A certain gene will always have the same gene loci.

ISBN 978-1-108-88711-3

VIDEO 8A–2 SKILLS: COMPILING TERMS FROM ACROSS DIFFERENT TOPICS

## 8A SKILLS

### Compiling terms from across different topics

In this chapter, it is important to be able to recall much of the knowledge you have learned previously, and to apply it when answering questions. You should already have seen from this section that key terms and diagrams from Chapters 1, 3 and 7 are being used extensively.

It is crucial for your understanding of this section that you know the differences between these terms, how to represent them diagrammatically or label them in a diagram, and use them in the correct written context.

For a diagram like Figure 8A–7, you should be able to explain the difference between sister and non-sister chromatids, and know which contain the same or different alleles/nucleotides. You need to be aware that terms such as 'DNA' and 'gene' could be used interchangeably, and that an allele is just a form of a gene or a specific sequence of nucleotides. You should also be able to add extra detail to these images. In this instance, could you represent and explain how a chromosome unravels to form DNA, and what the structure of DNA looks like? Could you look at this image and explain whether a cell would be going through mitosis or meiosis? If a cell is going through meiosis, what stage includes the presence of pairs of homologous chromosomes?

This skill of adding new information and relating it to previously learned knowledge is crucial for understanding Units 3 and 4 Biology, and for successfully answering questions in assessments and in the end-of-year exam. This is also why developing concept maps and/or mind maps, which have been covered in earlier chapters, is an excellent way to compile and make sense of all this information.

## Section 8A questions

1 What results in the genome of an amoeba being larger than the genome of a human?
2 Compare prokaryotic and eukaryotic chromosomes by outlining two differences between them.
3 Draw one fully labelled diagram that has the following features correctly shown:
   - **a** homologous chromosomes
   - **b** genes
   - **c** gene loci
   - **d** alleles
   - **e** centromere
   - **f** sister chromatids
   - **g** non-sister chromatids.
4 The diploid number ($2n$) in horses is 64.
   - **a** What does $n$ equal?
   - **b** Give two examples of the types of cells in a horse that would be diploid.
5 A karyotype is shown of the chromosomes for *Drosophila melanogaster* (fruit fly).
   - **a** How many chromosomes does this fly have in each somatic cell?
   - **b** How many chromosomes does this fly have in its gametes (sex cells)?
   - **c** Explain why it took geneticists less time to map the entire genome for the fruit fly than for the human.
   - **d** Give two reasons why the fruit fly is commonly used in the laboratory to study the inheritance of traits.
   - **e** Using your knowledge of karyotypes from Section 7B, would the karyotype shown on the right be of a male or female fruit fly? Explain your answer, comparing this karyotype to a typical human karyotype.

Karyotype of *Drosophila melanogaster*

6 Compare sister chromatids and non-sister chromatids within a pair of homologous chromosomes, by listing their similarities and differences.

ISBN 978-1-108-88711-3


# Introduction to genetics

**Study Design:**

- Use of symbols in the writing of genotypes for the alleles present at a particular gene locus
- The expression of dominant and recessive phenotypes, including codominance and incomplete dominance
- Proportionate influences of genetic material, and environmental and epigenetic factors, on phenotypes

**Glossary:**

Complete dominance
Dominant
Epigenetics
Genotype
Heterozygous
Homozygous
Phenotype
Recessive

## ENGAGE

### Genes are the recipe for proteins

Genes are like recipes. However, rather than a cake or a batch of biscuits, they contain the instructions for making proteins. These proteins determine your biological, chemical and physical traits – in fact, most of your traits. We all have almost exactly the same set of genes, so why aren't we all identical? Take a look around you: the person sitting next to you, your teacher, parents and siblings are all different (unless you have an identical twin). As you learned in the previous section, there are different versions of each gene, called alleles. As you inherit these alleles from both your mother and your father, the combinations of these makes you … well … you!

LINK 8A THE NATURE OF GENES

If you've ever made brownies, your recipe might include using dark chocolate. Someone else's recipe may use milk chocolate or white chocolate, or include raspberries or nuts. Even though they are all slightly different, they are still brownies.

This section explores the combinations of some distinctive alleles inherited from your parents, whether these are dominant or recessive, and how genotypes and phenotypes are determined.

ISBN 978-1-108-88711-3

## EXPLAIN

# Basic allelic notation

Most cells in an organism contain the same DNA and therefore the same number of chromosomes. As half your chromosomes are inherited from your mother and the other half from your father, every trait determined by your genes is coded for by two alleles. The two alleles can be the same or different. So in every diploid or somatic cell, there are two copies of a gene.

**Complete dominance** when the allele for the dominant trait completely masks (hides) the allele for the recessive trait

For traits determined by a single gene with only two alleles (**complete dominance**), rather than writing out the entire DNA base sequence for each allele, geneticists use letters to represent these. Commonly, an uppercase or a lowercase letter is used to denote each allele.

For example, consider the gene that codes for earlobes, which can be unattached or attached (Figure 8B–1). The letters 'E' and 'e' can be used to represent these two alleles, where:

'E = unattached' and 'e = attached'.

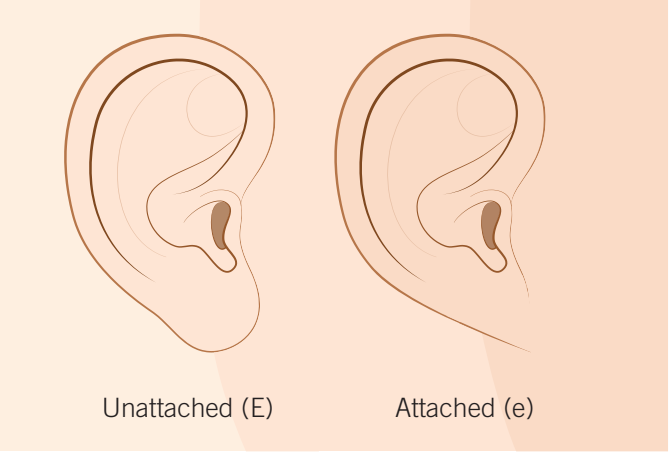



**Figure 8B–1** Unattached versus attached earlobes, a single-gene trait determined by only two alleles

**Dominant** the trait expressed in a heterozygous individual

**Recessive** the trait not expressed in a heterozygous individual

**Heterozygous** having two different alleles for a gene

**Homozygous** having two copies of the same allele for a gene

**Genotype** the combination of alleles that an organism has for a gene

An uppercase letter typically represents the **dominant** trait, and a lowercase letter typically represents the **recessive** trait. Therefore, in this example, unattached earlobes is the dominant trait, and attached earlobes is the recessive trait. A common misconception is to assume that the dominant trait is automatically the trait that is most common in the population, but this is not always the case. The dominant trait is the trait that is seen when an individual has two different alleles for a gene. For example, an individual with both an uppercase and a lowercase letter for the alleles for earlobe appearance (e.g. Ee) is referred to as being **heterozygous** (*hetero* = different, *zygous* = the diploid cell that forms from the fusion of two haploid cells). An individual with two copies of the same allele (e.g. EE or ee) is referred to as **homozygous** (*homo* = same or common).

## Genotypes and phenotypes

The combination of alleles that an organism has for a gene is referred to as its **genotype**. So, for the difference in earlobes, these two alleles can result in three possible genotypes, as shown in Table 8B–1.

**Table 8B–1** Genotype and phenotype of individuals with different earlobes, from Figure 8B–1

| Individual | Description | Genotype | Phenotype |
|---|---|---|---|
| 1 | Homozygous dominant | EE | Unattached earlobes |
| 2 | Heterozygous | Ee | Unattached earlobes |
| 3 | Homozygous recessive | ee | Attached earlobes |

ISBN 978-1-108-88711-3

The new term used in Table 8B–1 is **phenotype**. The phenotype is the observable characteristic or trait that is seen in the individual. An organism's phenotype is determined by its genotype. In the earlobes example, an individual with the genotype 'EE' would have the 'unattached earlobes' phenotype. An individual with the genotype 'Ee' would also have the 'unattached earlobes' phenotype. This is because the 'E' allele for the dominant 'unattached earlobes' phenotype overrides (masks or hides the presence of) the 'e' allele for the recessive 'attached earlobes' phenotype.

An organism's phenotype can also be affected by its environment. For example, an individual may inherit a combination of alleles from their parents that results in them having naturally light-coloured skin. However, that individual's lifestyle may mean they spend an excessive amount of time exposed to sunlight. Production of melanin, the pigment in your skin, increases when you are exposed to sunlight. This increase in melanin gives the skin a tanned appearance. This is just one example of how the environment and genotype together can both have an impact on an individual's observable characteristic, or phenotype.

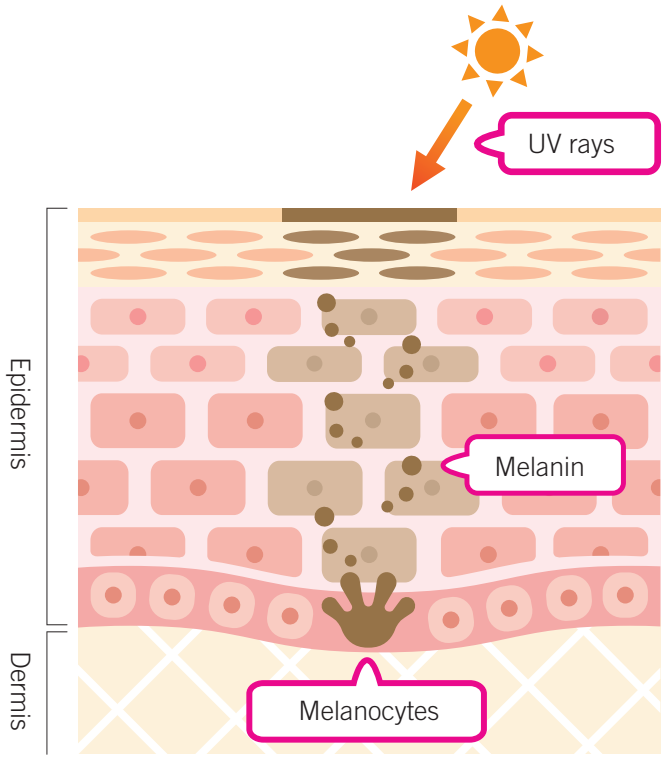



**Figure 8B–2** The change in skin colour caused by the effect of UV rays from the Sun on melanin production in epidermis cells

**WORKSHEET 8B–1** VARIATION: GENOTYPE AND PHENOTYPE

## Check-in questions – Set 1

1 Identify the difference between dominant and recessive.
2 How many alleles are there in a somatic cell for a particular gene? Explain where these alleles come from.
3 Classify the following as either homozygous or heterozygous:
   a AA
   b Bb
   c dd

**Phenotype** a physical characteristic in an organism, determined by the genotype and/or the environment

**Epigenetics** mechanisms that regulate gene expression, causing changes to the phenotype

## Epigenetics

It is known that both genotype and environmental factors can determine an individual's phenotype. In addition to these, **epigenetics** can also influence a phenotype. Epigenetic (*epi* = above, *genetics* = relating to genes or heredity) factors affect how genes are 'read' by cells and these changes influence the production of proteins, by regulating whether the genes are 'turned on' or 'turned off' in cells. This ensures that particular proteins are not produced in cells that do not require them. For example, you would not want the protein keratin, which makes up fingernails and toenails, to be produced in cells in your eye, so this gene is turned off in these cells. Epigenetics is also extremely important in helping to determine the specialisation of a cell from its stem cell or as an embryo develops into a foetus and then into a baby.

LINK **3A** WHERE DO NEW CELLS COME FROM?

ISBN 978-1-108-88711-3

In epigenetics, many things can cause chemical modifications that turn genes on or off, including:

- the food you eat
- where you live and who you interact with
- sleep
- exercise
- ageing.

The field of epigenetics is one of the most rapidly growing areas of research in recent years.

A common example of chemical modification is DNA methylation, a component of many biological processes. In DNA methylation, small chemical methyl groups ($CH_3$) are attached to regions of DNA/genes. This causes the gene to be turned off, and so the protein coded for by that gene is not produced. As you saw in Section 3C, errors in this process can occur, so rather than the gene being turned off, abnormal gene activity arises, leading to conditions such as neurodegenerative disorders, immune disorders and cancer.

3C CELL CYCLE REGULATION AND APOPTOSIS LINK

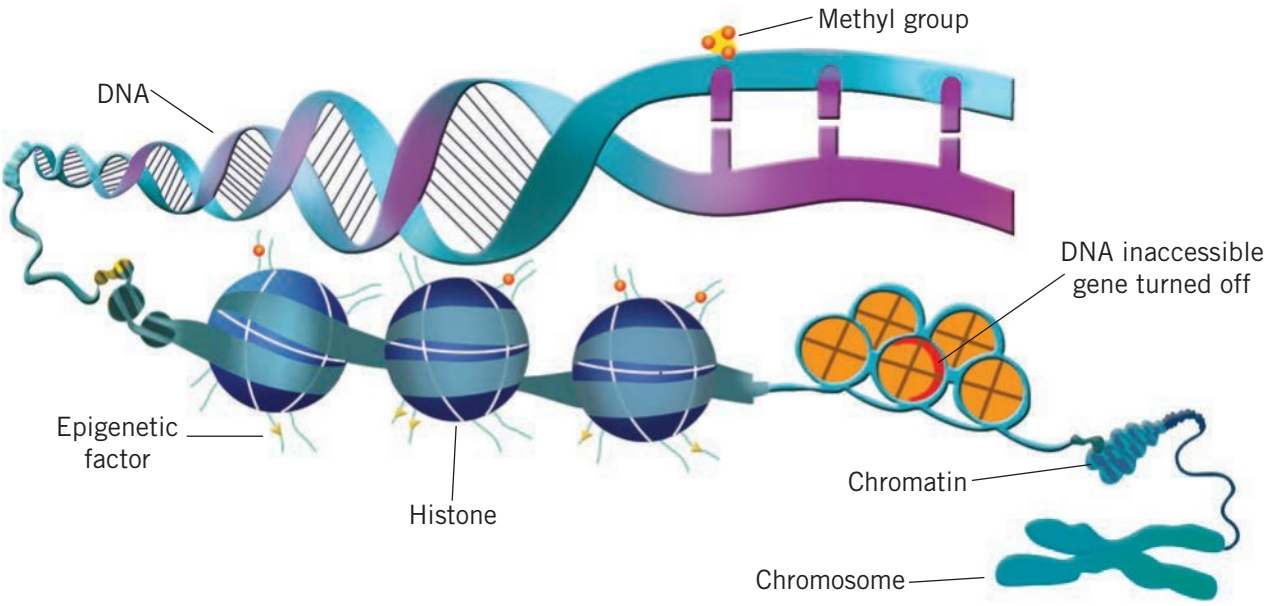



**Figure 8B–3** DNA methylation resulting in an inaccessible gene being turned off

An environmental factor is only classified as epigenetic if the DNA sequence is unchanged. If the DNA sequence is altered, the factor is not classified as epigenetic.

## 8B SKILLS

**Denoting letters for alleles**

If a question requires you to select your own alleles to represent a trait, choose letters that have a distinctly different uppercase and lowercase. In general questions, or even assessment situations, making sure your uppercase 'C' is larger than and distinct from your lowercase 'c' can waste valuable time. Letters like this can also be difficult for you or your teacher to distinguish between.

It is therefore best to avoid using letters such as:

'C' and 'c' 'M' and 'm' 'O' and 'o' 'P' and 'p' 'S' and 's'
'U' and 'u' 'V' and 'v' 'W' and 'w' 'X' and 'x' 'Z' and 'z'

Others such as 'L' and 'l' or 'Y' and 'y' could be hard to distinguish if you are working quickly, so these are best avoided also.

ISBN 978-1-108-88711-3

**'Dominant' vs 'recessive' misconceptions**

The first common misconception is that a 'dominant' phenotype/trait is the one that is most common in a population. This is not the case. For example, Huntington disease is dominant to the normal (non-Huntington disease) phenotype, and this is a condition that definitely does not affect most individuals within the population. 'Dominant' simply refers to the phenotype that overrides and hides the recessive phenotype in a heterozygous individual.

The second misconception or mistake many people make is to refer to 'dominant' and 'recessive' *alleles*. This is not entirely true, as you will see in Section 8C. If you refer to an allele being dominant or recessive compared to another allele, this becomes confusing when investigating traits that do not show complete dominance. There are phenotypes that are codominant, meaning both alleles are expressed in the heterozygous individual, and phenotypes that display incomplete dominance, where a blend of the two alleles is seen in the heterozygote, giving a different phenotype than either parent. Some traits are controlled by more than one gene, and for these it can be difficult to state that one specific allele is dominant over another.

Therefore, this textbook refers to phenotypes or specific *traits*, rather than alleles, as being dominant or recessive.

VIDEO 8B–1 SKILLS: 'DOMINANT' VS 'RECESSIVE' MISCONCPETIONS

LINK 8C MONOHYBRID CROSSES

## Section 8B questions

1 Cystic fibrosis is a homozygous recessive disorder.
   - **a** Using the letter 'c', define the alleles for both 'normal' (not having cystic fibrosis) and 'cystic fibrosis' traits.
   - **b** Why is 'c' not the best letter to use to represent these alleles? Provide a suitable alternative letter to use.
   - **c** Using the alternative letter you provided in part **b**, what is/are the possible genotypes for individuals with cystic fibrosis?
   - **d** What is/are the possible genotypes for individuals without cystic fibrosis?
   - **e** A carrier is a person who carries the cystic fibrosis allele but does not suffer from the disorder. What would their genotype be?

2 Explain the difference between:
   - **a** gene and allele
   - **b** genotype and phenotype
   - **c** homozygous and heterozygous
   - **d** dominant and recessive
   - **e** autosome and sex chromosome.

3 There are three factors that can determine an individual's phenotype.
   - **a** Identify these three factors.
   - **b** Explain the difference between general environmental factors and environmental factors that cause epigenetic changes.
   - **c** Give some examples of epigenetic factors that can regulate gene expression in cells.
   - **d** Draw a diagram that includes both DNA and a chromosome, with the presence of DNA methylation. (*Hint:* Use pages in this section to help.)

ISBN 978-1-108-88711-3

# 8C Monohybrid crosses

**Study Design:**

- Predicted genetic outcomes for a monohybrid cross and a monohybrid test cross
- The expression of dominant and recessive phenotypes, including codominance and incomplete dominance

**Glossary:**

Carrier
Codominant
Continuous variation
Discontinuous variation
Hemizygous
Incomplete dominance
Monohybrid cross
Multiple alleles
Polygenic trait
Punnett square
Sex-linked gene
Test cross
X-linked
Y-linked

## ENGAGE

### Representing genetic crosses

The study of genetics and inheritance began with the garden experiments of an Austrian monk, Gregor Mendel, in the Czech Republic in the mid-19th century. At this time, nothing was known of DNA or its structure, but at a similar time, work was being undertaken by Charles Darwin, in developing his theory on natural selection. (You'll learn more about this in Unit 4.)

UNIT 4 LINK

Mendel's work with key pea plant characteristics, including stem length, seed shape and seed colour, is regarded as the foundation of our understanding today. He observed, counted and recorded the results of 1064 plants. Like Darwin, Mendel noted that offspring resembled their parents. One key result came when he observed flower colour. After crossing a purple-flowered plant and a white-flowered plant, he noticed that all the offspring had purple flowers. However, when he then crossed those purple-flowered plants with each other, the flowers produced were both purple and white; there were no flowers of different colours or mixed colour. As with many other traits we know today, the colour of Mendel's flowers demonstrated that inheritance did not produce a mixture of the two traits, and that the presence of white flowers had skipped a generation. As you learned in Sections 8A and 8B, we now call these alternative forms of a gene 'alleles', and we refer to particular phenotypes as being dominant or recessive.

8A THE NATURE OF GENES LINK

8B INTRODUCTION TO GENETICS LINK

This section explores how scientists represent the passing on of alleles from parents to offspring using Punnett squares, and how Punnett squares are also used to predict genotypic and phenotypic ratios.

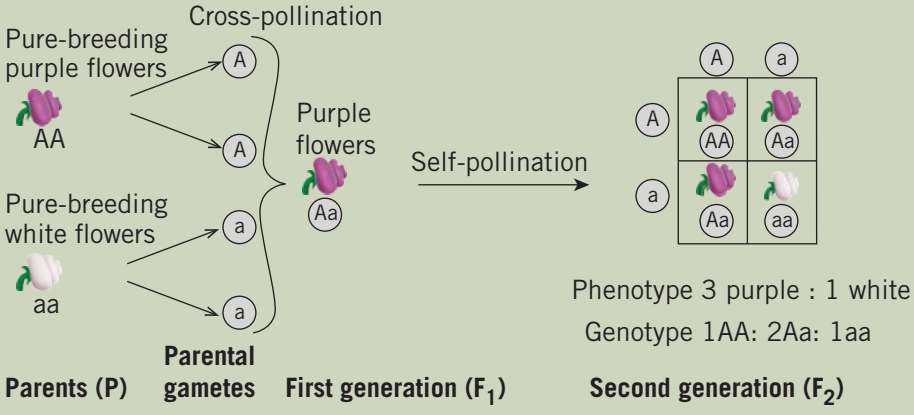



**Figure 8C–1** One of Mendel's pea plant experiments

ISBN 978-1-108-88711-3

## EXPLAIN

# Investigating the inheritance of one gene

Recall from Section 7B that gametes are formed from the process of meiosis, and that gametes are haploid. This means they only contain one set, or half, of the DNA compared to typical somatic diploid cells. Therefore, each gamete carries only one allele of a particular gene for that individual.

LINK **7B** SEXUAL REPRODUCTION AND MEIOSIS

To return to the example of earlobes from Section 8B, if a female has unattached earlobes with a genotype 'Ee', she will pass on either the 'E' or the 'e' allele to each of her gametes.

**VIDEO 8C–1** MONOHYBRID CROSSES

We can use this knowledge of the formation of gametes with the presence of particular alleles in parents from Figure 8C–2 to determine the possibility of different genotypes, and consequently phenotypes, in the offspring. This can be done using a **Punnett square**. A Punnett square represents the possible alleles in the gametes formed by each parent, where one parent is written along the top of the table and the other parent is written down the left-hand side of the table. It also shows the potential combination of alleles from both parents (genotype) in the offspring.

**Punnett square** a diagram used to determine the expected genotypes and phenotypes of offspring from the genotypes of both parents

1 Diploid cell showing one pair of homologous chromosomes, each carrying a different allele for earlobe appearance (individual is heterozygous)

2 Chromosomes paired up during prophase I of meiosis (note the absence of nuclear membrane here)

3 Separation of homologous chromosomes after telophase in meiosis I (note the re-formation of nuclear membrane here)

4 Separation of sister chromatids following meiosis II resulting in four haploid daughter cells

5 Cells form gametes in the female (ova), two with the 'E' allele and two with the 'e' allele

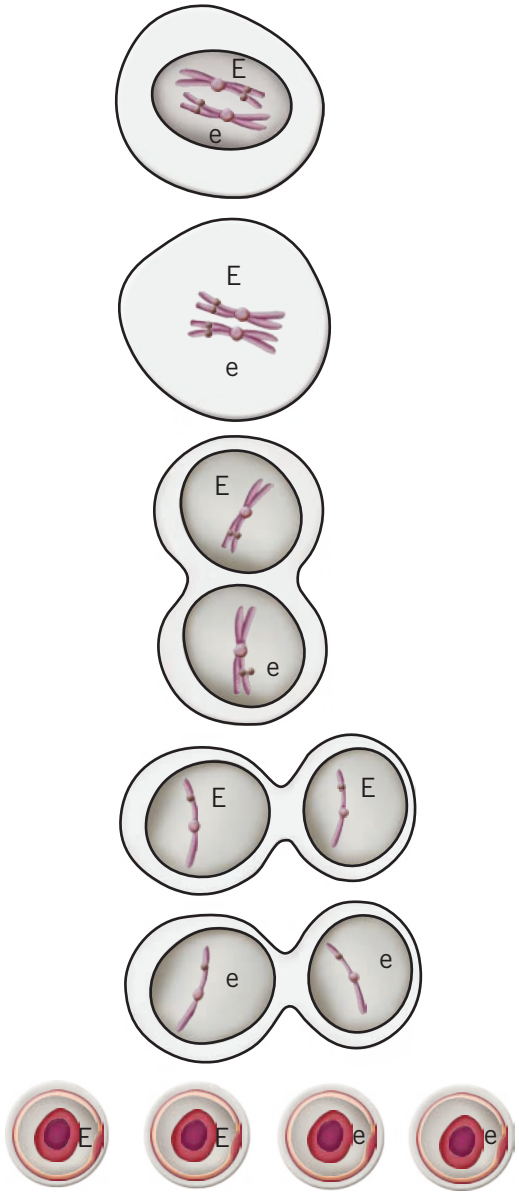



**Figure 8C–2** Passing on of alleles for earlobe appearance in a heterozygous female from diploid to haploid cells in the process of meiosis. The same process would take place for males in the production of sperm.

ISBN 978-1-108-88711-3

**Monohybrid cross** a genetic cross carried out to determine the possible genotypes and phenotypes of offspring inheriting one gene only

We will begin by investigating the inheritance of one gene using a Punnett square. This is called a **monohybrid cross** (*mono* = one, *hybrid* = the combining of two different elements), because you are determining the possible allele combinations of offspring for one gene only.

**VIDEO 8C–2** STEPS IN USING A PUNNETT SQUARE

## Steps in using a Punnett square

Follow these steps when working out a problem using a Punnett square.

**Step 1** Choose an appropriate letter (or the one asked of you in the question) to represent the alleles for the gene.

**Step 2** Draw a table like the one below and fill in the genotype of each parent, with a pair of letters representing their two alleles for that gene. One parent is written at the top and the other down the left.

| | | Genotype of female: Ee | |
|---|---|---|---|
| | | | |
| Genotype of male: Ee | | | |
| | | | |

**Step 3** Split the genotype of each parent by writing a single allele in each of the boxes below or next to the genotype. These are the gametes that would be formed in that parent.

| | | Genotype of female: Ee | |
|---|---|---|---|
| | | E | e |
| Genotype of male: Ee | E | | |
| | e | | |

Gametes for female parent

Gametes for male parent

**Step 4** Combine the alleles that align with the column and row for the first box (as shown). Always write these with the uppercase letter first. Then do the same for the other three boxes in the table. These form the possible genotypes for offspring.

| | | Genotype of female: Ee | |
|---|---|---|---|
| | | E | e |
| Genotype of male: Ee | E | EE | |
| | e | | |

Possible genotypes of offspring

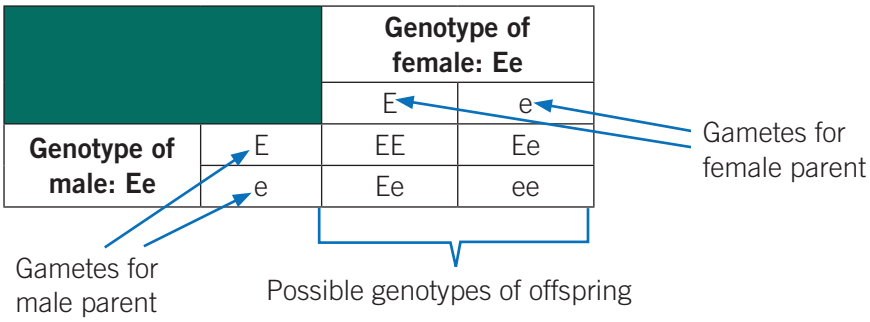
**Step 5** Write down the genotypic and phenotypic ratios for the offspring:
Genotypic ratio = 1 EE : 2 Ee : 1 ee
Phenotypic ratio = 3 dominant phenotype : 1 recessive phenotype

*Note*: You will need to state exactly what the actual dominant and recessive phenotypes are in the phenotypic ratio when when answering a question. This is shown in the worked examples throughout this section.

ISBN 978-1-108-88711-3

## Putting Punnett squares into practice

Putting this into the context of an example, imagine that both parents are heterozygous for unattached earlobes – 'Ee'. Therefore, in the female parent we know that each time an ovum is produced, it will have either the 'E' (unattached earlobes) or 'e' (attached earlobes) allele. Similarly, in the male parent, half of the sperm will have the 'E' allele and the other half will have the 'e' allele. From this we can set up the Punnett square, as shown here.




Notice that from a genetic cross between two heterozygous parents, the offspring can have any of the three possible genotypes. In fact, any cross between two heterozygous individuals will always give the same ratio of genotypes (1 : 2 : 1) and phenotypes (3 : 1).

The reason for the difference between these ratios is that the presence of the capital 'E' allele in the two heterozygous genotypes means that both these possibilities will display the dominant trait, as will the homozygous genotype. These ratios are represented as:

Genotypic ratio = 1 EE : 2 Ee : 1 ee

Phenotypic ratio = 3 unattached earlobes : 1 attached earlobes

Also note that these ratios are all determined based on probability. In real life, if you had a sample size of 100 individuals, you would not expect exactly three-quarters (75) of them to have unattached earlobes and one-quarter (25) of them to have attached earlobes. However, the numbers should be relatively close to these values. The larger the sample size of individuals being compared, the closer the actual numbers will be to those predicted by the ratios from the Punnett square.

The genotypic and phenotypic ratios will be different depending on the genotypes of the parents. If both parents are homozygous dominant, 'EE', then the only allele they will pass onto their gametes is 'E', so all offspring will have the same genotype and phenotype as both parents. The same applies to the scenario where both parents are homozygous recessive. All offspring will receive the lowercase 'e' allele, therefore again displaying the same genotype and phenotype as both parents.

The only other possible parental gen

ISBN 978-1-108-88711-3

VIDEO WORKED EXAMPLE 8C–1

## Worked example 8C–1

**Homozygous dominant × Heterozygous**

A homozygous dominant female parent for unattached earlobes is crossed with a heterozygous male parent.

| | | Genotype of female: EE | |
|---|---|---|---|
| | | E | E |
| Genotype of male: Ee | E | EE | EE |
| | e | Ee | Ee |

Genotypic ratio = 1 EE : 1 Ee

Phenotypic ratio = 1 unattached earlobes

*Note:* Where all genotypes or phenotypes of offspring are the same, use '1' (in this case meaning 'all') to represent the ratio.

## Check-in questions – Set 1

1 Briefly describe the steps required to set up a Punnett square.

2 Cystic fibrosis is a recessive hereditary disorder that results in the production of thick mucus, which leads to the blockage of pancreatic ducts, intestines and airways, resulting in digestive and respiratory system infections. Use 'F' to represent the allele for the normal condition and 'f' to represent the allele for cystic fibrosis.

- **a** If two carriers for the cystic fibrosis allele have a child, what is the chance that their child will suffer from cystic fibrosis? Use a Punnett square to explain your answer.
- **b** If a male carrier has a child with a homozygous normal female, what are the chances of the couple having a child with cystic fibrosis?

### Test crosses

**Test cross**
a genetic cross where an organism with the dominant phenotype (unknown genotype) is crossed with a homozygous recessive organism

Hopefully, by now you will have realised that an individual who displays the dominant phenotype could have one of two possible genotypes: homozygous (EE) or heterozygous (Ee). In order to determine this individual's genotype, a **test cross** is carried out. A test cross involves crossing the dominant parent (with an unknown genotype) with a homozygous recessive parent. The phenotype of the offspring produced can then be used to determine the genotype of the unknown parent – this is why it is called a 'test' cross. The possible outcomes for each situation are shown in the next two worked examples.

VIDEO WORKED EXAMPLE 8C–2

## Worked example 8C–2

**Homozygous dominant × Homozygous recessive**

A homozygous dominant female parent for unattached earlobes is crossed with a homozygous recessive male parent.

| | | Genotype of female: EE | |
|---|---|---|---|
| | | E | E |
| Genotype of male: ee | e | Ee | Ee |
| | e | Ee | Ee |

Genotypic ratio = 1 Ee

Phenotypic ratio = 1 unattached earlobes (i.e. expect 100% unattached earlobes)

ISBN 978-1-108-88711-3

## Worked example 8C–3

VIDEO WORKED EXAMPLE 8C–3

**Heterozygous × Homozygous recessive**

A heterozygous female parent for unattached earlobes is crossed with a homozygous recessive male parent.

| | | Genotype of female: Ee | |
|---|---|---|---|
| | | E | e |
| Genotype of male: ee | e | Ee | ee |
| | e | Ee | ee |

Genotypic ratio = 1 Ee : 1 ee
Phenotypic ratio = 1 unattached earlobes : 1 attached earlobes (i.e. expect 50% unattached and 50% attached earlobes)

### NOTE

In Worked example 8C–2, if the genotype is homozygous dominant, then all offspring will be heterozygous and therefore display the unattached earlobe phenotype. On the other hand, in Worked example 8C–3, if the genotype is heterozygous, then the offspring are expected to be a mix of the dominant phenotype and the recessive phenotype.

If any individuals with attached earlobes (or, more generally, individuals with the recessive phenotype) were produced, then the unknown parent must be heterozygous (Ee).

Another term that you will encounter in questions is 'pure-breeding'. This refers to when an individual is homozygous (either dominant or recessive) and will therefore pass on only one possible allele. For their offspring to also be pure-breeding and have the same phenotype, the other parent would also need to be pure-breeding for the same dominant or recessive trait.

## Check-in questions – Set 2

1 Define 'test cross', using correct terminology in your answer.

2 a If a tall pea plant is homozygous (TT), what results will you obtain if you cross it with a dwarf plant (tt)?

b If the same tall pea plant was heterozygous, what results would you obtain if you crossed it with a dwarf plant?

ISBN 978-1-108-88711-3

## Codominance and multiple alleles

8A THE NATURE OF GENES LINK

**Multiple alleles** when there are three or more alleles for a gene

You have seen that the gene for earlobe appearance has two alleles. Remember the example of sickle cell anaemia from Section 8A – this example discussed two alleles of the haemoglobin beta gene. But, in fact, it has more than two alleles. Many characteristics are coded for by more than two alleles (**multiple alleles**).

The same rules apply as previously. Even though there are more than two alternative forms of the gene, only two can be present in a single organism and determine their genotype. Rather than using a single letter, as was done with the previous example of earlobes, geneticists sometimes use a letter or a combination of letters (to represent the name of the gene or its location) with a superscript letter (to represent the allele). This is shown here and in Figure 8C–3:

**NOTE**

Hb is the abbreviation for haemoglobin.

$Hb^N$ = normal red blood cell (can carry oxygen efficiently)

$Hb^S$ = sickled red blood cell (cannot carry oxygen efficiently)

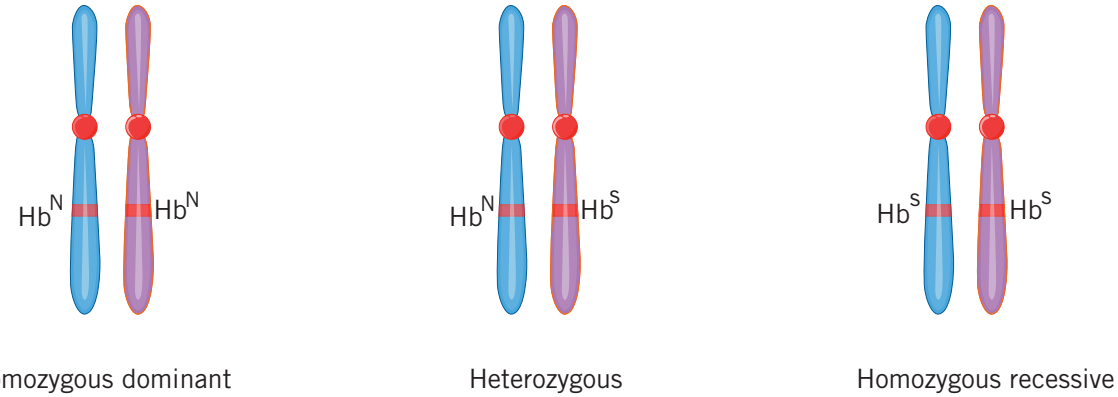



**Figure 8C–3** Genotypic representations of different individuals using letter and superscript letter notation to represent alleles for different traits

So, for the three individuals shown in Figure 8C–3, we can combine the two alleles to form their genotype. The phenotype determined by this genotype is also summarised in Table 8C–1.

**Table 8C–1** Genotype and phenotype of the normal or sickle cell anaemia individuals from Figure 8C–3

| Individual | | Genotype | Phenotype |
|---|---|---|---|
| 1 | $Hb^N\ Hb^N$ | Homozygous dominant | Normal red blood cells |
| 2 | $Hb^N\ Hb^S$ | Heterozygous | Normal *and* sickled red blood cells |
| 3 | $Hb^S\ Hb^S$ | Homozygous recessive | Sickled red blood cells |

**Codominant** when both alleles are expressed in the phenotype of an organism

As the heterozygous individual displays both alleles – for the normal phenotype and the sickle cell phenotype – we say that these alleles are **codominant**.

ISBN 978-1-108-88711-3

Another well-known example of codominance is blood groups. There are four blood groups: A, B, AB and O. There are three alleles for blood type: $I^A$, $I^B$ and $I^O$. The possible genotypes and phenotypes are shown in Table 8C–2.

**Table 8C–2** Genotypes and phenotypes of different blood groups

| Genotype | Phenotype (blood group) |
|---|---|
| $I^AI^A$ | A |
| $I^AI^O$ | A |
| $I^AI^B$ | AB |
| $I^BI^B$ | B |
| $I^BI^O$ | B |
| $I^OI^O$ | O |

From the table you can see that alleles $I^A$ and $I^B$ are codominant (when both are present, the individual has AB blood type). Both $I^A$ and $I^B$ are dominant over $I^O$ (in other words, $I^O$ is masked by the presence of either $I^A$ or $I^B$).

## Worked example 8C–4

VIDEO WORKED EXAMPLE 8C–4

**Multiple alleles**

A woman with blood group O married a man with blood group A. Assuming the man is heterozygous, what is the chance of their first child having blood group A?

| | | Genotype of female: $I^OI^O$ | |
|---|---|---|---|
| | | $I^O$ | $I^O$ |
| Genotype of male: $I^AI^O$ | $I^A$ | $I^AI^O$ | $I^AI^O$ |
| | $I^O$ | $I^OI^O$ | $I^OI^O$ |

Genotypic ratio = 1 $I^AI^O$ : 1 $I^OI^O$

Phenotypic ratio = 1 blood type A : 1 blood type O

Therefore, the chance of the first child having blood group A is $\frac{1}{2}$ or 50%.

## Check-in questions – Set 3

1 Explain the difference between 'codominance' and 'multiple alleles'.

2 A flower colour is due to codominance. The flower colours are yellow and blue. Yellow is represented as '$C^Y$' and blue is represented as '$C^B$'. Both these colours are dominant over white, represented as 'c'.

- **a** Write all possible genotypes for a blue-coloured flower.
- **b** Write the phenotypes for the following genotypes that could be present in the flowers.
  - **i** $C^BC^Y$
  - **ii** $C^Yc$
  - **iii** cc

ISBN 978-1-108-88711-3

## Incomplete dominance

**Incomplete dominance** when the allele for the dominant phenotype does not completely mask the presence of the allele for the recessive phenotype, and a blend of both alleles occurs

In the case of the gene determining earlobe appearance, one phenotype is dominant over the other. However, as you have seen, for other genes this is not always the case. Variations in phenotypes can also result when a combination of both parental phenotypes for a given trait is observed in the offspring. This is referred to as codominance, and was covered earlier.

There are also scenarios where one phenotype is not dominant or codominant with the other phenotype. Instead, a kind of intermediate phenotype is observed in offspring, due to a blending of both alleles. This is referred to as **incomplete dominance**.

An example of this can be seen in roses. When a pure-breeding red rose, with allele $F^R$, is crossed with a pure-breeding white rose, with allele $F^W$, the offspring will all be heterozygous. However, rather than showing a red, white, or red and white phenotype, a pink rose is produced (that is, a blend of both parents' phenotypes). This can be seen in Figure 8C–4 and the following worked example.

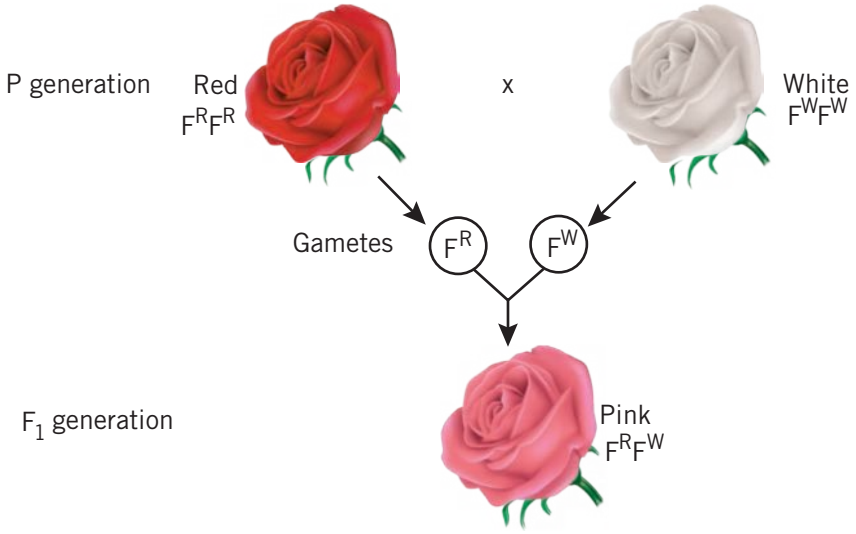



**Figure 8C–4** Incomplete dominance in roses: a cross between pure-breeding red and white roses produces all pink roses

VIDEO WORKED EXAMPLE 8C–5

## Worked example 8C–5

### Incomplete dominance

A pure-breeding red rose, with allele $F^R$, is crossed with a pure-breeding white rose, with allele $F^W$. All roses produced are pink. Using a Punnett square, show the genotype for the pink flowers and how this is possible.

| | | Genotype of red rose: $F^RF^R$ | |
|---|---|---|---|
| | | $F^R$ | $F^R$ |
| Genotype of white rose: $F^WF^W$ | $F^W$ | $F^RF^W$ | $F^RF^W$ |
| | $F^W$ | $F^RF^W$ | $F^RF^W$ |

Genotypic ratio = 1 $F^RF^W$
Phenotypic ratio = 1 pink rose
Therefore, the genotype for pink roses is $F^RF^W$.

ISBN 978-1-108-88711-3

## Comparing complete, incomplete and codominance

Table 8C–3 outlines the differences between the three types of inheritance covered in this section.

**Table 8C–3** Differences between complete, incomplete and codominance

| | Complete dominance | Codominance | Incomplete dominance |
|---|---|---|---|
| Pure-breeding parental genotypes and phenotypes | RR (red) and rr (white) | $F^RF^R$ (red) and $F^WF^W$ (white) | $F^RF^R$ (red) and $F^WF^W$ (white) |
| Gametes | R and r | $F^R$ and $F^W$ | $F^R$ and $F^W$ |
| $F_1$ genotypes | Rr | $F^RF^W$ | $F^RF^W$ |
| $F_1$ phenotypes | Red | Red and white | Pink |
| Heterozygous individual | Red (same phenotype as the individual with dominant phenotype) | Red and white (a combination of the phenotypes of both parents) | Pink (a blend/intermediate phenotype from both parents) |

## Check-in questions – Set 4

1 Explain how incomplete dominance is different from codominance.

2 Tail length in dogs can be determined by incomplete dominance. Offspring of long-tailed and short-tailed parents usually have medium-length tails. If a male dog with a medium-length tail is bred with a female with a short tail, what are the chances of the offspring having medium tails? Use '$H^S$' to represent short tail and '$H^L$' to represent long tail.

## Sex-linked genes

All the genes you have studied so far have been on autosomes. However, the sex chromosomes also contain many genes. A common **sex-linked gene** located on the X chromosome is one that produces a pigment in the cones of the retina. In some individuals, deficiencies or complete absence of these cones can result in colour blindness.

**Sex-linked gene** a gene located on a sex chromosome (X or Y in humans)

**X-linked** refers to a gene that is located on the X chromosome (in humans)

Red–green colour blindness is the most common inherited form of colour blindness and is caused by an **X-linked** (located on the X chromosome in humans) recessive gene. Therefore, its gene locus is on the X chromosome only; it does not exist on the Y chromosome, which is much shorter and carries fewer genes, as shown in Figure 8C–5.

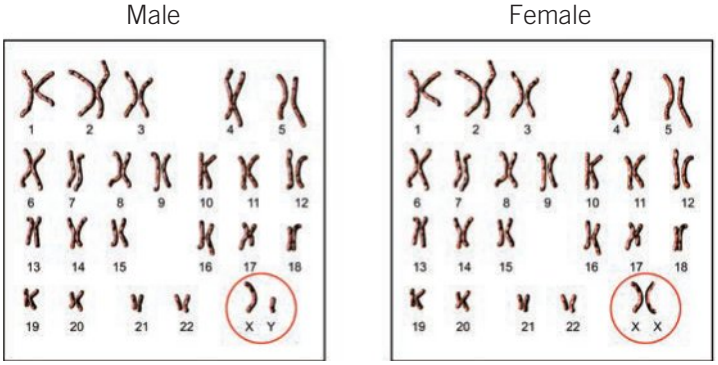



**Figure 8C–5** Human karyotypes showing the size difference between the X and Y chromosomes

ISBN 978-1-108-88711-3

**7B** SEXUAL REPRODUCTION AND MEIOSIS LINK

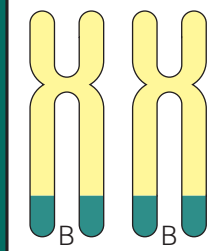
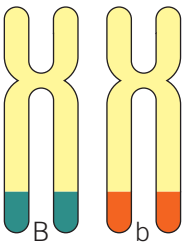
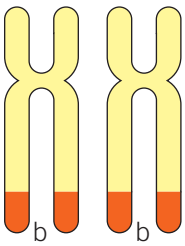
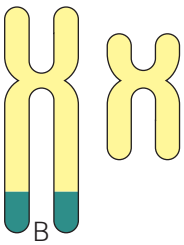
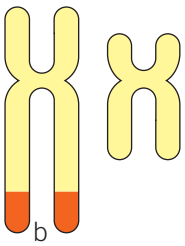
Recall from Section 7B that a female has two X chromosomes and a male has a single X and a single Y chromosome. This means that, for a female to be affected, she must inherit two alleles for the red–green colour-blind gene. If she only inherits one copy of the allele for red–green colour blindness, then she is referred to as a **carrier**. A male, on the other hand, only needs to inherit one colour blind allele, and this must come from the mother because the father passes on the Y chromosome to their sons. Males can never be carriers for a sex-linked gene. This is because, unlike other genes where two alleles are present in the individual, sex-linked genes in males only have one allele. Therefore, we say that males are **hemizygous**. As such, males are affected more frequently (approximately 8%) by sex-linked traits than females (less than 1%).

**Carrier**
an individual who has one copy of an allele for a trait but does not phenotypically express that trait

**Hemizygous**
when an individual, usually a male, has only one copy of an allele for a gene

Therefore, the possible genotypes for males and females are different from those for genes located on autosomes, and are also represented differently. This can be seen in Table 8C–4. The table shows how sex-linked genes are inherited and that this process is exactly the same as for other genes on autosomes.

**Table 8C–4** The genotypes and phenotypes of males and females with the X-linked recessive red–green colour-blind disorder

| | Females | | | Males | |
|---|---|---|---|---|---|
| **Diagram of the sex chromosomes** |  |  |  |  |  |
| **Genotype** | $X^BX^B$ | $X^BX^b$ | $X^bX^b$ | $X^BY$ | $X^bY$ |
| **Phenotype** | Normal female | Normal female (carrier) | Red–green colour-blind female | Normal male | Red–green colour-blind male |

**Y-linked**
refers to a gene that is located on the Y chromosome (in humans)

There are also **Y-linked** genes. These genes occupy a gene locus on the Y chromosome and therefore in humans are only present in males. With any Y-linked gene, if the father has the trait, then all his sons will also inherit the trait as he passes the Y chromosome to them. No daughters will show the trait, as they inherit the X chromosome from their father.

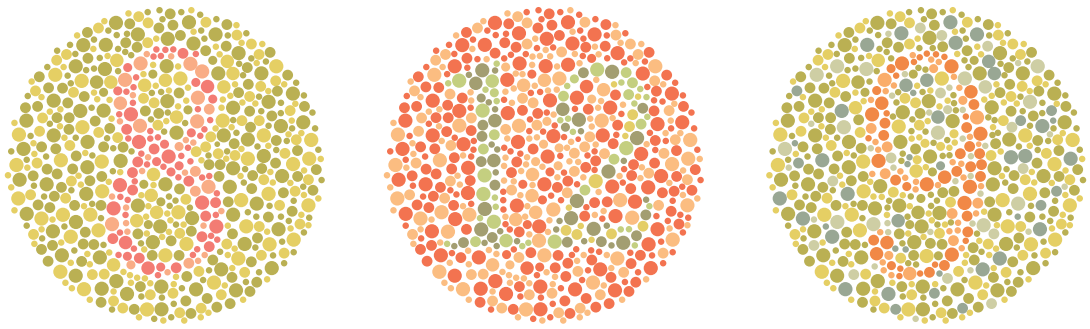


**Figure 8C–6** People with red–green colour blindness may find it difficult to see the numbers in the circles

ISBN 978-1-108-88711-3

## Worked example 8C–6

VIDEO WORKED EXAMPLE 8C–6

### Sex-linked genes

Red–green colour blindness is an X-linked condition. If a homozygous normal female married a colour-blind male, what would be the chances of them having a colour-blind child? Show all working, including the sex in your phenotypes.

| | | Genotype of female: $X^BX^B$ | |
|---|---|---|---|
| | | $X^B$ | $X^B$ |
| Genotype of male: $X^bY$ | $X^b$ | $X^BX^b$ | $X^BX^b$ |
| | Y | $X^BY$ | $X^BY$ |

*Note:* All the female offspring in this example will be carriers of the red-green colour-blind allele.

Genotypic ratio = 1 $X^BX^b$ : 1 $X^BY$
Phenotypic ratio = 1 normal female : 1 normal male
Therefore, chance of having a colour-blind child is 0%.

### NOTE

In the phenotypic ratio for Worked example 8C–6, the gender must be included as well as the observable characteristic they show.

See the Skills box for more examples of how to determine percentages of individuals in the context of how questions are worded. This is particularly relevant to sex-linked genes if gender is mentioned.

## Inheritance of characteristics determined by multiple genes

WORKSHEET 8C–1 PUNNETT SQUARES FOR MONOHYBRID CROSSES

A monohybrid cross involves a single gene, and this is the type of cross we have looked at so far. By contrast, **polygenic** (*poly* = many, *genic* = gene) **traits** are due to the action of many genes. Some examples of characteristics that are determined by multiple genes are skin colour, eye colour and height. If height was controlled by a single gene where the allele for one phenotype was completely dominant to the other, there would be short people and tall people, with nothing in between. Polygenic traits show **continuous variation**, whereas traits determined by a single gene (monogenic) show **discontinuous variation**.

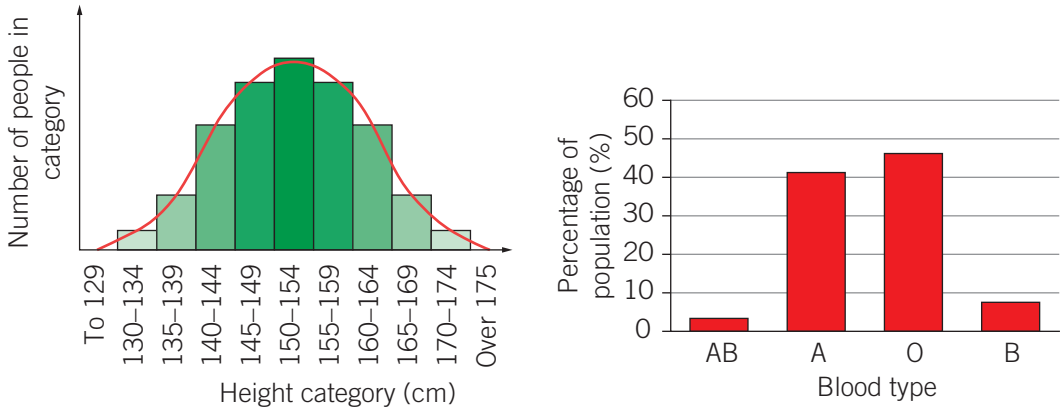



**Figure 8C–7** Graphs showing different phenotypes. Left: A polygenic trait with continuous variation. Right: A monogenic trait with discontinuous variation

**Polygenic trait** a trait that is controlled by more than one gene

**Continuous variation** when a trait does not have distinct phenotypes but instead shows a series of phenotypes on a continuum

**Discontinuous variation** when a trait has only a few phenotypes or discrete categories

ISBN 978-1-108-88711-3

## Check-in questions – Set 5

1 Assume that the gene for hairy ears is located on the Y chromosome.
   a How many copies of this gene would a male have? Briefly explain.
   b How many copies of this gene would a female have? Briefly explain.
   c What are males referred to as, if they carry only one allele for this gene?
2 Explain the difference between continuous and discontinuous variation.

VIDEO 8C–3
SKILLS: WRITING GENOTYPIC AND PHENOTYPIC RATIOS FOR MONOHYBRID CROSSES

## 8C SKILLS

**Writing genotypic and phenotypic ratios for monohybrid crosses**

As you have seen in the worked examples in this section, writing the genotypic and phenotypic ratios for Punnett squares is an important skill. In the examples used here, whole numbers have been used to represent the ratios, but in some cases fractions are used.

Looking back to Worked example 8C–1, where a homozygous dominant female with unattached earlobes was crossed with a heterozygous male, the following Punnett square and ratios were recorded:

| | | Genotype of female: EE | |
|---|---|---|---|
| | | E | E |
| Genotype of male: Ee | E | EE | EE |
| | e | Ee | Ee |

Genotypic ratio = 1 EE : 1 Ee

Phenotypic ratio = 1 unattached earlobes

The genotypic ratio can also be represented as:

Genotypic ratio = $\frac{1}{2}$ EE : $\frac{1}{2}$ Ee

If the phenotypic ratio were to be represented in this way, it would look like this:

Phenotypic ratio = $\frac{4}{4}$ unattached earlobes

The fraction $\frac{4}{4}$ is equal to 1. As in maths, a fraction or ratio is always simplified, and this is why this textbook uses whole numbers for representing the genotypic and phenotypic ratios. However, it is best to follow the method preferred by your teacher/school. (For example, some teachers might use percentages.)

**Importance of justifying answers using Punnett squares**

Many questions in this inheritance topic will be in the form: 'What are the chances of parents A and B having a child with condition X?'

If you know the genotypes of the parents and you've memorised the expected genotypic and phenotypic ratios of a cross between these two parents, then it appears quite simple to just provide the answer. However, when asked this type of question it is important to show proof. This is done by setting up and completing a Punnett square using the steps explained at the beginning of this section.

ISBN 978-1-108-88711-3

If the alleles are not provided for you in the question, you must first assign your own alleles for each phenotype. Remember to use letters and/or notations that are clearly distinctive.

**VIDEO 8C–4**
SKILLS: READING QUESTIONS CAREFULLY

**Reading questions carefully**

In this topic, it is important to read the question very carefully and identify exactly what it requires you to determine. The following question related to sex-linked genes is a prime example.

*Question*: The gene for colour blindness is an X-linked recessive disorder. If a heterozygous female married a normal male, what would be the chances of them having a normal child?

*Answer*:

Assign alleles: B = normal, and b = colour blind

Complete a Punnett square:

| | | **Genotype of female: $X^BX^b$** | |
|---|---|---|---|
| | | $X^B$ | $X^b$ |
| **Genotype of male: $X^BY$** | $X^B$ | $X^BX^B$ | $X^BX^b$ |
| | Y | $X^BY$ | $X^bY$ |

Complete genotypic and phenotypic ratios:

Genotypic ratio = 1 $X^BX^B$ : 1 $X^BX^b$ : 1 $X^BY$ : 1 $X^bY$

Phenotypic ratio = 2 normal female : 1 normal male : 1 colour-blind male

Work out the chance of the child being normal from the Punnett square:

Therefore, the chance of having a normal *child* is 75%.

However, if the last word in this question was changed from *child* to *daughter*, it would change the answer. See below:

*Question*: The gene for colour blindness is an X-linked recessive disorder. If a heterozygous female married a normal male, what would be the chances of them having a normal *daughter*?

*Answer*:

Complete a Punnett square:

| | | **Genotype of female: $X^BX^b$** | |
|---|---|---|---|
| | | $X^B$ | $X^b$ |
| **Genotype of male: $X^BY$** | $X^B$ | $X^BX^B$ | $X^BX^b$ |
| | Y | $X^BY$ | $X^bY$ |

Complete genotypic and phenotypic ratios:

Genotypic ratio = 1 $X^BX^B$ : 1 $X^BX^b$ : 1 $X^BY$ : 1 $X^bY$

ISBN 978-1-108-88711-3

Phenotypic ratio = 2 normal female : 1 normal male : 1 colour-blind male

Work out the chance of the daughter being normal from the Punnett square:

Therefore, the chance of having a normal *daughter* is 50%. It is also worth noting that this question is potentially ambiguous. If the question asks for '*the chance of a daughter being normal*', then the answer could also be 100%, as all females expected from this Punnett square would be normal (no colour-blindness).

*With questions like these, it is helpful to highlight the key words. In this case, 'child' or 'daughter' would be the key word.*

Here is another example:

*Question*: Achondroplasia is an autosomal dominant bone disorder that causes dwarfism. If one allele for achondroplasia is inherited, an individual has the condition. However, if an individual inherits two alleles (that is, homozygous dominant), the condition is lethal (offspring do not survive). What are the chances of two individuals with achondroplasia having a child who also has the disorder?

**Figure 8C–8** Achondroplasia is an autosomal dominant disorder that causes dwarfism in humans.

*Answer*:

Assign alleles: A = achondroplasia, a = normal

Complete Punnett square:

| | | **Genotype of female: Aa** | |
|---|---|---|---|
| | | A | a |
| **Genotype of male: Aa** | A | AA | Aa |
| | a | Aa | aa |

Complete genotypic and phenotypic ratios:

Genotypic ratio = 1 AA : 2 Aa : 1 aa

Phenotypic ratio = 1 lethal : 2 achondroplasia : 1 normal

Work out chance from Punnett square:

Therefore, the chance of having a child with achondroplasia is 67% or $\frac{2}{3}$.

You might have thought that the answer is 50%, because 2 out of 4 individuals in the Punnett square are heterozygous (will have achondroplasia). However, the question stated that inheritance of two alleles for this disorder is lethal. This means an embryo/foetus that is homozygous dominant will not be born/survive. Therefore, there are only three possible options in the Punnett square, and two of these have achondroplasia. Hence $\frac{2}{3}$ or 67%.

ISBN 978-1-108-88711-3

## Section 8C questions

1 In a breeding experiment, a pure-breeding black guinea pig was crossed with a pure-breeding white guinea pig. All the $F_1$ offspring were black. Let 'B' represent the allele for black, the dominant phenotype, and 'b' represent the allele for white, the recessive phenotype.

   a Explain this information by means of a Punnett square.
   b If the $F_1$ offspring were allowed to breed among themselves, what proportion of the $F_2$ generation would be expected to be heterozygous? Show all working using a Punnett square.
   c If you were given a black guinea pig, explain how you would attempt to find out whether it was homozygous or heterozygous.

2 Consider two pure-bred flowers that were crossed, one with red petals and the other with white petals. All $F_1$ generation plants had pink flowers.
   a Using alleles $F^W$ and $F^R$, use a Punnett square to explain the results.
   b If the $F_1$ offspring were interbred, use a Punnett square to determine the phenotypic ratio in the $F_2$ generation.

3 Tongue rolling is dominant to non-tongue rolling.
   a Using the letter 't', define the alleles and genotype(s) for tongue rolling and non-tongue rolling.
   b If a non-tongue-rolling female mates with a heterozygous tongue-rolling male, what are the chances that their child will be a tongue roller? Show all working.

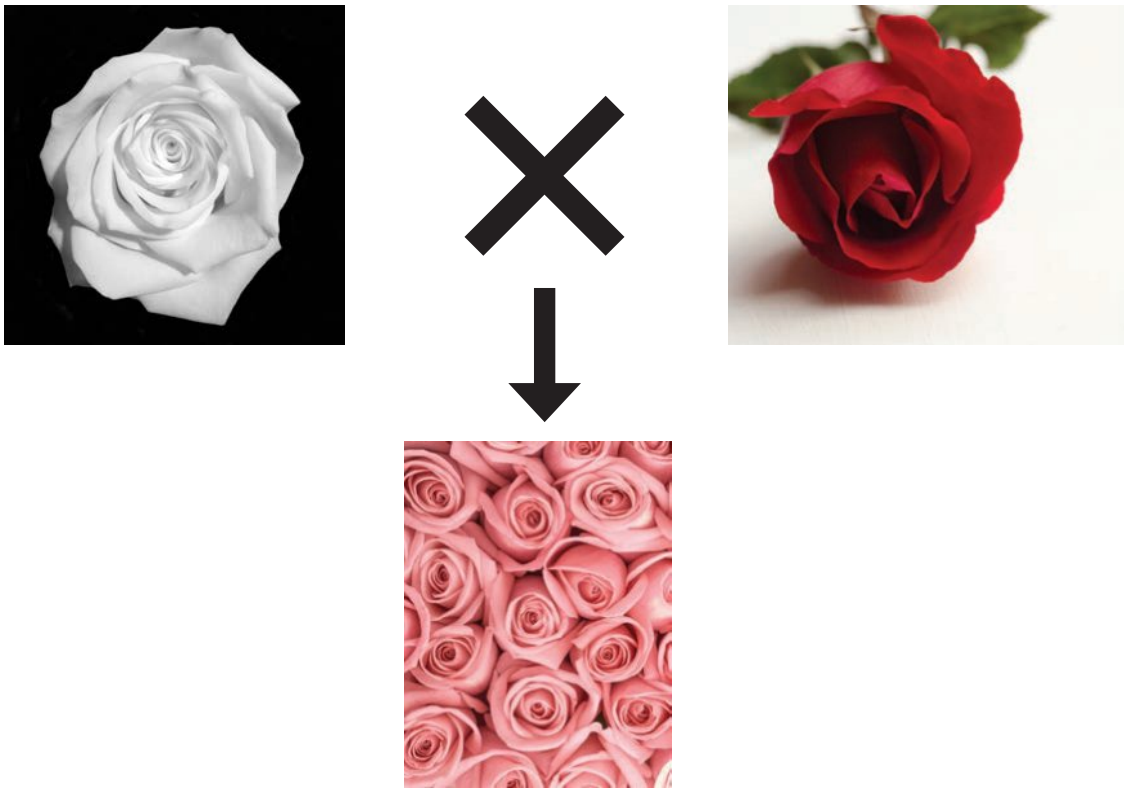
4 A man with red hair (rr) marries a woman with brown hair (Rr).
   a Classify the parents as homozygous or heterozygous.
   b What is the dominant phenotype? Explain.
   c Define the individual alleles for red and brown hair.
   d Using a Punnett square, determine the phenotypic and genotypic ratios for their possible children.

5 Cystic fibrosis is a homozygous recessive disorder.
   a Using the letter 'a', define the alleles for cystic fibrosis and 'normal' (no cystic fibrosis).
   b Using the same letter, what is/are the possible genotype(s) for people who suffer from cystic fibrosis and those who are normal?
   c In the context of cystic fibrosis, describe what a 'carrier' is.
   d If two carriers mate, what is the chance that their child will suffer from cystic fibrosis? Use a Punnett square to explain your answer.
   e If a male carrier mates with a homozygous normal female, what are the chances of them having a child with cystic fibrosis?

6 A black dog mates with a gold dog and has a litter of eight black puppies.
   a Define the alleles for black and gold.
   b Based on the information given, what are the genotypes of the puppies? How did you determine this from the information?

ISBN 978-1-108-88711-3

**7** Refer to the image below.



**a** Is this an example of complete dominance, incomplete dominance or codominance?

**b** Give a definition of the type of inheritance you listed in part **a**.

**8** X-linked disorders can be dominant. One example is incontinentia pigmenti, an extremely rare disorder in which a blister-like rash occurs in a newborn, followed by brown swirls and then light swirls on the skin. Other health problems related to this disorder involve the nervous system, nails and hair.

**a** If the gene for this disorder is on the X chromosome, would males and females have the same number of copies of alleles?

**b** The possible alleles for this gene are: $X^I$ = incontinentia pigmenti, $X^i$ = normal. What would be the phenotypes for the following individuals?

**i** $X^IX^I$

**ii** $X^IY$

**iii** $X^IX^i$

**c** What does 'X-linked dominant' mean? How is this different from 'X-linked recessive'?

**d** Are males or females more likely to be affected by this disorder? Explain.

**e** If a normal male mated with a female heterozygous for incontinentia pigmenti, what would be the chances of them having a child with the disorder?

**f** If this same couple decided to have two more children (in separate pregnancies) what would be the chances of them having a boy and a girl, both with the disorder?

**g** Imagine you are geneticist and you want to determine whether a female who had incontinentia pigmenti was homozygous or heterozygous. A colleague suggests performing a test cross to determine the genotype of the female. Do you agree or disagree with their suggestion? Explain.

ISBN 978-1-108-88711-3

# 8D Dihybrid crosses

**Study Design:**
Predicted genetic outcomes for two genes that are either linked or assort independently

**Glossary:**
Crossing over
Dihybrid cross
Independent assortment
Linked genes
Parental class
Recombinant class
Segregation
Unlinked genes
Vestigial

## ENGAGE

### Mendel's laws of inheritance

In Mendel's experiments with pea plants, he investigated the colour and shape of the seeds, as well as many other traits, and attempted to find out which phenotypes were dominant over others.

**Mendel's laws**

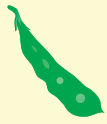
| | Flower colour | Seed shape | Seed colour | Pod colour | Pod shape | Pod height | Pod position |
|---|---|---|---|---|---|---|---|
| **Dominant** |  Purple |  Round |  Yellow |  Green |  Inflated |  Tall |  Axial |
| **Recessive** |  White |  Wrinkled |  Green |  Yellow |  Constricted |  Short |  Terminal |

**Figure 8D–1** Mendel's garden pea plant experiments attempted to determine which phenotypes for each trait were dominant or recessive.

Mendel carried out crosses that compared a single trait (e.g. a white-flowered plant crossed with a purple-flowered plant) – we call these monohybrid crosses (discussed in Section 8C). He also carried out crosses that compared two traits at a time (e.g. a short white-flowered plant crossed with a tall purple-flowered plant). For both types of crosses, he obtained similar results, and proposed a set of principles, which we now know as 'laws':

- *The law of* **segregation** – when an individual has two alleles for a gene, those alleles are separated during meiosis when gametes are formed.

LINK 8C MONOHYBRID CROSSES

**Segregation**
in biology, the separation of two alleles during the formation of gametes

ISBN 978-1-108-88711-3

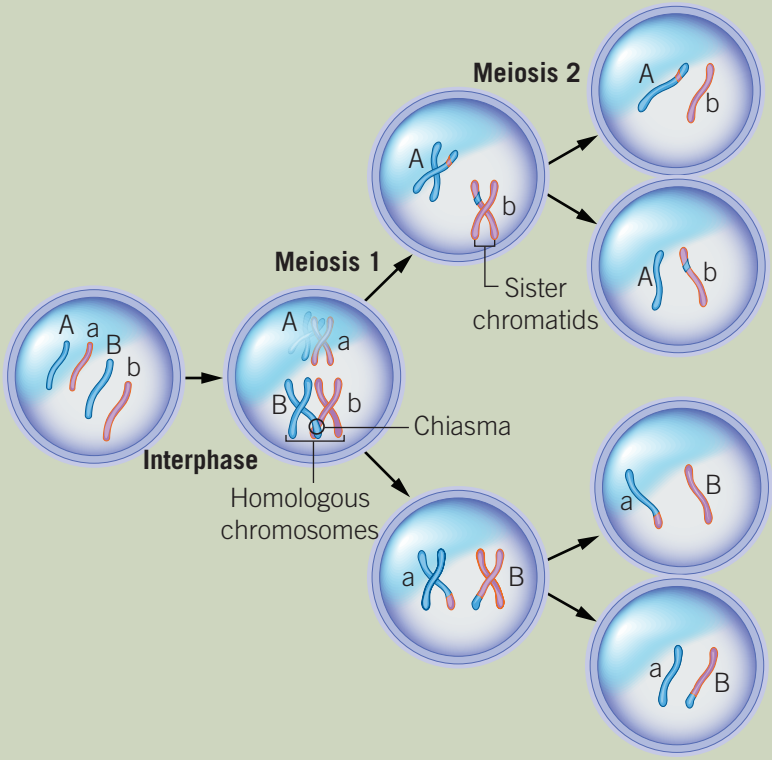



**Figure 8D–2** The law of segregation showing the separation of alleles from the diploid parent cell into haploid gametes during meiosis

- *The law of dominance* – if an individual inherits two different alleles, for example, Aa (they are heterozygous), they will display the dominant phenotype.
- *The law of* ***independent assortment*** – during meiosis when gametes are formed, the segregation of one pair of alleles has no impact on how another pair of alleles is segregated. You might recall the term 'independent assortment' from Section 7B, where the independent assortment of chromosomes was discussed. In this situation, however, we are referring to the alleles carried by those chromosomes.

**Independent assortment** the random arrangement of pairs of homologous chromosomes during meiosis, resulting in the random combination of alleles into gametes, thereby increasing variation

What Mendel did not realise is that the different genes he investigated either were located on different chromosomes in the pea plants or were so far apart on the same chromosome that they behaved independently of each other. There were no genes/alleles so close together on the same chromosome that they influenced the inheritance of each other.

**7B** SEXUAL REPRODUCTION AND MEIOSIS LINK

This section explores the inheritance of two genes and how to determine whether they are linked (on the same chromosome) or unlinked (on different chromosomes).

## EXPLAIN

## Independent assortment (unlinked genes)

When Mendel was studying the inheritance of multiple characteristics in pea plants, he discovered that the genes for seed shape and colour were inherited independently. This means that when an allele for one gene gets sorted into a gamete, it has no influence on the alleles of another gene. In other words, because the two genes under investigation are on different chromosomes, the inheritance of one chromosome from a homologous pair has no effect on the inheritance of a chromosome from the other pair. Therefore, each

ISBN 978-1-108-88711-3

of the alleles from a given gene has an equal chance of combining with each of the alleles from another gene. These genes are said to be **unlinked genes** and we know this process as independent assortment.

Independent assortment takes place in metaphase I of meiosis, when homologous chromosomes align at the equator of the cell, as you learned in Section 7B. In metaphase I, shown in Figure 8D–3, the two genes for seed shape and colour are heterozygous (Aa and Bb). Notice that there are two possible orientations for the two homologous pairs of chromosomes.

LINK 7B SEXUAL REPRODUCTION AND MEIOSIS

**Unlinked genes** genes that are located on different chromosomes or very far apart on the same chromosome

If many cells were undergoing meiosis, approximately half would be in each arrangement. At the end of meiosis, there are two possible types of gametes for each orientation (equalling four in total).

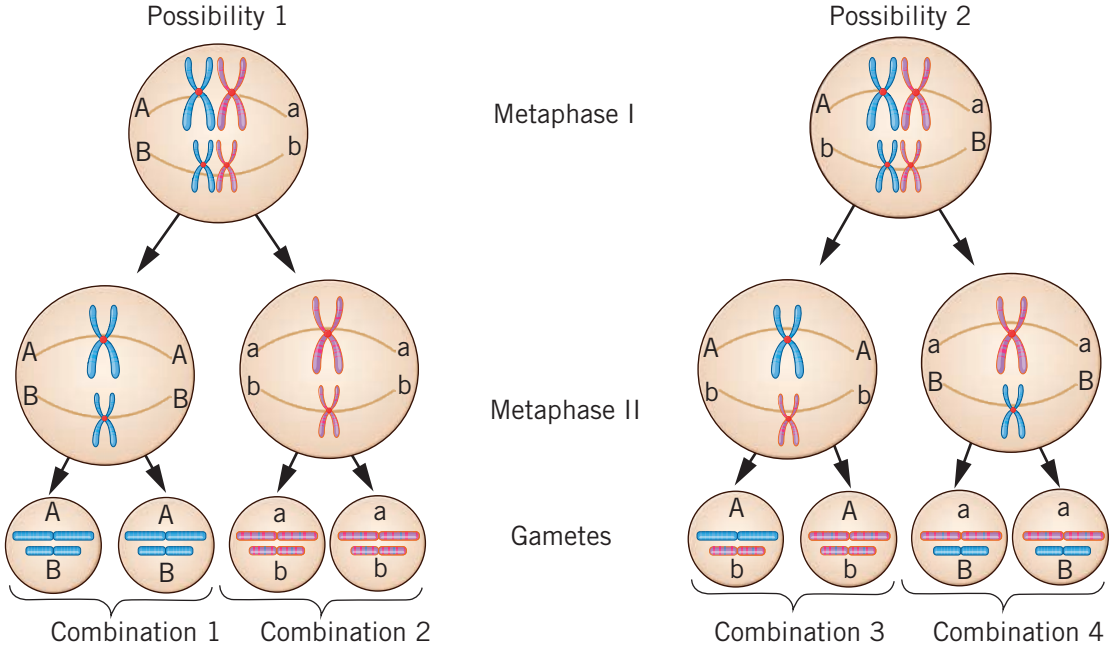



**Figure 8D–3** Independent assortment of two genes located on different chromosomes during the stages of meiosis

Remember that, for each gene, a gamete contains only one allele. When considering two genes, the same rules apply for each gene. Therefore, we would expect four types of gametes to be produced, in roughly equal number: A B, a b, A b and a B. These are the four combinations shown in Figure 8D–3.

The study of the inheritance of two genes using a Punnett square is called a **dihybrid cross**.

**Dihybrid cross** the study of inheritance for phenotypes of two different genes through the mating of organisms over generations

## Setting up a Punnett square for two genes (dihybrid crosses)

In Section 8C, you learned how to set up a Punnett square for a monohybrid (single gene) cross. The same rules apply for a dihybrid cross.

- The trait represented by the uppercase allele is dominant to the trait represented by the lowercase allele.
- Each gamete can only have one allele for each gene.

However, because there are more possible combinations in the gametes (four instead of two), the Punnett square will have 16 boxes, rather than four.

LINK 8C MONOHYBRID CROSSES

VIDEO 8D–1 DIHYBRID CROSSES

ISBN 978-1-108-88711-3

Again, there are some common parental combinations and subsequent phenotypic ratios that you will need to recall for dihybrid crosses.

VIDEO WORKED EXAMPLE 8D–1

## Worked example 8D–1

**Dihybrid cross between two double heterozygous (heterozygous for both genes) individuals**

Mendel investigated two genes in pea plants: seed shape and seed colour. Round seed 'A' is dominant to wrinkled seed 'a', and yellow seed 'B' is dominant to green seed 'b'. Both parental genotypes are heterozygous for both genes. Determine the phenotypic ratio of the offspring, and use a Punnett square to show your working.


**Figure 8D–4** Two parental pea plant seeds, both round and yellow, being crossed to produce the first generation of pea plant seeds

**Step 1** Write the parental genotypes and the possible combinations of alleles (in gametes) for each parent. Remember that each gamete will receive only one allele from each gene, so you cannot have A and a, for example.

Possible gametes for one parent

| | | Parental genotype: AaBb | | | |
|---|---|---|---|---|---|
| | | A B | A b | a B | a b |
| **Parental genotype: AaBb** | A B | | | | |
| | A b | | | | |
| | a B | | | | |
| | a b | | | | |

**Step 2** Fill each of the boxes (total of 16) with the combination of alleles from the intersecting gametes from each parent.

| | | Parental genotype: AaBb | | | |
|---|---|---|---|---|---|
| | | A B | A b | a B | a b |
| **Parental genotype: AaBb** | A B | AABB | AABb | AaBB | AaBb |
| | A b | AABb | AAbb | AaBb | Aabb |
| | a B | AaBB | AaBb | aaBB | aaBb |
| | a b | AaBb | Aabb | aaBb | aabb |

*Note*: When writing out the genotypic ratio for a dihybrid cross, there is no need to write out the entire ratio. This would take too long. Instead, all you are required to do is write out the phenotypic ratio.

The trick for doing this is to remember that, if the genotype includes an uppercase letter, then that is the phenotype that will be displayed for that allele. Table 8D–1 shows a shorthand way to write the genotypes, where the '–' indicates that either the uppercase or the lowercase allele is present.

ISBN 978-1-108-88711-3

**Table 8D–1** Shorthand way of writing genotypes and phenotypes

| Genotype | Phenotype |
|---|---|
| A– B– | Round, yellow |
| A– bb | Round, green |
| aa B– | Wrinkled, yellow |
| aa bb | Wrinkled, green |

*Another handy trick: When calculating the ratio, as you tally the boxes, cross out the boxes that you have counted. Remember that the numbers at the end should add to 16.*

Therefore, the phenotypic ratio is:

9 round, yellow : 3 round, green : 3 wrinkled, yellow : 1 wrinkled, green

The 9 : 3 : 3 : 1 phenotypic ratio is always expected for a Punnett square of a dihybrid cross between two heterozygous organisms where the genes assort independently (are located on different chromosomes). This is shown in Figure 8D–5.

In real-life situations, you would not expect a perfect 9 : 3 : 3 : 1 phenotypic ratio. However, if a large number of offspring were produced, the phenotypes should be close to these expected numbers.

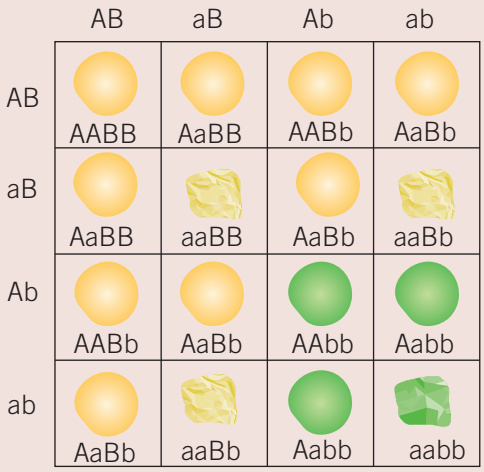



**Figure 8D–5** Visual representation of the phenotypes resulting from a dihybrid cross between two heterozygous round, yellow seeds. It shows the expected 9 : 3 : 3 : 1 phenotypic ratio.

## Check-in questions – Set 1

1 Define 'independent assortment'.
2 In what process and at what stage of this process does independent assortment occur?
3 What is the expected phenotypic ratio of offspring from a cross between two organisms that are heterozygous for:
   a a single gene?
   b two genes?

## Linked genes

As mentioned earlier, all of Mendel's work was with gene loci on different chromosomes, or very far apart on the same chromosome. Genes that are on the same chromosome are referred to as **linked genes**. For this reason, linked genes are *usually* inherited together. *Drosophila melanogaster* (fruit fly) can be used as an example here. Two genes in the fruit fly, body colour and wing size, are located close to each other on the same chromosome, as shown in Figure 8D–6.

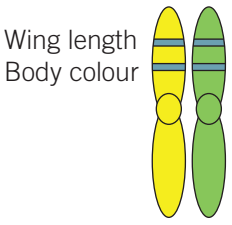



**Figure 8D–6** Homologous chromosomes of *Drosophila melanogaster*, showing the gene loci for wing length and body colour, which are close together (linked genes)

**Linked genes** two genes that are located on the same chromosome

ISBN 978-1-108-88711-3

7B SEXUAL REPRODUCTION AND MEIOSIS LINK

If two alleles are close together on the same chromosome, they will tend to be inherited together, unless **crossing over** occurs in prophase I of meiosis. This process was introduced in Section 7B. Crossing over increases the genetic diversity of the offspring, as non-sister chromatids break and then re-connect with the opposite chromatid. If crossing over occurs between the two gene loci, this results in the exchange of alleles between a maternal and a paternal chromatid, as shown in Figure 8D–7.

**Crossing over** the exchange of genetic material between non-sister chromatids of a homologous pair of chromosomes during prophase I of meiosis; occurs at the chiasmata and results in recombinant chromosomes, increasing variation between gametes

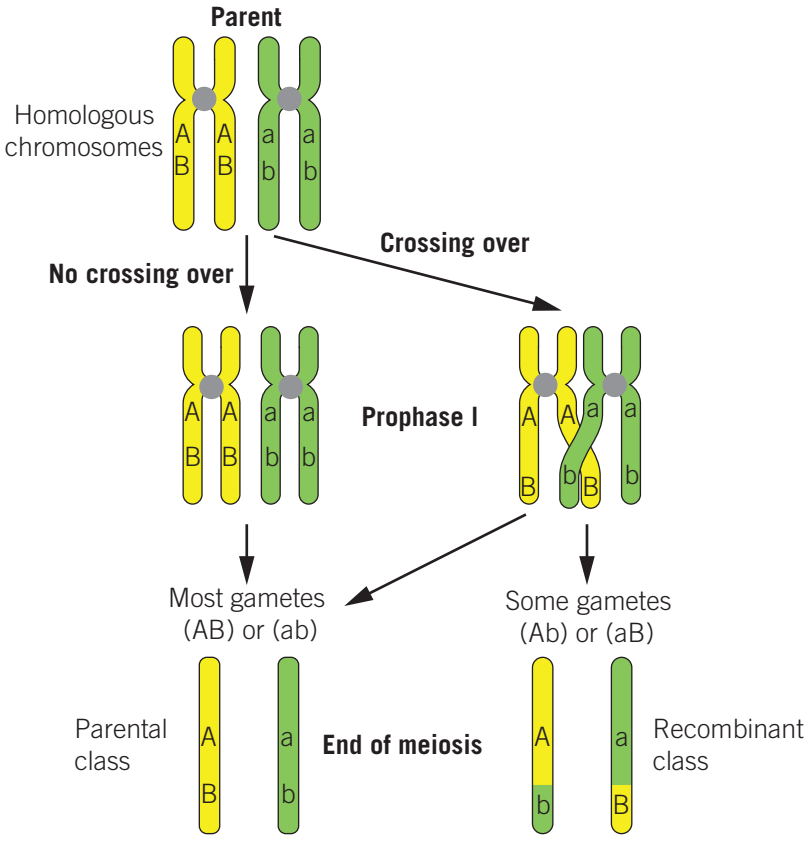



**Figure 8D–7** Crossing over versus no crossing over between genes in prophase I of meiosis. Crossing over occurs between non-sister chromatids (one chromatid of the yellow chromosome with one chromatid of the green chromosome). Results show the combination of alleles in gametes for both scenarios.

**Recombinant class** offspring that do not display the combination of alleles that are present together in the parent organisms

**Parental class** offspring that display the combination of alleles that are also present together in one of the parent organisms

Crossing over is a common event in prophase I of meiosis. If it occurs, then the combination of alleles present in the gamete will be different from those that were on the same chromatid in the parent. These offspring are referred to as the **recombinant class**.

However, the closer together two genes are, the less likely it is that crossing over will occur between them, and so at the end of meiosis, the gametes are more likely to receive the same combination of alleles (one for each gene) on the same chromatid as was seen in the parent cell. This is referred to as the **parental class**.

What is therefore expected when two genes are close together is that there will be more numbers produced with the parental class than with the recombinant class. This is not what we saw previously with monohybrid crosses (Section 8C) or with dihybrid crosses of two genes on separate chromosomes.

8C MONOHYBRID CROSSES LINK

ISBN 978-1-108-88711-3

But the further apart two genes are, the more likely it is that crossing over will occur between them. Consequently, there will be more of the recombinant class observed than if the two genes were closer together. All of this can be observed in Figure 8D–7.

### Representing linked genes

The way in which the genotypes of linked genes are represented differs from those that are unlinked. Because we have to consider that there are alleles for each gene on the same chromosome together, these need to be written together as well. For a heterozygous individual, if alleles 'A' and 'b' are together on the same chromosome, and 'a' and 'B' are on the other chromosome in the homologous pair, this individual's genotype would be written as: $\frac{\text{A b}}{\text{a B}}$.

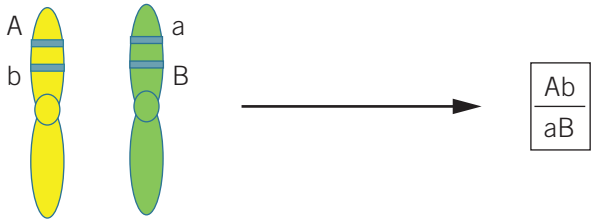


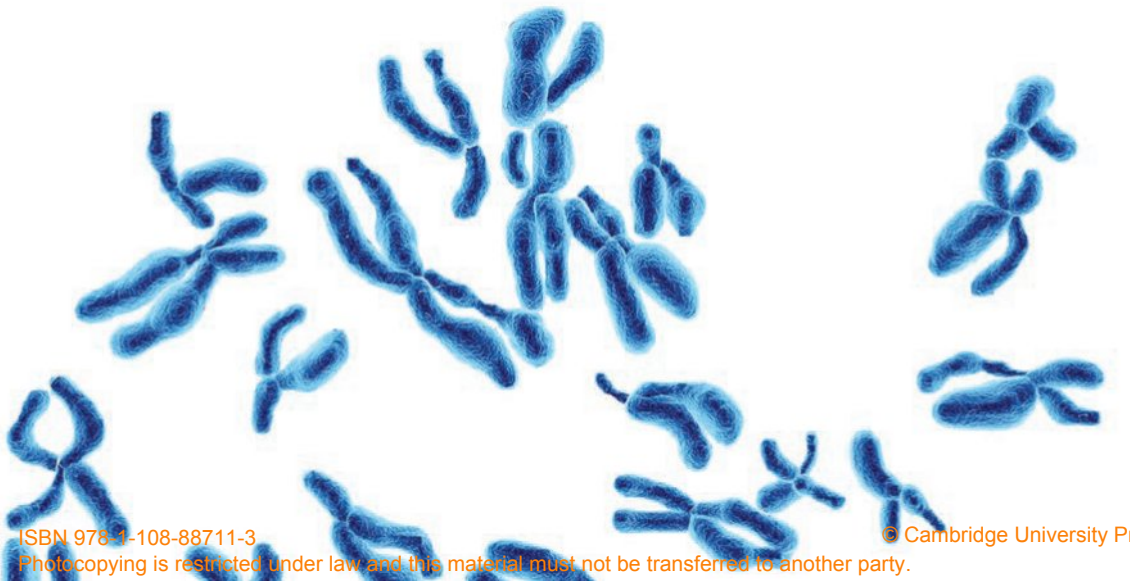

**Figure 8D–8** Left: Homologous chromosomes showing two gene loci and the combination of alleles on each chromosome. Right: How the genotype for this is written

## Check-in questions – Set 2

1 Define:
   - **a** parental class
   - **b** recombinant class.

2 Explain the difference between 'linked' genes and 'unlinked' genes.

3 How would you express the genotype of an organism in each of the following situations? (You can also use a diagram to support your answer.)
   - **a** Alleles 'R' and 'r' are on one homologous pair of chromosomes, whereas alleles 'T' and 't' are on a different pair of homologous chromosomes.
   - **b** Alleles 'R' and 'T' are on the same chromosome within a homologous pair of chromosomes, and alleles 'r' and 't' are on the other chromosome in the homologous pair.



ISBN 978-1-108-88711-3

8C MONOHYBRID CROSSES LINK

## Dihybrid test crosses

As you saw in Section 8C, a test cross includes one organism that is homozygous for the recessive trait(s) (in dihybrid test crosses, a double homozygous recessive). This organism is crossed with another organism that shows the dominant phenotype(s). The purpose of a test cross is to identify the genotype of the organism with the dominant phenotype(s) as homozygous or heterozygous. And, more importantly in dihybrid test crosses, it is also to determine whether the two genes under investigation are linked or unlinked (assorting independently).

The following worked examples will guide you through the scenarios of whether two genes are linked or unlinked, and the expected phenotypic ratios. In these examples, wing length and body colour in the fruit fly are used for each scenario. For these genes, alleles for the traits are as follows:

**Vestigial** smaller or undeveloped and not able to function (e.g. a trait affecting wings of some fruit flies)

A = normal wings, a = **vestigial** wings

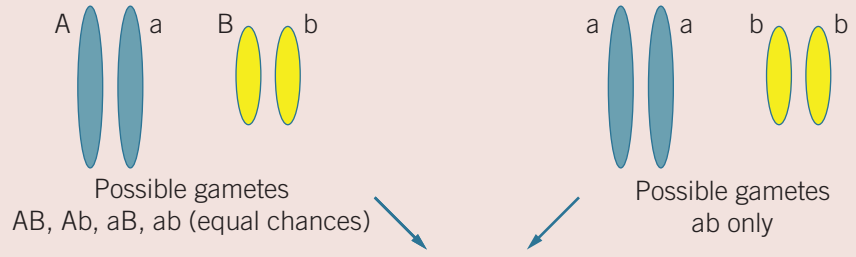
B = grey body, b = black body

VIDEO WORKED EXAMPLE 8D–2

### Worked example 8D–2

**Unlinked genes**

What is the phenotypic ratio in a dihybrid test cross with a known double heterozygous organism if the genes assort independently?




Punnett square:

| | | Parental genotype: AaBb | | | |
|---|---|---|---|---|---|
| | | A B | A b | a B | a b |
| Parental genotype: aabb | a b | AaBb | Aabb | aaBb | aabb |
| | ~~a b~~ | ~~AaBb~~ | ~~Aabb~~ | ~~aaBb~~ | ~~aabb~~ |
| | ~~a b~~ | ~~AaBb~~ | ~~Aabb~~ | ~~aaBb~~ | ~~aabb~~ |
| | ~~a b~~ | ~~AaBb~~ | ~~Aabb~~ | ~~aaBb~~ | ~~aabb~~ |

*Note*: The bottom three rows are crossed out, as the homozygous recessive parent (shown on the right) will always produce a gamete containing alleles 'a' and 'b'. No other options exist. The Punnett square only needs to show this once.

Phenotypic ratio = 1 normal wings, grey body : 1 normal wings, black body : 1 vestigial wings, grey body : 1 vestigial wings, black body

For unlinked genes, the expected phenotypic ratio for a dihybrid test cross with a heterozygous individual will always be 1 : 1 : 1 : 1.

If this ratio is observed, you know the two genes are located on different chromosomes and assort independently.

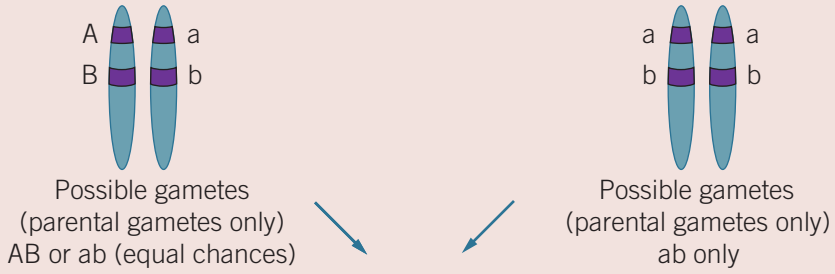
ISBN 978-1-108-88711-3

## Worked example 8D–3

VIDEO WORKED EXAMPLE 8D–3

### Linked genes with no crossing over

What is the phenotypic ratio in a dihybrid test cross with a known double heterozygous organism if the genes are linked but there is no crossing over?




Punnett square:

| | | Parental genotype: $\frac{AB}{ab}$ | | | |
|---|---|---|---|---|---|
| | | AB | ab | | |
| Parental genotype: $\frac{ab}{ab}$ | ab | $\frac{AB}{ab}$ | $\frac{ab}{ab}$ | | |
| | | | | | |
| | | | | | |
| | | | | | |

Phenotypic ratio = 1 normal wings, grey body : 1 vestigial wings, black body

For linked genes where there is no crossing over between them, the Punnett square will always display an expected phenotypic ratio for a dihybrid test cross with a heterozygous individual, of 1 : 1. If this ratio is observed, you know the two genes are located on the same chromosome and are likely very close together (no crossing over between them).

**Figure 8D–9** *Drosophila melanogaster* can have a black body (left) or a grey body (right).

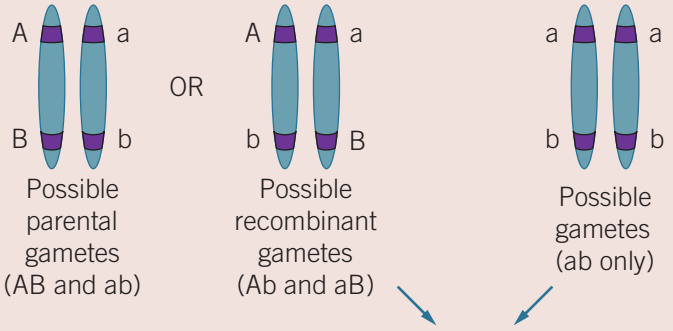
ISBN 978-1-108-88711-3

VIDEO WORKED EXAMPLE 8D–4

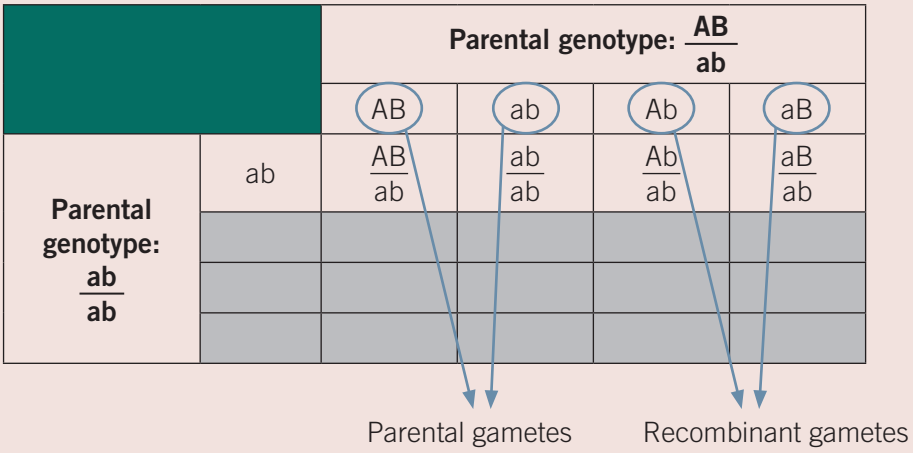
## Worked example 8D–4

**Linked genes with crossing over**

What is the phenotypic ratio in a dihybrid test cross with a known double heterozygous organism if the genes are linked and there is some crossing over between them?




Punnett square:




*Note*: In this scenario, a Punnett square seems to give a 1 : 1 : 1 : 1 phenotypic ratio. However, we know that because crossing over does not always occur between the two genes (and may occur outside this area), there will usually be *more* of the parental class observed in offspring compared to the recombinant class.

For example: phenotypic ratio = 0.48 normal wings, grey body : 0.02 normal wings, black body : 0.2 vestigial wings, grey body : 0.48 vestigial wings, black body.

For linked genes where there is some crossing over between them, the cross will always result in an expected phenotypic ratio for a dihybrid test cross with a heterozygous individual that is *not* 1 : 1 : 1 : 1.

There will still be four types of phenotypes observed in the offspring. Of these, there will be more of the two parental classes (and both in similar numbers) than of the recombinant class (which will also be in similar numbers). The larger the proportion of of the recombinant class, the further away the two linked genes are from each other.

If this ratio is observed, you know the two genes are located on the same chromosome and likely far enough apart for crossing over to have occurred between them.

ISBN 978-1-108-88711-3

## Know your ratios: summary

| Phenotypic ratio | Dihybrid cross |
|---|---|
| 9 : 3 : 3 : 1 | Unlinked genes – two heterozygous organisms |

| Phenotypic ratio | Dihybrid test cross |
|---|---|
| 1 : 1 : 1 : 1 | Unlinked genes |
| 1 : 1 | Linked genes (no crossing over) |
| Not 1 : 1 : 1 : 1 | Linked genes (with crossing over) |

**WORKSHEET 8D–1**
PUNNETT SQUARES FOR DIHYBRID CROSSES

## Check-in questions – Set 3

1 Explain the difference between unlinked and linked genes. In your answer, use the following terms:
unlinked, linked, independently assort, gene, gene loci, chromosome

2 Crossing over is a common event that occurs during prophase I in meiosis.
   a Is it more likely for crossing over to occur between genes that are close together or further apart?
   b Which are more commonly observed in the offspring of a dihybrid test cross with a double heterozygous organism: parental class or recombinant class?

3 Complete the following table of phenotypic ratios by classifying each as linked or unlinked and providing a reason for your answer in each case.

| | Observed phenotypic ratio | Linked or unlinked? | Reason |
|---|---|---|---|
| a | 93 yellow round : 31 green round : 28 yellow wrinkled : 11 green wrinkled | | |
| b | 27 black normal : 25 grey long | | |
| c | 20 hairless short : 18 hairy tall : 4 hairless tall : 3 hairy short | | |
| d | 3 red vestigial : 2 blue normal : 3 blue vestigial : 4 red normal | | |

## 8D SKILLS

**VIDEO 8D–2**
SKILLS: WRITING GENOTYPES FOR DIHYBRID CROSSES

### Writing genotypes for dihybrid crosses

It is important to re-emphasise for this section that writing the genotypes for linked and unlinked genes is very different, and you need to know how to do this for each situation and why they are represented in this way.

For unlinked genes, as the gene loci are on different chromosomes, the likelihood of one allele (say 'A') for a gene being inherited with an allele (say 'B') for the other gene is as likely as 'A' being inherited with 'b'. Therefore, these can simply be written as though they were for a single gene genotype – hence, AABb or Aabb, and so on. This way of representing the genotypes for an individual shows that the alleles for one gene are followed by the alleles for the other gene.

ISBN 978-1-108-88711-3

For linked genes, as the gene loci are on the same chromosome, the likelihood of one allele ('A') for a gene being inherited with an allele ('B' or 'b') for the other gene depends on which alleles can be found on the same chromosome within the parent organism. Therefore, this needs to be written as follows:


VIDEO 8D–3 SKILLS: SIMPLIFYING PUNNETT SQUARES

### Simplifying Punnett squares

As mentioned in Worked example 8D–2, for a dihybrid cross, if one parent is homozygous for a single trait, or even for both traits, this limits the number of potential gamete combinations from that parent. Therefore, when completing the Punnett square for the cross, there is no need to write the same combination of alleles more than once. It will not change the expected phenotypic ratios observed for the offspring.

For example, in a cross between the unlinked genes AaBb × AABB:

| | | Parental genotype: AaBb | | | |
|---|---|---|---|---|---|
| | | A B | A b | a B | a b |
| **Parental genotype: AABB** | A B | AABB | AABb | AaBB | AaBb |

Only gamete — Gametes

The four possible gametes produced from meiosis in this organism will all have the alleles 'A' and 'B'. But you only need to write this once, as the potential genotype (and phenotype) for the offspring will be the same as the first row shown. The ratio would not change.

### Working out the combination of alleles on chromosomes in the heterozygous parent

Questions about dihybrid test crosses involving linked genes will often ask you to determine the combination of alleles that are on the same chromosome (chromatid) together in the heterozygous parent.

Most students assume that the uppercase letters of the two genes are always together on one of the chromosomes and the lowercase letters of the two genes are together on the other chromosome in the homologous pair. But this is not always the case, and there is a 'trick' to working this out.

Let's look at an example:

*A test cross between a heterozygous grey body, normal-winged fruit fly and a black body, vestigial-wing fruit fly produced the following results:*

| Phenotype | Grey body, normal wings | Grey body, vestigial wings | Black body, normal wings | Black body, vestigial wings |
|---|---|---|---|---|
| Offspring number | 3 (Recombinant) | 45 (Parental) | 49 (Parental) | 2 (Recombinant) |

For this question, there are some things you can identify immediately:

- The ratio is not 1 : 1 : 1 : 1 and there are four distinct phenotypes. This means the two genes are linked and crossing over has occurred.

ISBN 978-1-108-88711-3

- The heterozygous fruit fly has grey body and normal wings. Therefore, these phenotypes must be dominant. Hence, alleles can be assigned, such as:
  G = grey body, g = black body
  N = normal wings, n = vestigial wings

Possible gametes (g n only)

**Figure 8D–10** The only possible allele combination in the gametes formed from the homozygous recessive parent

The homozygous recessive fruit fly must therefore have the genotype gn / gn. Thus, every gamete from this parent will have only the 'g' and 'n' alleles and their chromosomes will appear like the one in Figure 8D–10.

Therefore, the question may ask the following:

*Which one of the following three genotypes correctly represents the genotype of the heterozygous fruit fly parent?*

option 1: $\frac{\text{G N}}{\text{g n}}$ option 2: $\frac{\text{G n}}{\text{g N}}$ option 3: $\frac{\text{G N}}{\text{G N}}$

You can immediately rule out the third option, as this does not have all the alleles required for a heterozygous individual.

To work out which of the first two options is the answer, you need to refer back to the table of offspring numbers and apply the 'trick'.

**Step 1** Underneath each offspring number, write the alleles for the recessive traits, as these are the only possible alleles to have come from the homozygous recessive parent.

| Phenotype | Grey body, normal wings | Grey body, vestigial wings | Black body, normal wings | Black body, vestigial wings |
|---|---|---|---|---|
| Offspring number | 3 | 45 | 49 | 2 |
| | __ g __ n | __ g __ n | __ g __ n | __ g __ n |

**Step 2** Then, looking at the phenotype of the offspring, complete the other alleles remaining, which you now know must have come from the heterozygous parent.

| Phenotype | Grey body, normal wings | Grey body, vestigial wings | Black body, normal wings | Black body, vestigial wings |
|---|---|---|---|---|
| Offspring number | 3 | 45 | 49 | 2 |
| | **G** g **N** n | **G** g **n** n | **g** g **N** n | **g** g **n** n |

**Step 3** As you know that the two types of offspring with the highest numbers will be the parental class, these alleles that you filled in from the heterozygous parent (and shown in bold and underlined), must have been together on the same chromosome.

Therefore, in this example, 'G' and 'n' are together on one chromosome, and 'g' and 'N' are together on the other chromosome in the heterozygous parent.

(The other offspring types with smaller numbers are the recombinant class.)

Therefore, the answer is option 2: $\frac{\text{G n}}{\text{g N}}$

ISBN 978-1-108-88711-3

## Section 8D questions

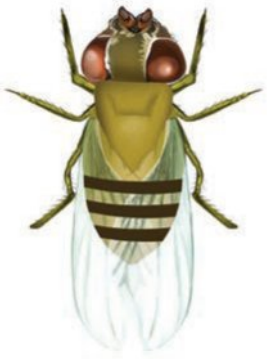
**1** In the cross below:

$$\frac{A\ B}{a\ b} \times \frac{a\ b}{a\ b}$$

**a** What genotypes of offspring are possible if:
- **i** no crossing over occurs between the two gene loci?
- **ii** crossing over occurs between the two gene loci?

**b** How would the phenotypic ratios differ between the scenarios in part **a i** and part **a ii** above?

**2** Geneticists working with *Drosophila melanogaster* in the laboratory have been trying to determine the number of offspring produced in a cross between a yellow-bodied normal-winged female and a black-bodied vestigial-winged male.
*Note*: Yellow body is dominant to black, and normal wings are dominant to vestigial wings.



The Punnett square for the dihybrid test cross has been partially worked out:

| | | **Parental genotype: BbWw** | | | |
|---|---|---|---|---|---|
| | | B W | B w | b W | b w |
| **Parental genotype: bbww** | b w | | | | |
| | b w | | | | |
| | b w | | | | |
| | b w | | | | |

**a** Complete the Punnett square by filling in the possible genotypes.

**b** What is the expected genotypic ratio of the offspring?

**c** What is the expected phenotypic ratio of the offspring?

**d** Results from the mating of these two organisms in the lab produced the following results:

| Phenotype | Number of offspring |
|---|---|
| Yellow body, normal wings | 13 |
| Yellow body, vestigial wings | 11 |
| Black body, normal wings | 17 |
| Black body, vestigial wings | 12 |

Explain why the ratio observed is not exactly 1 : 1 : 1 : 1.

**e** From the information given in the question, are these two genes linked or unlinked? Explain your answer using relevant biological terminology.

ISBN 978-1-108-88711-3

**3** A test cross between a heterozygous red-eyed, normal-winged fly with a recessive yellow-eyed, curly-winged fly, produced the following offspring numbers:

| Red eyes, normal wings | Red eyes, curly wings | Yellow eyes, normal wings | Yellow eyes, curly wings |
|---|---|---|---|
| 45 | 41 | 47 | 44 |

**a** Do the results support the conclusion that the two genes are linked or assorting independently? Explain.
**b** Assign alleles for eye colour and wing type.
**c** Draw a diagram to represent the chromosomes for the heterozygous red-eyed, normal-winged fly.
**d** What are the possible gametes for the heterozygous fly in part **c**?
**e** Draw a diagram to represent the chromosomes for the recessive yellow-eyed, curly-winged fly.
**f** What are the possible gametes for the recessive fly in part **e**?

**4** In guinea pigs, the gene for coat colour is located on the same chromosome as the gene for coat length. In a mating between a black, long-haired guinea pig and a white, short-haired guinea pig, a number of unexpected black, short-haired and white, long-haired guinea pigs were born. This would not be possible if the same alleles were always inherited together. Explain in depth how new allele combinations occur, outlining the process in which this takes place.

**5** A gene locus for eye colour in blowflies has two alleles: 'E' for red eyes and 'e' for white eyes. A second gene locus for body colour also has two alleles: 'B' for black and 'b' for yellow. A test cross was conducted using a female that was heterozygous at both gene loci. The numbers of offspring from the cross are shown below.

| Phenotype | Number of offspring |
|---|---|
| Red eyes, black body | 31 |
| White eyes, yellow body | 33 |
| White eyes, black body | 4 |
| Red eyes, yellow body | 5 |

Determine whether the following statements are true or false. If true, explain why. If false, explain why and adjust the comment so that it is true.

**a** The male fly that was crossed with the heterozygous female fly would have had red eyes and a yellow body.
**b** The two gene loci are assorting independently.
**c** The two gene loci are close together on the same chromosome.
**d** The offspring with white eyes and black body colour are the result of recombination in the female parent.

ISBN 978-1-108-88711-3

# 8E Pedigrees

**Study Design:**
Pedigree charts and patterns of inheritance, including autosomal and sex-linked inheritance

**Glossary:**
First filial generation ($F_1$)
Parental generation (P)
Pedigree chart

## ENGAGE

### Using pedigrees to track inheritance of traits

Have you or your family ever completed a family tree? A family tree is a chart that displays individuals and their relationships across many generations.

**Pedigree chart** a chart used to trace the inheritance of a phenotype over generations

In biology, geneticists use a similar type of structure, called a **pedigree chart**, to map the inheritance of a phenotype across more than one generation. As you have seen from Mendel's work, mapping the inheritance of characteristics across multiple generations is easier in pea plants, as their generation cycles are much shorter than those of humans. And if you think back to the key aspects of scientific investigations (explored in Chapter 6), pea plants can be grown in controlled conditions manipulated by the scientist. This helps to minimise any uncontrolled variables. The pea plants can also be produced from seeds in large numbers, as increasing the sample size improves the reliability and accuracy of investigations.

6A INVESTIGATIVE DESIGN LINK
6B SCIENTIFIC EVIDENCE LINK

**Figure 8E–1** A family tree shows individuals and their relationship with each other over many generations.

ISBN 978-1-108-88711-3

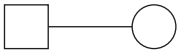
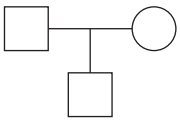
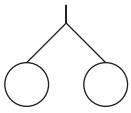
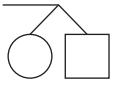
## EXPLAIN

### Pedigree symbols – what to know

VIDEO 8E–1 PEDIGREES

Before you start drawing pedigrees, there are some symbols and representations of relationships that you need to be aware of. These are shown in Table 8E–1. Note that females are represented as a circle and males as a square. If a shape is coloured in, this means the individual has the phenotype being analysed in the pedigree.

**Table 8E–1** Pedigree symbols

| Pedigree symbol | Meaning | Pedigree symbol | Meaning |
|---|---|---|---|
|  | Unaffected female |  'Horizontal line' | Mating |
|  | Affected female |  'Vertical line to individual(s)' | Offspring |
|  | Unaffected male |  'Vertical line then splits to both individuals' | Identical twins |
|  | Affected male |  'Direct split to both individuals' | Non-identical twins |
|  | Unidentified gender |  | Death |

### Pedigree numbering rules

A pedigree chart follows a numbering system:

- Individuals in the same generation are always written horizontally at the same level.
- Within the same generation, each individual is numbered, starting from 1 at the left through to the last individual at the right. (When progressing to the next generation, the same rule applies, again starting from the left with number 1.)
- Each generation is numbered with a roman numeral, starting with I at the top and working vertically down.
- When referring to a specific individual in the pedigree, first write the roman numeral for the generation that the individual appears in, followed by a horizontal dash, then the number of that individual in that generation; for example, II-2, as shown in Figure 8E–2 at the top of the next page.

ISBN 978-1-108-88711-3

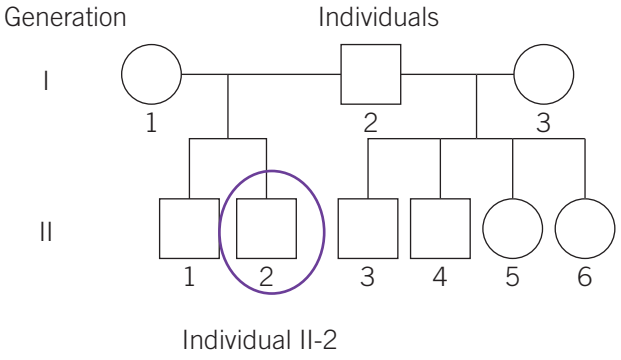



**Figure 8E–2** Pedigree chart highlighting the numbering system for each generation and individual. The male circled is in generation II and second from the left and hence is denoted II-2.

**Parental generation (P)** the first set of parents in a cross/pedigree

**First filial generation ($F_1$)** offspring resulting from the parental cross/generation

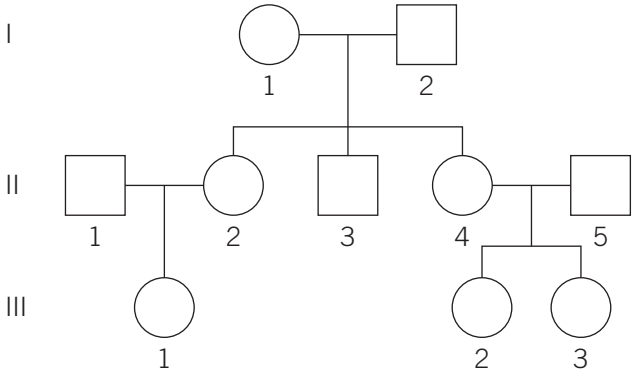
In questions, you will often also see the first generation (I) referred to as 'P'. This 'P' stands for **parental generation**. Their children can then also be referred to as '$F_1$', meaning **first filial generation**. These are the offspring from that parental cross/mating. Following on from this, the next generation, or second filial generation, is known as '$F_2$'.

## Check-in questions – Set 1

1 How are males and females represented in pedigree charts? How is this representation different if they are affected with an inherited disorder or characteristic?

2 Where is the generation number written on a pedigree chart, and what numbering system represents this?

3 Use the pedigree chart below to answer the following questions.




**a** How many males are represented in the pedigree?

**b** What is the relationship between individuals:

**i** I-1 and II-4?

**ii** III-2 and III-3?

**iii** III-1 and III-3?

ISBN 978-1-108-88711-3

## Analysing pedigrees

Genetic disorders arise from mutations and, as you know, these disorders may be dominant or recessive. Their gene locus may be on an autosome or a sex chromosome. The alleles for these phenotypes are passed on to offspring from the parents. The advantage of observing individuals in the pedigree is that you can determine whether a disorder (or any trait) is dominant or recessive, and also predict the transmission from parents to offspring. In order to do this, you will need to use your knowledge of genotypes and phenotypes, dominant and recessive, homozygous and heterozygous, and Punnett squares, as you have learned in Sections 8A to 8C. Some traits and their patterns to watch for are described in the following worked examples.

LINK 8A THE NATURE OF GENES
LINK 8B INTRODUCTION TO GENETICS
LINK 8C MONOHYBRID CROSSES

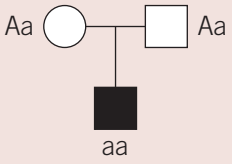
### Worked example 8E–1

VIDEO WORKED EXAMPLE 8E–1

**Identifying autosomal recessive traits**

Recall that for a recessive trait to be displayed, an individual needs to have two copies of the same allele for that trait (homozygous), which they have inherited from each parent.

It is possible for two unaffected (do not display the phenotype) parents to produce affected (have the phenotype) offspring. For this to occur, both parents must be heterozygous (carriers), and the offspring therefore need to inherit one allele for the trait from each parent. Additionally, the trait can skip a generation. This is shown in the diagram on the right.




A = allele for 'normal' (unaffected) phenotype

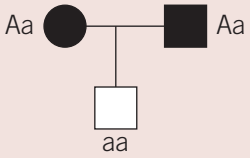
a = allele for (affected) phenotype in the pedigree

### Worked example 8E–2

VIDEO WORKED EXAMPLE 8E–2

**Identifying autosomal dominant traits**

Recall that for dominant traits, an individual only needs to have one copy of the allele. Therefore, affected offspring must have at least one parent with the phenotype.




A = allele for (affected) phenotype in the pedigree

a = allele for 'normal' (unaffected) phenotype

It is possible for two affected parents to have an unaffected child. Again, both parents must be heterozygous for this to occur, and the offspring must inherit one allele for the normal/unaffected trait from each of them. This is not possible if the trait is recessive.

Usually (but not always, as a mutation would have to occur in the production of sex cells from one parent), dominant traits will appear in every generation.

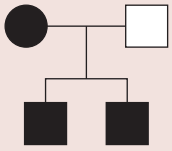
For both autosomal recessive and autosomal dominant traits, there are approximately (but not always) equal numbers of males and females affected.

ISBN 978-1-108-88711-3

VIDEO WORKED EXAMPLE 8E–3

## Worked example 8E–3

**Identifying X-linked recessive traits**



Recall from Section 8C that for X-linked recessive traits, females must have two copies of the allele, whereas males only have one X chromosome and are said to be hemizygous.

8C MONOHYBRID CROSSES LINK

Therefore, if females display the phenotype, then all their sons will also display the phenotype, as the sons inherit the X chromosome from their mother.

As with autosomal recessive traits, the trait can skip a generation. However, we cannot eliminate the possibility that the trait is autosomal, from just this evidence.

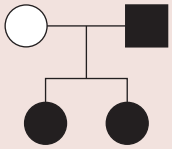
### NOTE

For both X-linked recessive and X-linked dominant traits, there are usually more of one gender affected than the other.

VIDEO WORKED EXAMPLE 8E–4

## Worked example 8E–4

**Identifying X-linked dominant traits**



Recall that for X-linked dominant traits, females only need to have one copy of the allele, whereas males have one X chromosome and are said to be hemizygous.

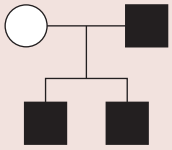
This means that any male who displays the phenotype will pass the allele for this trait to all his daughters. (Sons are not affected as they inherit the Y chromosome from their father.)

Again, we cannot eliminate the possibility that the trait is autosomal from just this evidence.

VIDEO WORKED EXAMPLE 8E–5

## Worked example 8E–5

**Identifying Y-linked traits**



As only males have the Y chromosome and they therefore inherit this from their father, any allele that controls a phenotype that appears on the Y chromosome will also be observed in all sons.

WORKSHEET 8E–1 USING PEDIGREES TO DETERMINE THE MODE OF INHERITANCE

## Check-in questions – Set 2

1 Complete the table by outlining ways in which each type of inherited trait can be determined in a pedigree.

2 Outline the difference between 'autosomal' and 'sex-linked'.

| Inherited trait | How this is determined |
|---|---|
| Autosomal recessive | |
| Autosomal dominant | |
| X-linked recessive | |
| X-linked dominant | |
| Y-linked | |

ISBN 978-1-108-88711-3

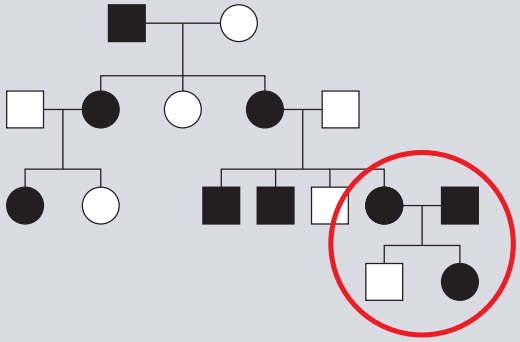
## 8E SKILLS

VIDEO 8E–2
SKILLS: ASSIGNING GENOTYPES TO INDIVIDUALS IN PEDIGREES

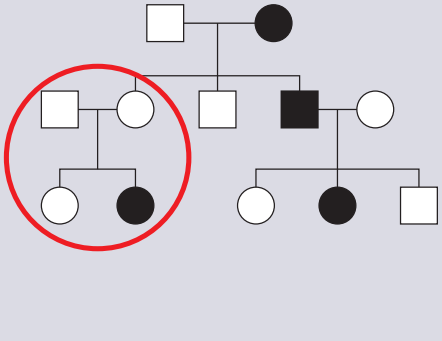
### Assigning genotypes to individuals in pedigrees

When you are asked to assign a genotype to each individual in a pedigree, a few simple strategies will make this easier. Two examples are shown below, with each step outlined.

**Step 1** Work out whether the trait is dominant or recessive.

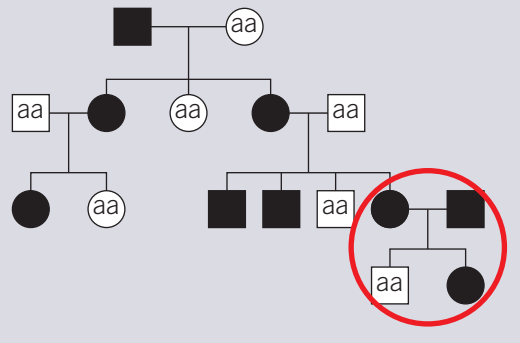


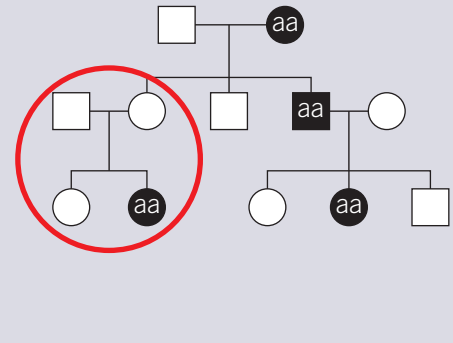
Dominant – two affected parents have unaffected offspring



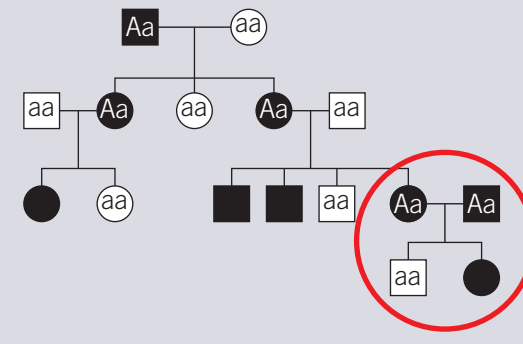
Recessive – two unaffected parents have an affected offspring

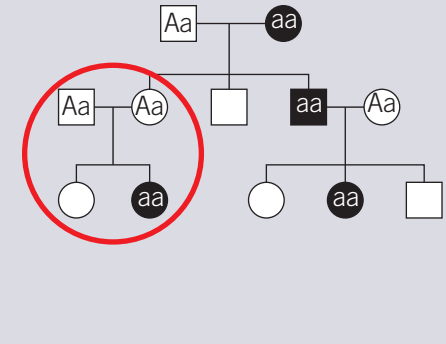
**Step 2** If the trait is recessive, write the genotypes of those affected (shown right). If the trait is dominant, write the genotype of those unaffected (shown left).



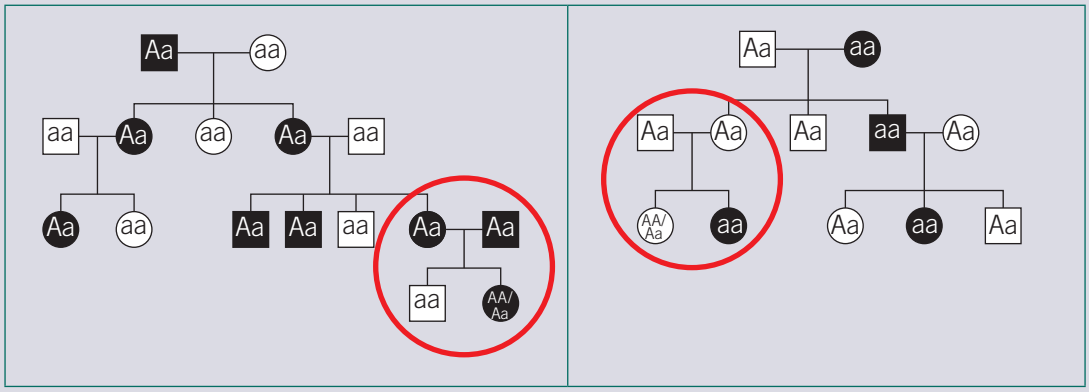

**Step 3** In the dominant example, complete the genotypes for the parents of any unaffected offspring as heterozygous (shown left). In the recessive example, complete the genotypes for the parents of affected offspring as heterozygous (shown right).




ISBN 978-1-108-88711-3

**Step 4** Complete the genotypes for all remaining individuals. For those that have two possible genotypes (homozygous dominant or heterozygous), include both. There is not enough information on further generations produced from these individuals to determine their exact genotype.

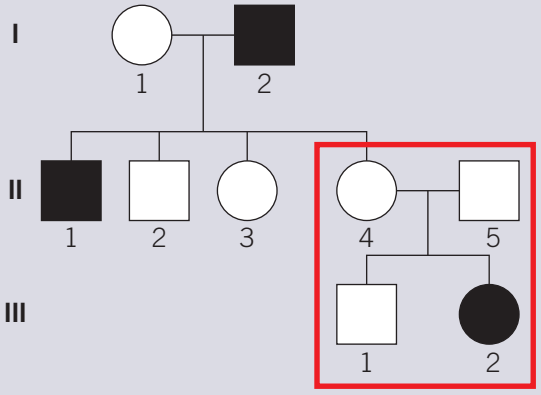



*Note*: It is usually easier to start assigning genotypes from the bottom of the pedigree and work your way up.

VIDEO 8E–3
SKILLS: IDENTIFYING DOMINANT AND RECESSIVE TRAITS FROM PEDIGREES

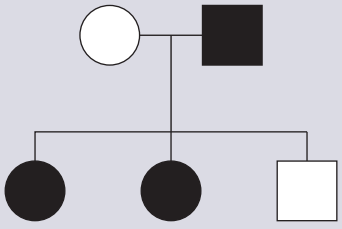
**Identifying dominant and recessive traits from pedigrees**

The following pedigree shows a family with individuals who have cystic fibrosis. Is this disorder dominant or recessive, or is the information inconclusive?




At first glance you might think this trait is dominant, as there is an individual with cystic fibrosis present in every generation. However, upon closer viewing, you can see that individuals II-4 and II-5, who are both unaffected, have an affected daughter III-2. Therefore this is a recessive condition.

Sometimes a pedigree is not informative enough for you to tell whether the trait is dominant or recessive, like the one on the right.



Try assigning genotypes for individuals, assuming the trait is dominant, using the steps outlined above. Then do the same, assuming the trait is recessive. If it can work both ways, this pedigree is classified as being 'inconclusive'.

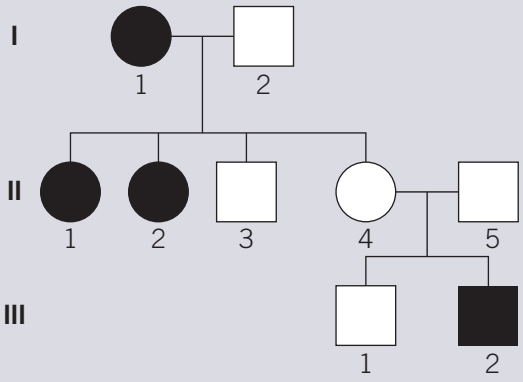
ISBN 978-1-108-88711-3

VIDEO 8E–4
SKILLS: PROVIDING PROOF FOR DOMINANT AND RECESSIVE TRAITS IN PEDIGREES

**Providing proof for dominant and recessive traits in pedigrees**

In answering questions that require you to determine whether a phenotype is dominant or recessive, you must explicitly refer to individuals in the pedigree. For example, in the pedigree below, you would be required to say:

*This is a recessive trait as unaffected individuals II-4 and II-5 have an affected son III-2.*




Often you will also be asked to determine whether a trait is autosomal or X-linked (sex-linked). To prove that the trait shown in the pedigree here is autosomal, you need to find evidence that it is not X-linked. For example:

*If this trait was X-linked recessive, affected mother I-1, who has two copies of the allele for the trait), will definitely pass this allele to all her sons. As her son, individual II-3, is not affected, it cannot be X-linked. Therefore, this trait is autosomal.*

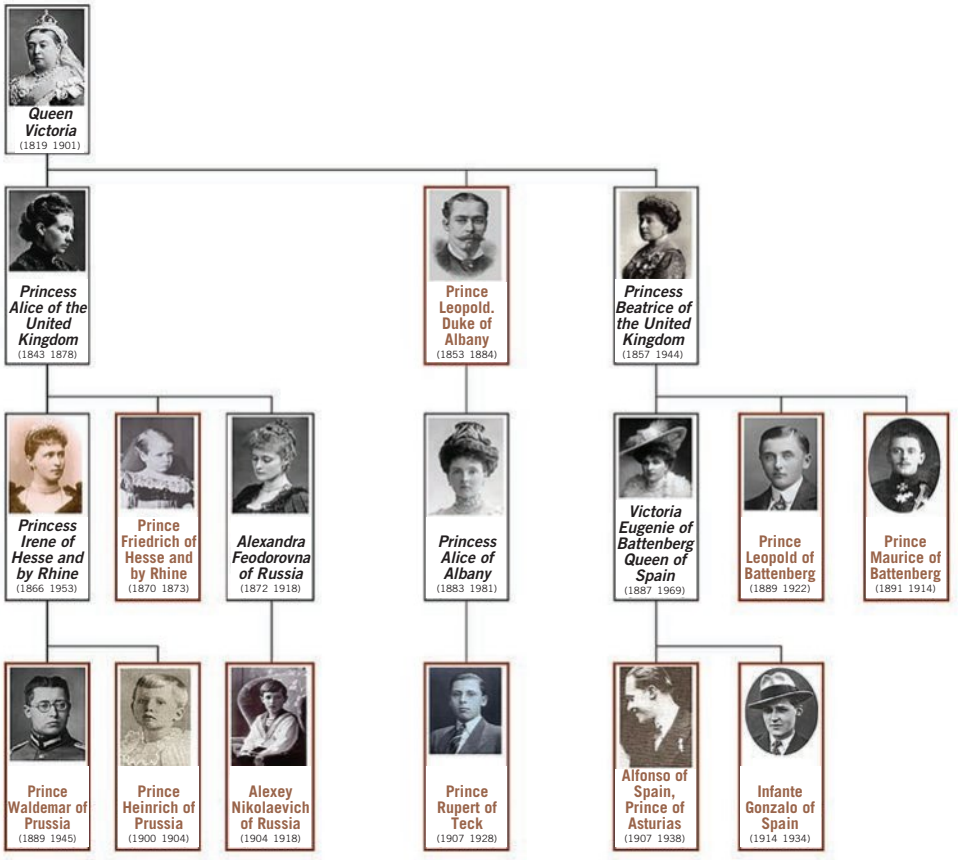



**Figure 8E–3** Queen Victoria was a carrier of haemophilia, an X-linked recessive mutation, and the disease occurred in a number of her descendants in European royal families, as shown here by the names of the males in brown.

ISBN 978-1-108-88711-3

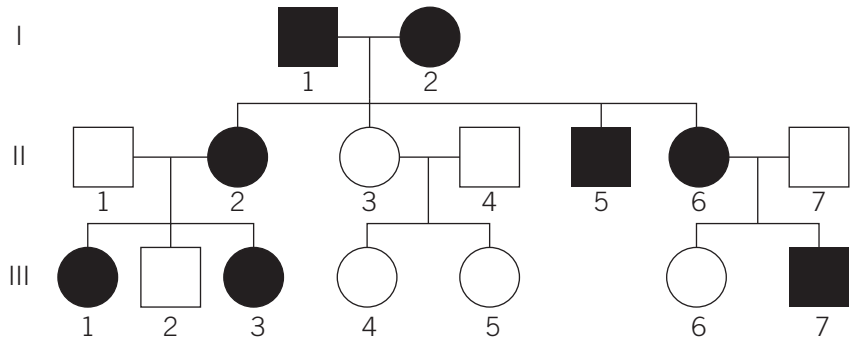
## Section 8E questions

**1** In a pedigree, the death of an individual is represented by a diagonal line through the symbol for that individual. Using this knowledge, how would you represent a couple who have married, had children, and then divorced in a pedigree chart?

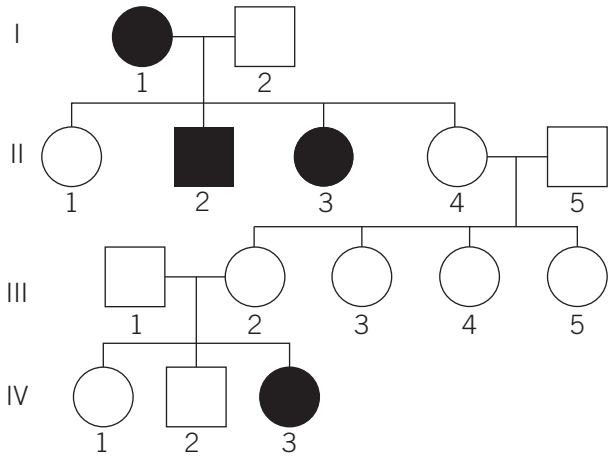
**2** The following pedigrees display traits/disorders that have been inherited over multiple generations. Recall the rule that the affected individuals are shaded. For each pedigree:

- **i** determine whether the trait/disorder is dominant or recessive (describe or draw the part of the pedigree that highlights this)
- **ii** determine whether the trait/disorder is autosomal, X-linked or Y-linked, and give reasons for your choice
- **iii** define alleles for the normal and trait/disorder phenotypes
- **iv** complete the genotypes for all individuals in the pedigree.

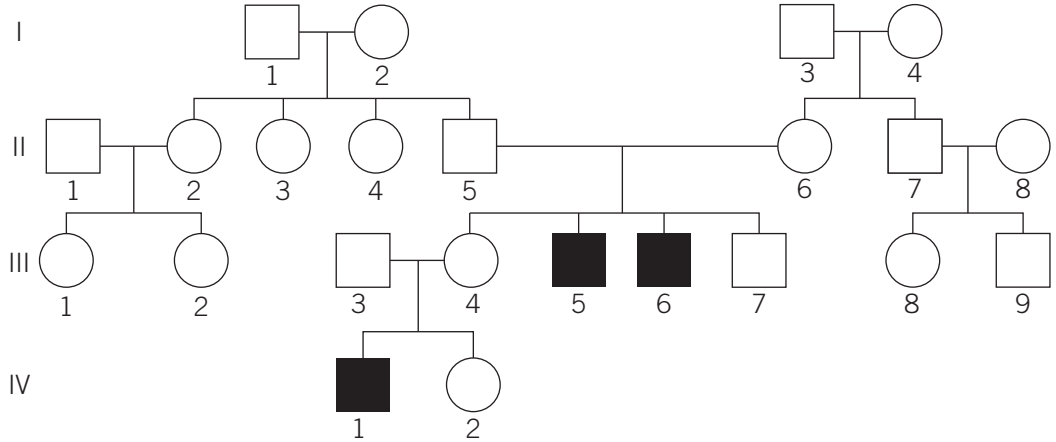
**a**




**b**

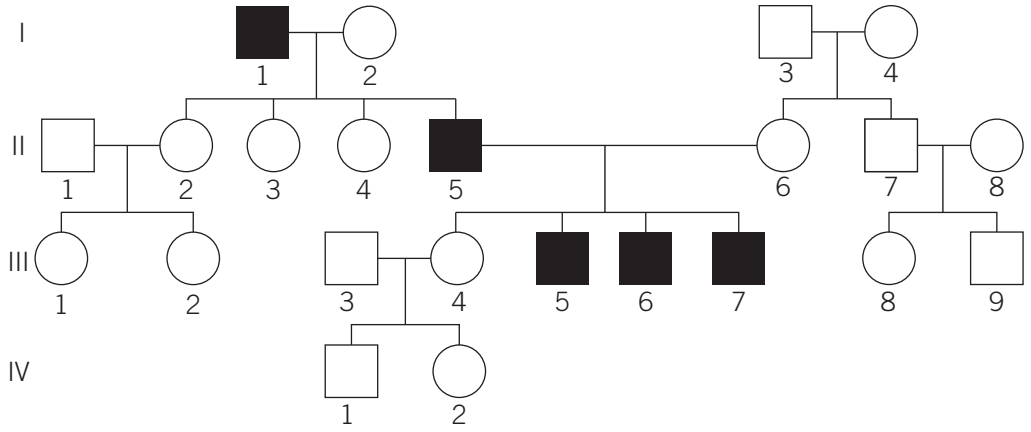



**c**

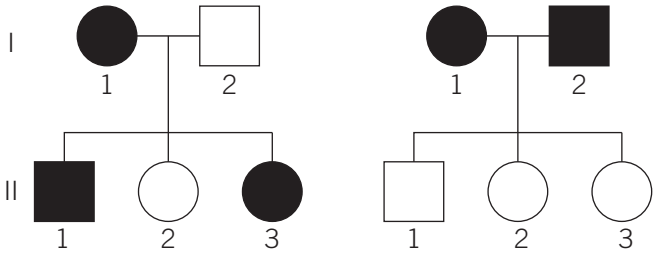



ISBN 978-1-108-88711-3

**d**




**3** Huntington disease can cause movement and cognitive symptoms, which usually do not present until the person is at least in their mid- to late-thirties. The pedigree below shows the inheritance of Huntington disease in two unrelated families.




**a** What is the mode of inheritance for Huntington disease? Explain your reasoning, ruling out other possibilities.

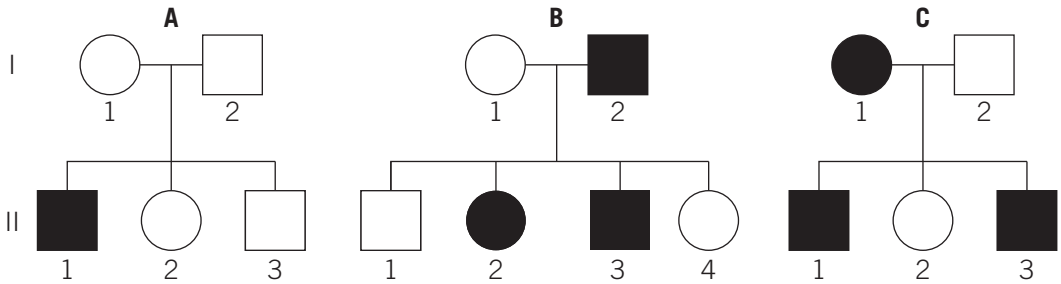
**b** Based on your answer to part **a**, assign appropriate genotypes for each person in the pedigree.

**c** Individuals II-3 (from family on the left) and II-1 (from family on the right) are planning to marry, and are interested in having children. What are the chances of a daughter from this couple developing Huntington disease?

**d** If you were a genetic counsellor, what discussions or advice would you give the couple?

**4** Red–green colour blindness is a common X-linked recessive trait.

**a** Which of the pedigrees below could represent a family with red–green colour blindness? Explain your choice.




**b** If the parents in pedigree C wanted to have another daughter (to give them two sons and two daughters), what are the chances of her being red–green colour blind?

ISBN 978-1-108-88711-3

**5** X-linked diseases can also be dominant. Incontinentia pigmenti is an extremely rare disease that is caused by an allele for an X-linked dominant trait. The main symptoms occur in the skin, where a blistering rash occurs in a newborn, followed by the blisters becoming raised-like warts. Next, brown swirls appear in the skin, followed by the appearance of light swirls. The result is a 'marble cake' appearance of the skin. Other health problems can involve the eyes, central nervous system, teeth, nails and hair. The severity varies from person to person.

**a** If the gene for incontinentia pigmenti is on the X chromosome, how many copies of this gene would a male have? Explain.

**b** If the gene for incontinentia pigmenti is on the X chromosome, how many copies would a female have of this gene? Explain.

**c** The possible alleles for the IP gene are:
$X^a$ = incontinentia pigmentia
$X^A$ = normal
What would be the phenotype for the following individuals? Include the sex.

**i** $X^AY$

**ii** $X^aY$

**iii** $X^AX^A$

**iv** $X^AX^a$

**v** $X^aX^a$

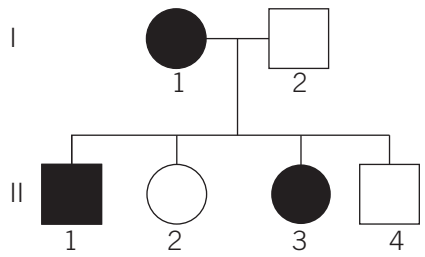
**d** This disease is described as X-linked dominant. What does this mean?

**e** Are males or females more likely to be affected by this disease? Why?

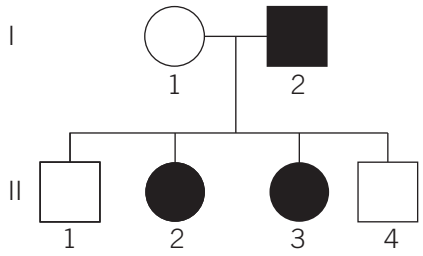
**f** If a normal female married an incontinentia pigmenti male, what would the chances be of them having an incontinentia pigmenti child? Show all working. Include the sex in your phenotypes.

**g** The following pedigrees represent families with a history of incontinentia pigmenti. Assign the possible genotype for each individual.

**i**




**ii**




**h** Using the pedigrees as a guide only, could the IP gene be classified as an autosomal dominant condition? Justify your answer.

ISBN 978-1-108-88711-3

# Chapter 8 review

## Summary

Create your own set of summary notes for this chapter, on paper or in a digital document. A model summary is provided in the Teacher Resources and can be used to compare with yours.

## Checklist

In the Interactive Textbook, the success criteria are linked to the review questions and will be automatically ticked when answers are correct. Alternatively, print or photocopy this page and tick the boxes when you have answered the corresponding questions correctly.

'ITB' in the linked questions columns means there is a question on this success criterion in the Interactive Textbook.

| Success criteria – I am now able to: | | Linked question |
|---|---|---|
| **8A.1** | Define gene, allele and genome | 17d☐ |
| **8A.2** | Apply the terms gene and allele in the correct context within a question | 17d☐ |
| **8A.3** | Draw and annotate a pair of homologous chromosomes | 18d☐, f☐, g☐ |
| **8A.4** | Explain how chromosomes vary between and within species | 13☐, 18f☐ |
| **8B.1** | Define genotype and phenotype | ITB☐ |
| **8B.2** | Distinguish between genotype and phenotype | 11☐, 12b☐, 14☐, 15b☐, c☐, 18e☐, f☐, 20c☐ |
| **8B.3** | Identify the difference between dominant and recessive phenotypes | 14☐, 17a☐, b☐, 19c☐ |
| **8B.4** | Define homozygous and heterozygous | 12e☐, 14☐, 17a☐ |
| **8B.5** | Classify genotypes as homozygous or heterozygous | 6☐, 12c☐, e☐, 14☐, 17c☐, 19c☐ |
| **8B.6** | Write genotypes for individuals using correct allele combinations for dominant and recessive phenotypes | 1☐, 2☐, 6☐, 12a☐, b☐, c☐, 15a☐, b☐, c☐, e☐, 17c☐, 18b☐, h☐, 19b☐, c☐, 20c☐ |
| **8B.7** | Define epigenetic factors | ITB☐ |
| **8B.8** | Explain how epigenetic factors affect phenotypes | ITB☐ |
| **8B.9** | Give examples of environmental factors that affect phenotypes | ITB☐ |
| **8C.1** | Define monohybrid cross and test cross | 12d☐ |
| **8C.2** | Draw Punnett squares for single gene traits | 2☐, 8☐, 12b☐, c☐, e☐, 15b☐, c☐, 20c☐ |

ISBN 978-1-108-88711-3

| Success criteria – I am now able to: | | Linked question |
|---|---|---|
| **8C.3** | Predict chance of individuals acquiring traits from the genotype and/or phenotypes of the parents | 2☐, 12b☐, c☐, e☐, 15b☐, c☐, 20c☐ |
| **8C.4** | Complete a monohybrid test cross | 12c☐ |
| **8C.5** | Know the ratio expected from different monohybrid test crosses | 2☐, 12c☐ |
| **8C.6** | Distinguish between codominance and incomplete dominance | 3☐, 15d☐ |
| **8C.7** | Explain how codominance and incomplete dominance are different to dominant and recessive phenotypes | 15d☐ |
| **8C.8** | Write genotypes for codominant and incompletely dominant and sex-linked traits | 1☐, 4☐, 7☐, 15b☐, c☐, 16☐, 19c☐ |
| **8C.9** | Define and draw Punnett squares for sex-linked inheritance | 7☐, 19d☐ |
| **8C.10** | Outline the relationship between monogenic, polygenic, continuous variation and discontinuous variation | ITB☐ |
| **8D.1** | Define dihybrid crosses | ITB☐ |
| **8D.2** | Compare linked genes with those that independently assort | 9☐, 10☐, 18a☐ |
| **8D.3** | Know the phenotypic ratio for a dihybrid cross between two heterozygous individuals | ITB☐ |
| **8D.4** | Know the phenotypic ratio for a dihybrid test cross for genes that independently assort | 10☐, 18a☐ |
| **8D.5** | Know the phenotypic ratio for a dihybrid test cross for genes that are linked and close together | 10☐, 18a☐ |
| **8D.6** | Know the phenotypic ratio for a dihybrid test cross for genes that are linked and far apart | 10☐, 18a☐ |
| **8E.1** | Identify and represent males and females in pedigrees | 5☐, 19a☐, 20b☐ |
| **8E.2** | Identify and represent different relationships using a pedigree | 5☐, 19a☐, 20a☐ |
| **8E.3** | Correctly refer to and name affected and unaffected individuals in a pedigree | 8☐, 19a☐, 20b☐ |
| **8E.4** | Identify autosomal dominant traits using a pedigree | 6☐, 20a☐ |
| **8E.5** | Identify autosomal recessive traits using a pedigree | 8☐ |
| **8E.6** | Identify X-linked dominant traits using a pedigree | 19a☐, 20a☐ |
| **8E.7** | Identify X-linked recessive traits using a pedigree | 19a☐ |
| **8E.8** | Identify Y-linked traits using a pedigree | ITB☐ |
| **8E.9** | Use correct genetic terminology to answer pedigree-based questions | 19a☐ |

ISBN 978-1-108-88711-3

## Multiple-choice questions

**1** Which of the following shows the genotype for a sex-linked heterozygous organism?
- **A** Aa
- **B** $X^AY^a$
- **C** BB
- **D** $X^RX^r$

**2** The trait for mid-digit hair is dominant to the trait for no hair. If two heterozygous organisms mate, then
- **A** all their children will have mid-digit hair.
- **B** three-quarters of their children will have mid-digit hair.
- **C** half of their children will have mid-digit hair.
- **D** one-quarter of their children will have mid-digit hair.

*The following information relates to Questions 3 and 4.*

Andalusian chickens with the genotype $C^BC^B$ are black, those with the genotype $C^WC^W$ are white, and those with the genotype $C^BC^W$ are grey.

**3** What is the type of inheritance represented by this trait?
- **A** complete dominance
- **B** incomplete dominance
- **C** codominance
- **D** dihybrid inheritance

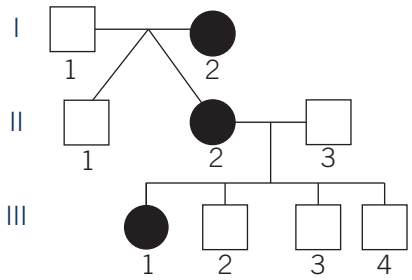
**4** What is the expected genotypic ratio of a cross between a $C^BC^B$ individual and a $C^BC^W$ individual?
- **A** 1 $C^BC^B$ : 1 $C^BC^W$
- **B** 3 $C^BC^B$ : 1 $C^WC^W$
- **C** 3 $C^BC^B$ : 1 $C^BC^W$
- **D** 1 $C^BC^B$ : 2 $C^BC^W$ : 1 $C^WC^W$

*The following information relates to Questions 5 and 6.*

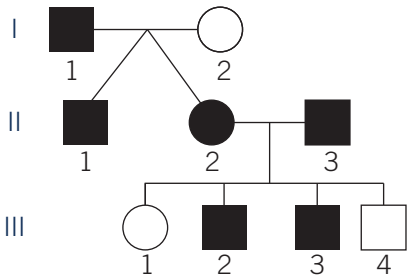
**5** Simon married Linsey. Simon has unattached earlobes and Linsey has attached earlobes. They had two children (twins), Wells and Delaney. Both Wells and Delaney have unattached earlobes. Delaney married Easton, as she was attracted to his unattached earlobes. They had four children: three boys and a girl. Two of the boys have unattached earlobes and the other two children have attached earlobes.

The pedigree that could represent the inheritance of the detached earlobes in this family is

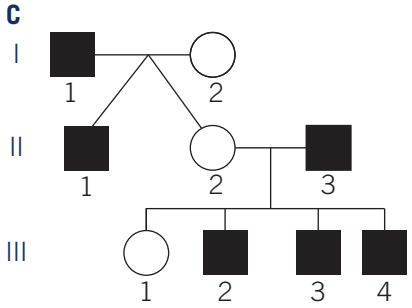
**A**



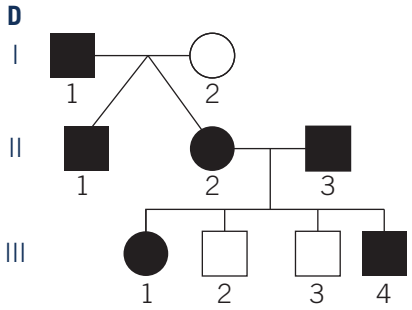

**B**




**C**




**D**



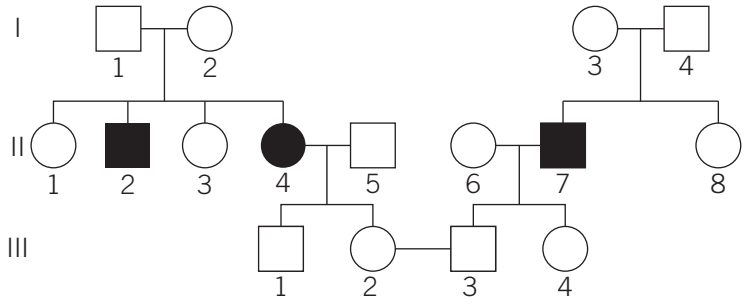

**6** Easton's daughter has the genotype
- **A** EE or Ee.
- **B** EE.
- **C** Ee.
- **D** ee.

ISBN 978-1-108-88711-3

**7** The gene that codes for a protein needed for blood clotting factor VIII is on the X chromosome. A normal woman who is heterozygous mated with a normal male. What are the chances of them having a child with haemophilia, a disorder in which the blood doesn't clot properly?

**A** 0%
**B** 25%
**C** 50%
**D** 100%

**8** In the pedigree below, shaded individuals have the same autosomal genetic defect.



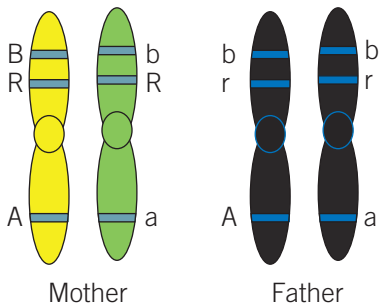

From this pedigree you can conclude that

**A** individuals II-6 and II-7 are homozygous.
**B** individuals I-1 to I-4, and II-1 are all heterozygous for the genetic defect.
**C** individual I-1 is the aunt of individual II-4.
**D** if individuals II-4 and II-5 had a child, the child would have a 75% chance of having the defect.

**9** In humans, each chromosome carries many genes. Some of the genes on chromosome number 1 are shown in the table.

| Gene function | Alleles |
|---|---|
| Shape of red blood cells | B = elliptical blood cell<br>b = normal-shaped blood cell |
| Rhesus blood group | R = Rhesus positive<br>r = Rhesus negative |
| Production of amylase | A = amylase produced<br>a = no amylase produced |

In a large family, the parents have the following combinations of alleles on their number 1 chromosomes.




From this information, it is reasonable to assume that

**A** some of the children would have elliptical red blood cells.
**B** some of the children would be Rhesus negative.
**C** none of the children would produce amylase.
**D** the father is heterozygous at two of the gene loci.

ISBN 978-1-108-88711-3

**10** A particular species of plant has the following genes and alleles:
green leaf colour = L, white leaf colour = l
wrinkled seed = W, round seed = w
A test cross between two parents produced the following numbers of offspring.

| Phenotype | Number of offspring |
|---|---|
| Green leaves, wrinkled seeds | 130 |
| White leaves, round seeds | 121 |
| Green leaves, round seeds | 19 |
| White leaves, wrinkled seeds | 17 |

The genotypes of the two parents must be:

**A** $\frac{\text{L W}}{\text{l w}} \times \frac{\text{l w}}{\text{l w}}$

**B** $\frac{\text{L w}}{\text{l W}} \times \frac{\text{l w}}{\text{l w}}$

**C** $\frac{\text{L W}}{\text{l w}} \times \frac{\text{L W}}{\text{l w}}$

**D** $\frac{\text{L W}}{\text{l w}} \times \frac{\text{L w}}{\text{l w}}$

## Short-answer questions

**11** Which two factors affect the phenotype of an organism? (1 mark)

**12** A farmer is growing peas. Green peas are dominant to yellow peas.

**a** Define the alleles for green and yellow peas. (1 mark)

**b** What are the genotypic and phenotypic ratios for the offspring if a homozygous green pea is crossed with a heterozygous green pea? Show your working. (2 marks)

**c** A yellow pea plant is crossed with a green pea plant. All the offspring produce green peas. What is the most likely genotype for the green pea parent? Show your working. (2 marks)

**d** What is the name for the type of cross that occurred in part **c**? (1 mark)

**e** Two green pea plants mate and produce a yellow pea plant. Using a Punnett square, explain how the green pea plants could produce a yellow pea plant. (2 marks)

**13** Thinking back to the sizes of the X and Y chromosomes from Chapter 7, which do you think will have more genes? Explain. (1 mark)

**14** Two scientists were having a discussion in the laboratory.

Juan said: 'A dominant trait is one that is expressed by a greater percentage of the population, and a recessive trait is one that is expressed by a very small percentage of the population.'

Anita said: 'A dominant trait is expressed by individuals with the heterozygous genotype, and a recessive trait is only expressed by individuals with a homozygous genotype.'

Who is correct? Give reasons for your answer. (2 marks)

**15** In blood groups, if a person has the alleles $I^BI^O$ then their blood type is B. The presence of the recessive $I^O$ allele has no effect on the blood type in the presence of the dominant $I^B$ allele.

**a** What other possible allele combination(s) can create the same type B blood group? (1 mark)

**b** If Dinesh is heterozygous for blood type B, and his wife Ann is heterozygous for blood type A, what are the chances of them having a child who is the same phenotype as Dinesh? (3 marks)

**c** How would this percentage change if Dinesh was homozygous for the B blood type? Show your working. (3 marks)

ISBN 978-1-108-88711-3

**d** Is blood type an example of complete dominance, incomplete dominance or codominance? Explain. (3 marks)

**e** The crosses in the table at right show the inheritance pattern of ABO blood groups in humans. Three alleles determine the blood groups: $I^A$, $I^B$ and $I^O$. The possible phenotypes are blood groups A, B, AB and O.

Which one of the crosses shown is *not* possible? Explain. (3 marks)

| Cross | Parents | | Offspring |
|---|---|---|---|
| | Mother | Father | |
| 1 | AB | O | O |
| 2 | AB | A | B |
| 3 | A | B | O |
| 4 | A | O | O |

**16** In Manx cats, the allele for no tail, $M^T$, is dominant over the allele for normal tail, $M^t$. A cross between two heterozygous tailless Manx cats shows that for every two tailless offspring there is one normal-tailed offspring. Explain why the phenotypic ratio for the cross is not the expected 3 : 1 ratio. In doing so, show your reasoning using a Punnett square. (3 marks)

**17** A common garden plant has flowers that are either red or white. Many plants were grown, each expressing one of the two colours. All the plants were allowed to self-pollinate, meaning that the parents of a particular cross all had the same genotype and phenotype. The phenotypes and ratios of offspring produced from the self-pollinations were recorded in the table.

| Cross number | Phenotype of parents | Ratio and phenotype of offspring |
|---|---|---|
| 1 | Red-flowered | All red-flowered |
| 2 | Red-flowered | 3 red-flowered : 1 white-flowered |
| 3 | White-flowered | All white flowered |

**a** Focusing on cross 1 only, explain whether there is sufficient evidence to determine whether the red colour is dominant or recessive. (2 marks)

**b** Which cross in the table indicates that the red colour is dominant to white colour? (1 mark)

**c** Which genotypes could produce a red-flowered plant? (1 mark)

**d** To answer part **c**, you needed to assign alleles to the different phenotypes. What is an allele? (1 mark)

**18** A test cross between a heterozygous red-eyed, normal-winged fly with a recessive yellow-eyed, curly-winged fly produced the following offspring numbers.

| Red eyes, normal wings | Red eyes, curly wings | Yellow eyes, normal wings | Yellow eyes, curly wings |
|---|---|---|---|
| 24 | 4 | 3 | 27 |

**a** Do these results support the conclusion that the two genes are linked or assort independently? Explain. (2 marks)

**b** Assign alleles for both eye colour and wing type. (1 mark)

**c** What are the phenotypes for the parental classes? Explain. (2 marks)

**d** Draw a diagram to represent the chromosomes for the heterozygous red-eyed, normal-winged fly. (1 mark)

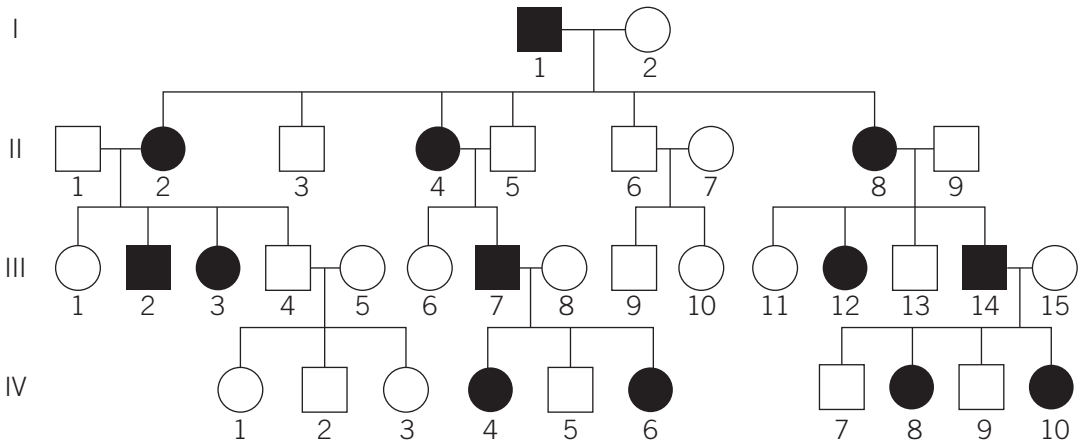
**e** What are the phenotypes for the recombinant classes? Explain. (2 marks)

**f** Draw a diagram to show how these recombinant classes are possible. (2 marks)

**g** Draw a diagram to represent the chromosomes for the recessive yellow-eyed, curly-winged fly. (1 mark)

ISBN 978-1-108-88711-3

**19** The gene for hypophosphataemia, a genetic disorder that can cause bone deformity and short stature, is located on the X chromosome. A family with a history of this condition is shown in the pedigree below.



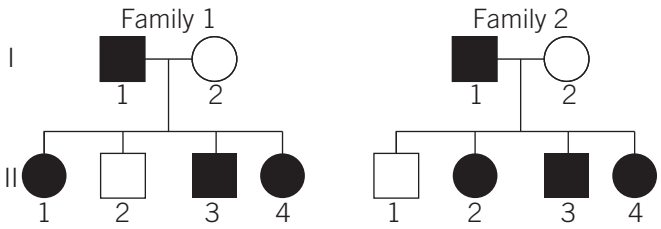

**a** Is this condition X-linked recessive or X-linked dominant? Provide two reasons from the pedigree for your justification. (2 marks)

**b** Assign appropriate alleles for this trait. (1 mark)

**c** Write the genotypes and phenotypes of individuals II-8 and II-9. (2 marks)

**d** What is the chance of individuals II-8 and II-9 having another affected son? Show all your working and use the alleles you assigned in part **b**. (3 marks)

**20** The pedigrees below show the pattern of inheritance of dark hair and red hair in two families. Dark hair is the dominant phenotype (shaded) and red hair is the recessive phenotype (unshaded).




**a** From these pedigrees, is it possible to determine whether hair colour is autosomal or X-linked? Explain. (2 marks)

**b** Assign genotypes for all individuals in the pedigrees. (2 marks)

**c** If individuals II-4 (from family 1) and II-1 (from family 2) have a child together, what can be determined about the hair colour of their children? (2 marks)

ISBN 978-1-108-88711-3

UNIT 2

# HOW DOES INHERITANCE IMPACT ON DIVERSITY?

CHAPTER 9

# RESEARCH TASK STRATEGIES

## Introduction

Unit 2 Outcome 3 requires you to investigate and communicate a response to an issue in genetics and/or reproductive science. To assist you in this process, this chapter explores a range of genetic and reproductive technologies. Section 9B provides an outline of four considerations you need to acknowledge when discussing your chosen technology.

When conducting research, you will encounter a wide range of views and materials, some of which may be biased. Section 9C provides you with strategies to enable you to digest the material and analyse its validity and reliability.

The chapter concludes with a suggested process for framing your investigation and weaving together the different threads of your understanding, using thinking organisers.

## Curriculum

**Area of Study 3 Outcome 3**
**How do humans use science to explore and communicate contemporary bioethical issues?**

| Study Design | Learning intentions – at the end of this chapter I will be able to: |
|---|---|
| **Scientific communication**<br>• Biological concepts specific to the investigation: definitions of key terms; use of appropriate biological terminology, conventions and representations | **9A Genetic and reproductive technologies**<br>**9A.1** Recall the different technologies<br>**9A.2** Understand what the technologies are<br>**9A.3** Describe how the different technologies are used<br>**9A.4** Utilise diagrams to support the explanation of different technologies |
| • The influence of social, economic, legal and political factors relevant to the selected research question<br>**Analysis and evaluation of bioethical issues**<br>• Ways of identifying bioethical issues<br>• Characteristics of effective analysis of bioethical issues | **9B Ethical, social, legal and economic considerations**<br>**9B.1** Recall the four different considerations: ethical, social, legal and economic<br>**9B.2** State what the different considerations are in a context<br>**9B.3** Apply the considerations to different stakeholders<br>**9B.4** Apply the considerations to different technologies<br>**9B.5** Make connections between the different considerations while being appropriate to the context of the research task<br>**9B.6** Recall the three different approaches to bioethics |

ISBN 978-1-108-88711-3

| Study Design | Learning intentions – at the end of this chapter I will be able to: |
|---|---|
| • Approaches to bioethics and ethical concepts as they apply to the bioethical issue being investigated | **9B.7** Understand that there are different ethical concepts to consider when exploring an ethical issue<br>**9B.8** Apply one or more ethical concepts to a bioethical issue that has been identified and explored |
| **Scientific evidence**<br>• The nature of evidence and information: distinction between opinion, anecdote and evidence, and scientific and non-scientific ideas<br>• The quality of evidence, including validity and authority of data and sources of possible errors or bias<br><br>**Scientific communication**<br>• 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<br>• The use of data representations, models and theories in organising and explaining observed phenomena and biological concepts, and their limitations | **9C Thinking organisers**<br>**9C.1** Recall the sections of CRAP detection to determine limitations of resources<br>**9C.2** Complete a CRAP detection for a given resource<br>**9C.3** Make conclusions to be included in a research report based on a CRAP detection<br>**9C.4** Apply the use of CRAP detection to determine limitations of resources<br>**9C.5** Recall the sections of a SWOT analysis<br>**9C.6** Complete all sections of a SWOT analysis<br>**9C.7** Elaborate on potential applications of technologies for different stakeholders through the assistance of a SWOT analysis<br>**9C.8** Present balanced arguments in the form of a research task with the assistance of a SWOT analysis |

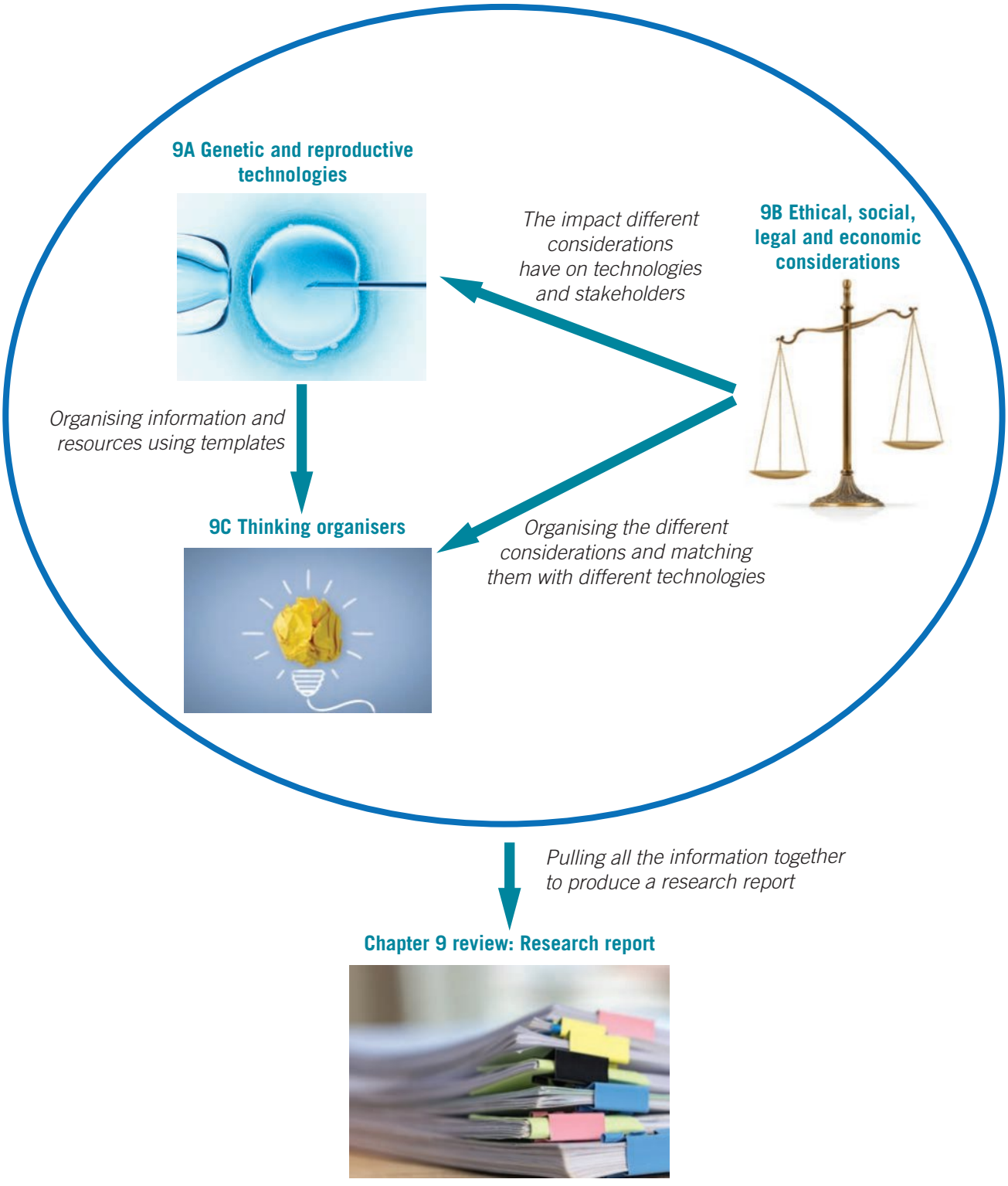


## Glossary

Authority
CRAP detection
Currency
Ethics
Integrity
In vitro fertilisation (IVF)
Opinion
Reliability
Respect
Rubric
Social norms
Stakeholder
SWOT analysis

ISBN 978-1-108-88711-3

## Concept map




*See the Interactive Textbook for an interactive version of this concept map interlinked with all concept maps for the course, and for a quiz of prior knowledge from Years 9 & 10 science.*

ISBN 978-1-108-88711-3


# Genetic and reproductive technologies

**Study Design:**
Biological concepts specific to the investigation: definitions of key terms; use of appropriate biological terminology, conventions and representations

**Glossary:**
In vitro fertilisation (IVF)
Rubric

## ENGAGE

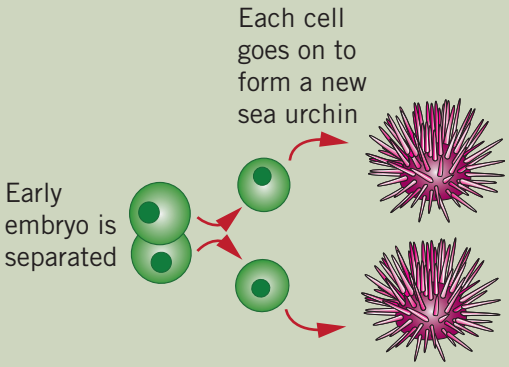
### The beginnings of cloning

Some people try to overcome the loss of a beloved pet by having the animal cloned, to produce a genetically identical replicate. This may seem futuristic and impossible, but such a service is available, with a hefty price tag: between US$50 000 and $100 000 to clone a dog. The first cloned dog was created in 2005 in South Korea at Seoul National University. Cloning in general raises many ethical questions, and these are explored in Section 9B.

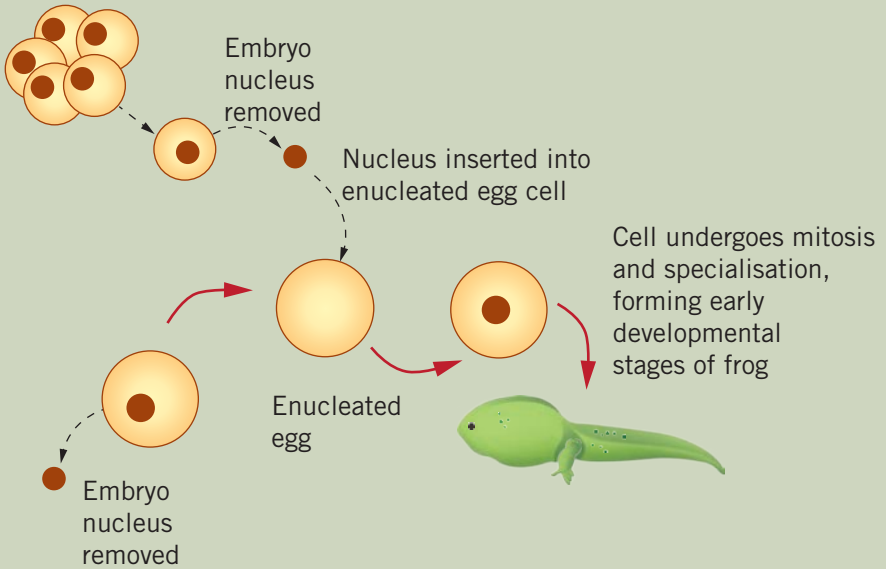
LINK 9B ETHICAL, SOCIAL, LEGAL AND ECONOMIC CONSIDERATIONS

The practice of cloning was underway well before 2005. Here is a brief outline of different cloning achievements:

- **1885:** First demonstration of artificial embryo twinning on a sea urchin (splitting of a two-celled embryo to produce two identical cells, or clones)



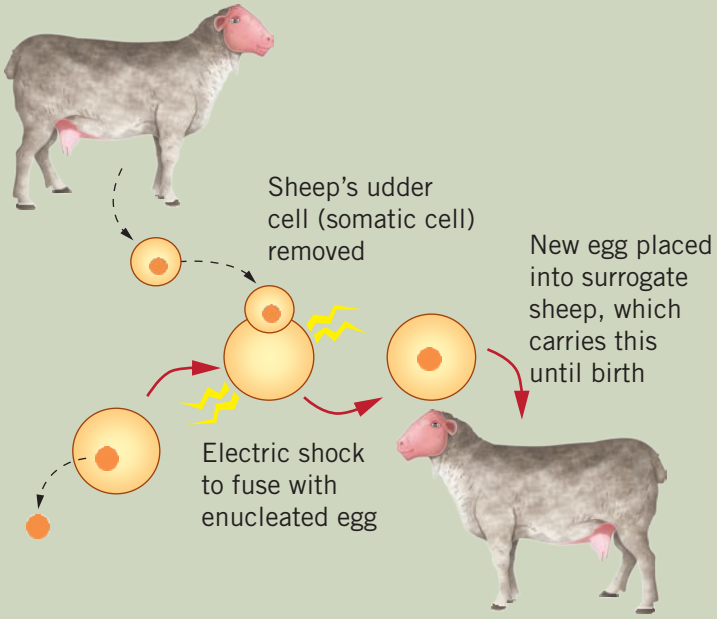

- **1902:** Artificial twinning in a vertebrate (salamander)
- **1952:** First successful nuclear transfer in a frog (transferring a nucleus from an early tadpole embryo into an enucleated frog egg)




LINK 3B THE CELL CYCLE

ISBN 978-1-108-88711-3

- **1958:** First nuclear transfer from a differentiated somatic cell into an enucleated frog egg
- **1984:** First successful use of nuclear transfer of an early embryo nucleus to produce a mammal
- **1996:** First successful somatic cell nuclear transfer to produce a mammal, after 277 attempts, giving rise to a famous lamb named Dolly




- **1997:** First successful use of embryonic cell nuclear transfer to produce a primate, demonstrating that humans' closest relatives can be cloned
- **2001:** Endangered animals cloned by somatic cell nuclear transfer
- **2013:** Human embryonic stem cells created by somatic cell nuclear transfer, providing a source of embryonic stem cells for a patient with a rare genetic disorder

As you can see, producing Dolly the sheep was not the first time cloning was achieved. What you may also notice is that early successes in cloning involved organisms that were simpler in nature. As technologies and our understanding have improved, scientists have been able to clone more complex organisms.

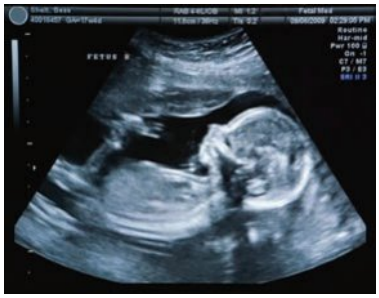
**EXPLAIN**

## Choosing a topic

The starting point for your Unit 2 AoS 3 task is to select a topic related to genetics and/or reproductive science. Table 9A–1 provides an outline of technologies and techniques, as a stimulus for you to start your research. The table includes diagrams referring to the techniques. How to use diagrams in your research report is explored in the Skills box.

ISBN 978-1-108-88711-3

**Table 9A–1** Summary of genetic and reproductive science technologies

| Technology | What it is | Techniques used |
|---|---|---|
| Cloning | The production of new organisms that are genetically identical to the original | Horticulture:<br>• cuttings and grafts<br>• tissue culture<br>Agriculture:<br>• embryo splitting<br>• nuclear transfer |
| | See Figure 9A–1 on the following page. | |
| Genetically modified organism | An organism that has had its genetic information altered or modified through genetic engineering. This can also involve the inclusion of genetic material from a different organism (transgenically modified) | • *Agrobacterium tumefaciens*<br>• Particle gun<br>• Clustered regularly interspaced short palindromic repeats, CRISPR |
| | See Figure 9A–2 on the following page. | |
| Assisted reproductive technologies | The use of medical procedures to address infertility | • **In vitro fertilisation (IVF)**<br>• Artificial insemination (AI)<br>• Ovulation induction (OI)<br>• Intracytoplasmic sperm injection (ICSI)<br>• Cryopreservation |
| |  <br>**In vitro fertilisation** | |
| Prenatal and genetic testing | Prenatal screening tests are procedures to determine whether a baby is likely to have a birth defect. If a screening test is positive, diagnostic tests can be used. | Screening tests:<br>• ultrasound<br>• blood test<br>• glucose screening<br>• non-invasive prenatal testing (NIPT)<br>• harmony test<br>Diagnostic tests:<br>• amniocentesis<br>• chorionic villus sampling (CVS)<br>• ultrasound |
| |  <br>**Ultrasound image of a human foetus** | |

LINK 7A ASEXUAL REPRODUCTION

LINK UNIT 3

**In vitro fertilisation (IVF)** a medical procedure in which an egg is fertilised by sperm outside the body

LINK 3A WHERE DO NEW CELLS COME FROM?

ISBN 978-1-108-88711-3

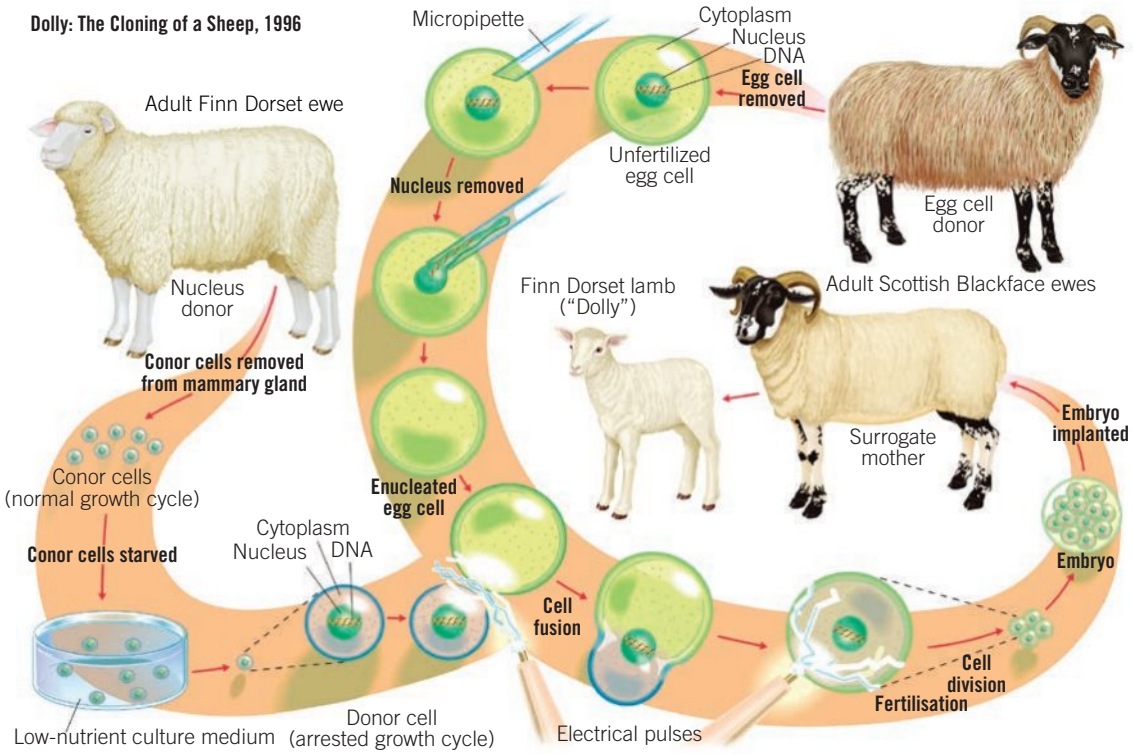



**Figure 9A–1** Cloning by nuclear transfer

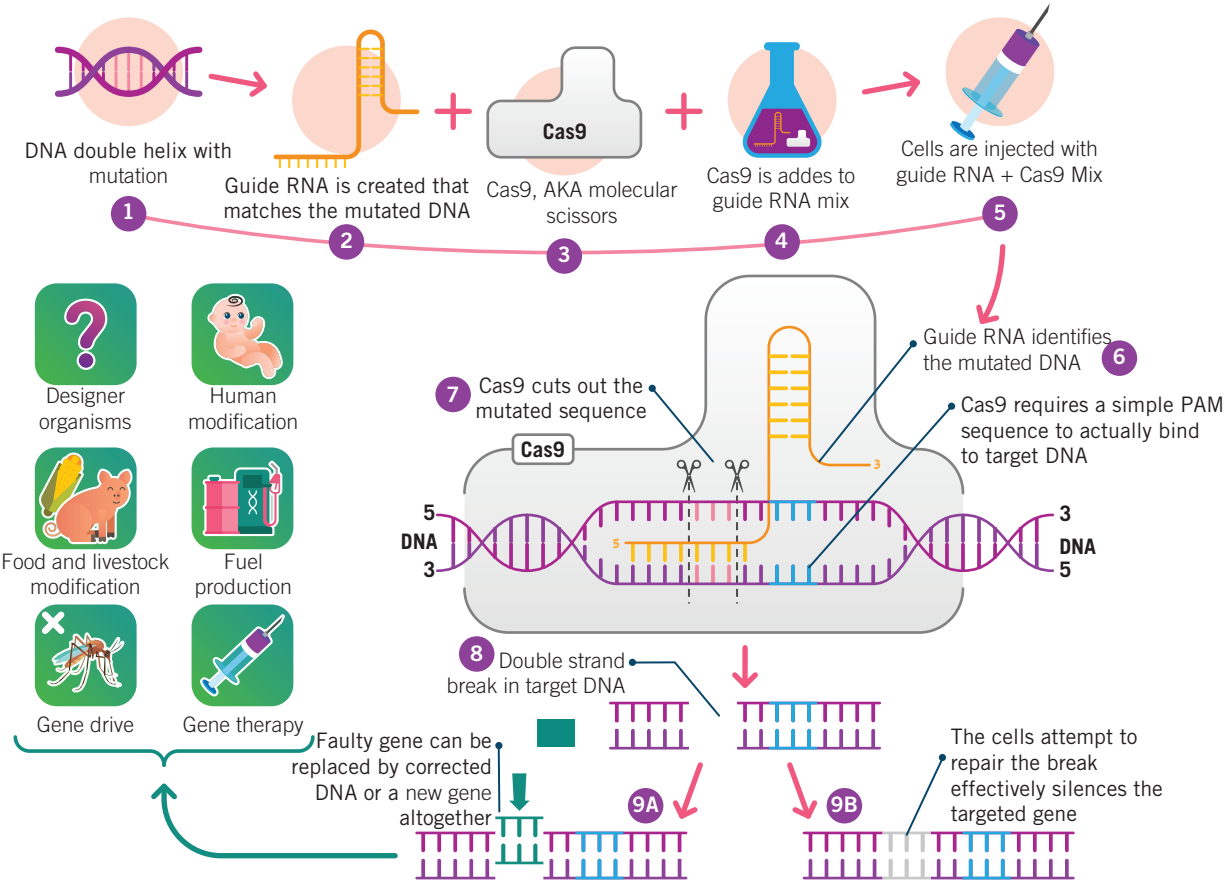



**Figure 9A–2** Genetic modification using CRISPR gene editing technology

ISBN 978-1-108-88711-3

## 9A SKILLS

### Incorporating diagrams into a research report

VIDEO 9A–1
SKILLS: DIAGRAMS IN RESEARCH REPORTS

Diagrams can be a powerful way of communicating your scientific understanding of technologies or procedures. They can be used in different ways and at different levels of complexity.

Below is a sample **rubric** that could be used to assess your use of diagrams in completing your research task. As the criteria go from 1.1 to 1.4, the level of use increases in difficulty, with a corresponding increase in the number of marks given. If you satisfy criterion 1.4, you would be given 4 marks. However, if you only meet criterion 1.0, you would receive no marks.

**Rubric**
a scoring guide; a set of criteria used to evaluate students' responses

**Rubric for use of diagrams**
1.0: There is no diagram present.
1.1: A diagram is present.
1.2: The diagram is referred to as a reference.
1.3: A single section of the diagram is used to support the explanation of the technology.
1.4: Multiple sections of the diagram are used to support the explanation of the technology.

Figure 9A–3 is a diagram produced for the research task, and Table 9A–2 on the next page gives examples of applying the rubric to how the diagram is used in the report.

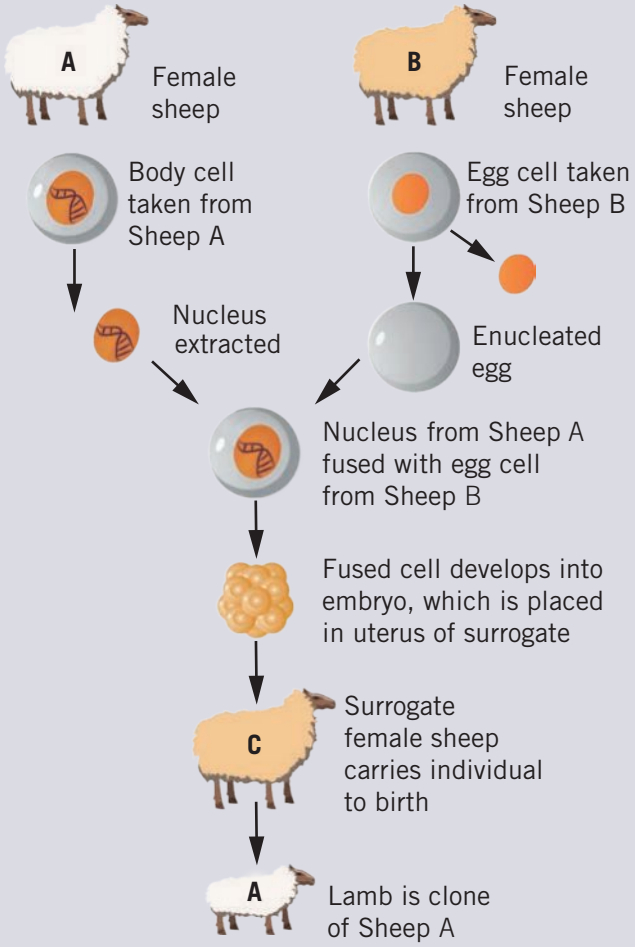



**Figure 9A–3** A potential diagram used in the Unit 2 AoS 3 task to do with animal cloning

ISBN 978-1-108-88711-3

**Table 9A–2** Use of diagrams rubric applied to Figure 9A–3

| Criterion level | What the text reference to the diagram could look like | Why it is marked at this criterion level |
|---|---|---|
| 1.1 | 'Somatic nuclear transfer involves the placement of a nucleus from a somatic cell into an enucleated egg from a different organism. The egg is then placed into a surrogate.' | There is no linking back to the diagram even though it is physically present in the research report. |
| 1.2 | 'The process of somatic nuclear transfer is outlined in Figure 9A–3 (continues to explain what the process is).' | The explanation references the diagram as a whole. There is no reference to the specific sections of the diagram to help support the explanation. |
| 1.3 | 'It can be seen that Sheep A from Figure 9A–3 has had its genetic material removed and inserted into an enucleated egg from a different sheep. That egg is then placed into a surrogate until the cloned lamb is born.' | A single specific reference from the diagram has been used, which demonstrates a higher level of understanding. The student has been able to appropriately match the written explanation with a diagrammatic representation. |
| 1.4 | 'As you can see in Figure 9A–3, the genetic material from Sheep A has been fused with the enucleated egg from Sheep B. This is finally transplanted into the surrogate Sheep C until it gives birth to a lamb, which would be an exact clone of Sheep A.' | Multiple steps explaining the process have incorporated specific examples from the diagram. It aids the marker in developing a deeper understanding of the process so that the written words are matched with the visual representation in the diagram. This has also demonstrated that the student has a more complex and deeper understanding of the content due to the continued matching of the whole process. |

These examples do not represent complete responses that you can use in your research report. They are given here merely to highlight the different ways in which you can use diagrams to support your explanations. The more you are able to connect your written words to the visual representations, the higher the level of understanding you are demonstrating.

## Section 9A questions

1 Explain the following terms with examples of each: cloning, genetically modified organism, assisted reproductive technologies, prenatal and genetic testing.
2 List three genetic or reproductive technologies.
3 Outline one of the technologies you listed for Question 1.
4 Explain why the representation of genetically modified food shown on the right is not accurate.
5 What is the difference between cloning and genetically modified organisms?

ISBN 978-1-108-88711-3

# 9B Ethical, social, legal and economic considerations

**Study Design:**
- The influence of social, economic, legal and political factors relevant to the selected research question
- Ways of identifying bioethical issues
- Characteristics of effective analysis of bioethical issues
- Approaches to bioethics and ethical concepts as they apply to the bioethical issue being investigated

**Glossary:**
Ethics
Integrity
Respect
Social norms
Stakeholder

## ENGAGE

### The dubious price of progress

In many fields of research, some of the experiments conducted in the past are now considered to have been ethically questionable or unacceptable, and would not be allowed to be conducted today. Unethical experiments have informed procedures and processes in the field of medicine and some discoveries were made by accident – penicillin as an example.

Penicillin, known for its antibiotic properties, became paramount in treating syphilis. Syphilis is a sexually transmitted infection caused by the bacterium *Treponema pallidum*. Before penicillin, treatments for syphilis included mercury, different salts, neosalvarsan (an arsenic compound) and deliberate malarial infection (to induce fever). The discovery of penicillin provided a potential successful treatment for syphilis, but the problem was that the dosage required for effective treatment was unknown.

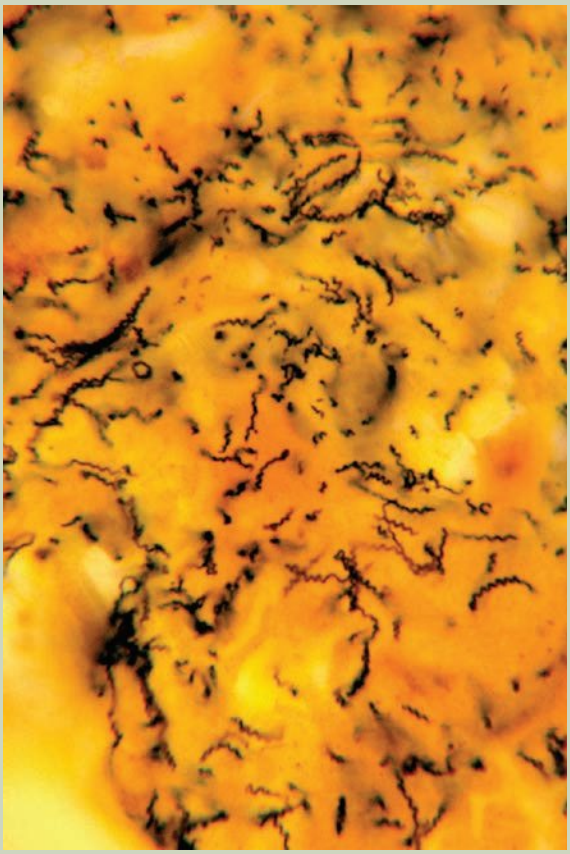


**Figure 9B–1** The bacterium *Treponema pallidum*, which causes syphilis, magnified 2000 times

During 1946–1948, US researchers deliberately infected unsuspecting people in Guatemala with the bacterium that causes syphilis. The people infected included sex workers, those with a mental health disability, prisoners and soldiers. The researchers then administered different dosages of penicillin in order to determine how much was required to treat the disease. The results assisted in the development of treatment plans for syphilis, but this progress came at a huge human cost.

ISBN 978-1-108-88711-3

## EXPLAIN

## Considerations for your stakeholder

Once you have determined the technology you are going to focus on for your research task, it is important that you define who you are going to identify as your **stakeholder**. The stakeholder is anyone or anything (such as an organisation) that will be in some way affected by the technology. How broadly or specifically you define your stakeholder will dictate how broad or specific the scope of your research will be.

**Stakeholder** the person or organisation that will be affected by the factor under consideration

**Ethics** moral principles that guide our beliefs about what is right or wrong conduct

**Ethical**, social, legal and economic considerations are the four areas you will need to discuss when outlining the impact of your chosen technology on your stakeholder. Table 9B–1 outlines each of these considerations. The Skills section on pages 434–5 demonstrates how to build connections between these four types of considerations. The difficulty of this research task lies in how well you can weave the four considerations together while being specific to the context of the stakeholder you have identified.

**Table 9B–1** Ethical, social, legal and economic considerations in relation to the impact of technology on stakeholders

| Consideration | Definition | Relation to stakeholders |
|---|---|---|
| Ethical | A sense of right or wrong based upon morals and beliefs in producing or obtaining the technology | A range of technologies are available and that gives an individual choice as to what service to use, if any. The decision to engage these technologies will be based upon an individual's personal ethical considerations.<br>To conduct scientific research involving humans or animals requires approval by an ethics committee. |
| Social | The influence of society on **social norms** | An individual's decision-making will be influenced by the context they are in. For example, people from different countries may have different attitudes towards what is socially acceptable in regards to different technologies. Attitudes may also differ across different communities within the same country. |
| Legal | The legislative rules and processes applicable in the jurisdiction in which the stakeholder or technology is located | The ability to receive reproductive services is different in each of the states of Australia.<br>To start up a service with a technology may require permits under relevant legislation in order for research to be conducted. |
| Economic | The availability of funds in order to obtain or produce the technology | The use of technologies such as cloning and reproductive services is extremely expensive. These technological services may not be equitable for all to access.<br>Also consider who is funding the research for the technology. For example, a company might bias its results by emphasising positive outcomes and downplaying negative outcomes. |

**Social norms** standards of what is considered socially acceptable within a community

ISBN 978-1-108-88711-3

Each of the four considerations is complex and involves more elements than those presented in Table 9B–1.

As mentioned earlier, how you present your information will depend on which stakeholder's point of view you use when addressing these considerations. You will need to conduct further research to understand how each consideration can influence your stakeholder in the context of your chosen technology.

## Approaching the ethical consideration

To assist you in unpacking the ethical consideration, the Study Design has outlined approaches to bioethics and ethical concepts (see tables 9B–2 and 9B–3). How you approach the ethical consideration is an essential element of the research task. In light of this importance, when framing how you will explore the ethical consideration you should be influenced by one or more of the approaches and ethical concepts outlined in tables 9B–2 and 9B–3.

**Table 9B–2** Approaches to bioethics

| Approach | What is it? |
|---|---|
| Consequence-based | Places importance on how the consequence of an action is achieved with maximum positive outcomes and minimal negative effects |
| Duty-based *and/or* rule-based | Focuses on the importance of people acting in a particular way so the ethical rules are followed, regardless of the consequences that could follow |
| Virtues-based | Places importance on the moral character of the person carrying out the action, where they have been influenced by the characteristics and behaviours a good person would seek to achieve to be able to act in the right way |

**Table 9B–3** Ethical concepts

| Ethical concept | What is it? |
|---|---|
| **Integrity** | The commitment to searching for knowledge, understanding, and the honest reporting of all sources of information and communication of results |
| Justice | The moral obligation to ensure that there is fair consideration of competing claims, that there is no unfair burden on a particular group from an action, and that there is fair distribution and access to the benefits of an action |
| Beneficence | The commitment to maximising benefits and minimising the risks and harms involved in taking a particular position or course of action |
| Non-maleficence | Involves avoiding causing harm. Scientific research may involve some degree of harm, and therefore the harm resulting from any position or course of action should not be disproportionate to the benefits from that position or course of action |
| **Respect** | Involves consideration of the extent to which living things have an intrinsic value and/or instrumental value; giving due regard to the welfare, liberty and autonomy, beliefs, perceptions, customs and cultural heritage of both the individual and the collective |

**Integrity** the commitment to searching for knowledge and understanding, and the honest reporting of sources and results

**Respect** giving consideration to the extent to which living things have an intrinsic value; giving due regard to the welfare, liberty, autonomy, beliefs, perceptions, customs and cultural heritage of individuals and the collective

ISBN 978-1-108-88711-3

The approach you decide to use to frame your research task will depend on the technology, your stakeholder and the context of the issue. For example, if your stakeholder is a biotechnology company, you could discuss the ethical concerns from a consequence-based approach, where all the outcomes need to be positive, with very few negative effects. While this company was conducting its own research, it would need to be mindful of the ethical concept of 'respect'.

The Skills section explores how you can build your own framework by starting with the ethical consideration.

VIDEO 9B–1 SKILLS: CREATING A FRAMEWORK TO MAKE CONNECTIONS

## 9B SKILLS

### Creating a framework to make connections

This research task involves many ideas and considerations, all of which appear to be interwoven, and this can make it difficult to present your information in a coherent way while demonstrating a deep understanding of the technology and its impact.

The purpose of this section is to model a method of constructing your own framework, providing one possible template for presenting information. There are many ways to look at the four considerations. This is just one way that you may find useful. You could also use this process to construct a framework of your own that suits the way you want to write.

**Step 1** Pick a central idea to which all factors connect.

The ethical consideration has strong links to all the remaining considerations. The social setting, the legal environment and any financial burden influence what is right or wrong. As a result, a good starting point to explore the technology is from an ethical point of view in the context of your stakeholder.

Things to consider when exploring the ethical consideration include:

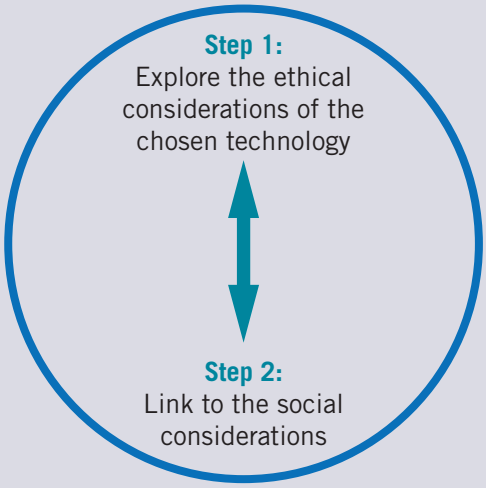
- Who would benefit from the use of the technology?
- Who might be harmed by the use of the technology?
- Is there informed consent and confidentiality?
- Is the autonomy of individuals being respected?
- Are the interests of the community being considered and respected?


As you continue, keep referring back to who is affected and how they are affected.

**Step 2** Explore the next consideration that affects the central idea.

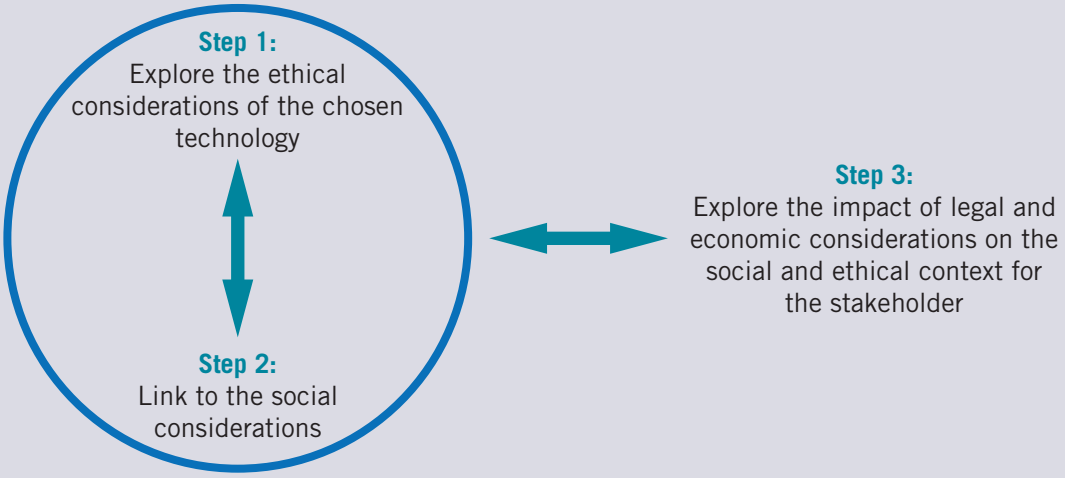
The social setting in which the technology is available influences how different stakeholders would behave. These two considerations appear closely linked, and as a result would be explored after the ethical issues have been fleshed out. First, outline the social context of the technology and your identified stakeholder. Follow this up by demonstrating the interconnectedness between the two.

ISBN 978-1-108-88711-3




**Step 3** Complete the connections.

Legal and economic considerations can equally and interchangeably affect and reflect social beliefs about what is right or wrong. As a result, these last two considerations work well to draw all the ideas together and complete the picture. First, define the context of the legal and economic climate for the stakeholder, and then explore how these relate back to the ethical and social considerations.




## Section 9B questions

1 Aside from ethical issues, state the other three considerations that need to be addressed in carrying out your research task.

2 Consider the following issue in light of the four considerations discussed in this section: Should employers be able to use genetic tests to screen potential employees?
   - **a** Identify who would be positively affected by the introduction of genetic tests in this situation.
   - **b** Identify who could be negatively affected by the introduction of genetic tests.
   - **c** Outline whether you would take a genetic test in order to obtain a job. Give your reason(s).

3 Provide an annotated (with notes) flow chart (as highlighted in the Skills section) to connect the four considerations discussed in this section, in reference to:
   - **a** cloning
   - **b** prenatal testing.

ISBN 978-1-108-88711-3

# 9C Thinking organisers

**Study Design:**

- The nature of evidence and information: distinction between opinion, anecdote and evidence, and scientific and non-scientific ideas
- The quality of evidence, including validity and authority of data and sources of possible errors or bias
- 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
- The use of data representations, models and theories in organising and explaining observed phenomena and biological concepts, and their limitations

**Glossary:**
Authority
CRAP detection
Currency
Opinion
Reliability
SWOT analysis

## ENGAGE

### Reading critically

If you visit the 'Dihydrogen monoxide FAQ' website, you will be presented with information, claimed to be unbiased, about dihydrogen monoxide, including claims about the many health effects of this substance. If you read the information thoroughly, you may realise (or you might already know) that dihydrogn monoxide is in fact water.

This site is an example of the need to be careful when reading information online and to cast a critical eye on the details being presented.

Much of your research will be conducted online. The following letters at the end of each URL indicate the type of organisation that published the information on the website. Knowing this can help you to assess the reliability of the information.

.com = commercial

.edu = educational

.gov = government

.org = non-profit

ISBN 978-1-108-88711-3

## EXPLAIN

# Using the CRAP and SWOT methods

Two key thinking organisers can help you to assess the information you access while conducting your research:

- **CRAP detection** – use this to determine whether the source of the information is reliable
- **SWOT analysis** – use this to develop arguments for and against an issue, so that you are able to present a balanced research investigation.

CRAP is an acronym for: currency, reliabilty, authority, purpose. You may need to include CRAP detection as part of your investigation, as evidence of being critical about the resources you have based your arguments or information on. Note that, although medical journals are reliable, you do not need to limit yourself to these as your only resource. Whatever source you use, assess and acknowledge its reliability in supporting a particular argument.

Table 9C–1 lists questions you should ask about each piece of information you find. Use these questions to assess the reliability and credibility of the information.

**Table 9C–1** CRAP detection: questions to ask

| | |
|---|---|
| **Currency** | When was the information published?<br>Has it been updated and when? |
| **Reliability** | Is this information based on **opinion** or factual evidence?<br>Is it a primary or secondary source?<br>Does it cite, or refer to, other research or clinical studies?<br>Have you checked those references?<br>Is the content general or detailed, balanced or biased? |
| **Authority** | Who is the author of, or organisation responsible for, the information?<br>Do they have expertise/experience in the topic being covered? |
| Purpose | Why and for whom was the information written?<br>Does the source have a vested interest in the topic and the information that is included? |

**CRAP detection**
a method of determining whether a source is reliable, based on the currency, reliability, authority and purpose of the information

**SWOT analysis**
a method of assessing an issue by considering strengths, weaknesses, opportunities and threats associated with the issue

**DOCUMENT 9C–1**
CRAP DETECTION TEMPLATE

**Currency**
timeliness; how up to date information is

**Reliability**
the extent to which an experiment always yields the same results under the same conditions; or the degree to which information is accurate and dependable

**Opinion**
a view or judgement that may be based on personal feelings, not necessarily on facts or research

**Authority**
the level of expertise and relevance of an author in relation to the information they provide

**DOCUMENT 9C–2**
APA-STYLE REFERENCING

### NOTE

For your own credibility, it is important to acknowledge your sources by referencing each one used – this means listing full details of the author(s), date of publication, title, website and so on. In science, APA style (author–date style) is usually used for referencing. Refer to Document 9C-2 in the online resources to find out how to reference a range of resources.

ISBN 978-1-108-88711-3

**DOCUMENT 9C–3** SWOT ANALYSIS TEMPLATE

SWOT stands for: strengths, weaknesses, opportunities, threats. A SWOT analysis is a way of ordering your thinking to help you build the discussion section of your research report. Do not paste your SWOT analysis as a table into your research report (unless you have been instructed to do so).

**NOTE**

SWOT is not a framework for how to construct your discussion. It is a guide to help you elaborate, make connections and present balanced arguments or evidence in your discussion.

Table 9C–2 describes how to use SWOT to help build your discussion.

**Table 9C–2** SWOT analysis

| S (Strengths) | W (Weaknesses) |
|---|---|
| • Record the basic facts about the positive aspects of the technology. | • Record the basic facts about the negative aspects of the technology. |
| *This is a list of facts from your sources. It can be in dot point form. It can be cut and pasted from resources. Be sure to include the source for each point listed.* | |
| **O (Opportunities)** | **T (Threats)** |
| • Elaborate on the facts (listed in the dot points in your Strengths list).<br>• Identify potential future applications for the technology.<br>• Discuss positive links to the stakeholders. Link the identified opportunities to the four considerations (ethical, social, economic, legal). | • Elaborate on the facts (listed in the dot points in your Weaknesses list).<br>• Identify potential setbacks for the technology in the future (or those that have occurred in the past).<br>• Discuss negative links to the stakeholders. Link the identified threats to the four considerations (ethical, social, economic, legal). |
| *This is where you put the content into your own words and make connections.* | |

**Figure 9C–1** A SWOT analysis will help you make connections and strengthen your ideas

ISBN 978-1-108-88711-3

The Skills box below provides two actual student attempts to use a SWOT analysis during the planning of their research task.

VIDEO 9C–1 SKILLS: HOW TO USE A SWOT ANALYSIS

## 9C SKILLS

### How to use a SWOT analysis: making connections between sections

Note the annotations around the examples, highlighting features done well and areas for improvement.

There has been a missed opportunity to link the strengths to the opportunities (and the listed weaknesses to threats). Doing this would have made it easier to structure the discussion in a more coherent and organised way.

The S and W section is well done. It lists different points and is succinct.
To improve the resources, the details of where these points came from could be included (with correct referencing).

**SWOT analysis of laboratory cultured meat**

| S (Strengths) | W (Weaknesses) |
|---|---|
| • Less cruelty towards animals<br>• More cost efficient<br>• Better end result (no more subpar cuts of meat, since it's all genetically identical) | • Animal testing<br>• Since the effect of consuming many GM crops on humans is not really known |
| **O (Opportunities)** | **T (Threats)** |
| • With the new technology, advancements such as trialling new meats and bringing extinct animals to life could be prompted. | • The livelihood of many farmers will be threatened and contesting a large contributor to the trade of Australia. |

Starts to elaborate on a point that is a potential opportunity. But it stops short of elaborating on why it is a good thing. It is better if you link your opportunity to a resource that is supporting your point of view by including the reference.

Another missed opportunity to elaborate further as to why this is a threat to the application of the technology.

**Figure 9C–2** Student A's SWOT analysis of replacing meat production with laboratory-cultured meat

As highlighted in Figure 9C–2, Student A completed all the sections of the SWOT analysis. A successful SWOT requires connections between the Strengths and Opportunities, and between the Weaknesses and Threats sections, which Student A did not demonstrate. In the Opportunities and Threats sections, elaboration of the points listed in the Strengths and Weaknesses sections is required. Not making these connections and elaborations will make completing the discussion section of your research task more difficult.

ISBN 978-1-108-88711-3

**SWOT analysis of genetically modified crops**

| S (Strengths) | W (Weaknesses) |
|---|---|
| *Genetically modified crops contain specific genes, taken from other related plants with beneficial traits such as increased crop yield, pesticide resistance, insect resistance, higher nutrient level and resistance to viral infections (Phillips, 2008).* | *The use of GM crops has been known to give rise to 'super weeds' (Stewart, 2004).* |
| **O (Opportunities)** | **T (Threats)** |
| Maharashtra Hybrid Seed Company bioengineered eggplant seeds to contain a *Bacillus thuringiensis* cryl Ac gene (Mondal, 2016). *Bacillus thuringiensis* is a bacterium that produces the protein cryl Ac, which is toxic to pests when ingested (Ibrahim, 2010). This change to the eggplant genome allowed eggplants to become resistant to EFSB. Pesticide use dropped by 80% within three years and profit increased six-fold due to less costs and increased crop yield (Shelton et al. 2018). | A report by Dale et al. 1993 states that 'Under the selection pressure of herbicide, introgression between the GM crop and wild relative could produce new biota that might disrupt ecological balances.' This directly translates to super weeds, as they acquire herbicide resistance through cross-breeding. Super weeds become an extremely dangerous prospect as more toxic chemicals are required to subdue the weeds, namely 2,4-dichlorophenoxyacetic acid, which will endanger human health (Mortensen, 2012). |

Throughout the SWOT a variety of references have been used. This reflects the student's detailed research into the task on both sides.

There is a clear connection between the S and O sections and between the W and T sections. Within the O and T sections, the student has elaborated and provided more details about what was stated in the S and W sections.

The clear connection back to the stakeholder and considerations could still be developed further.

**Figure 9C–3** Student B's SWOT analysis of the introduction of genetically modified crops

Student B (Figure 9C–3) showed a greater level of understanding of the content and how to use the SWOT analysis framework than Student A. All sections were completed with appropriate linking to subsequent sections. Throughout the analysis, Student B included references, and this reflected the research they had done to understand the positive and negative aspects of the application of technology. An area of improvement for Student B was in connecting the Opportunities and Threats sections back to the stakeholder and the four considerations required in the research task. This would have elevated the SWOT analysis even further. Constructing your discussion section in the final research report will be easier if you put effort into the SWOT analysis.

## Section 9C questions

1 What do the letters in CRAP detection stand for?
2 What is the main purpose of using CRAP detection?
3 What sections of a SWOT analysis need to be linked together?
4 Outline the benefit of using a SWOT analysis when completing a research task.

ISBN 978-1-108-88711-3

# Chapter 9 review

## Summary

Create your own set of summary notes for this chapter, on paper or in a digital document. A model summary is provided in the Teacher Resources and can be used to compare with yours.

## Checklist

The nature of this chapter means that there are no questions linked to the success criteria. Instead you should self-assess against the success criteria. This can be done in the Interactive Textbook. Alternatively, print or photocopy this page and tick the boxes when you have achieved the criteria.

| Success criteria – I am now able to: | | Check |
|---|---|---|
| **9A.1** | Recall the different technologies | ☐ |
| **9A.2** | Understand what the technologies are | ☐ |
| **9A.3** | Describe how the different technologies are used | ☐ |
| **9A.4** | Utilise diagrams to support the explanation of different technologies | ☐ |
| **9B.1** | Recall the four different considerations: ethical, social, legal and economic | ☐ |
| **9B.2** | State what the different considerations are in a context | ☐ |
| **9B.3** | Apply the considerations to different stakeholders | ☐ |
| **9B.4** | Apply the considerations to different technologies | ☐ |
| **9B.5** | Make connections between the different considerations while being appropriate to the context of the research task | ☐ |
| **9B.6** | Recall the three different approaches to bioethics | ☐ |
| **9B.7** | Understand that there are different ethical concepts to consider when exploring a ethical issue | ☐ |
| **9B.8** | Apply one or more ethical concepts to a bioethical issue that has been identified and explored | ☐ |
| **9C.1** | Recall the sections of CRAP detection to determine limitations of resources | ☐ |
| **9C.2** | Complete a CRAP detection for a given resource | ☐ |
| **9C.3** | Make conclusions to be included in a research report based on a CRAP detection | ☐ |
| **9C.4** | Apply the use of CRAP detection to determine limitations of resources | ☐ |
| **9C.5** | Recall the sections of a SWOT analysis | ☐ |
| **9C.6** | Complete all sections of a SWOT analysis | ☐ |
| **9C.7** | Elaborate on potential applications of technologies for different stakeholders through the assistance of a SWOT analysis | ☐ |
| **9C.8** | Present balanced arguments in the form of a research task with the assistance of a SWOT analysis | ☐ |

ISBN 978-1-108-88711-3

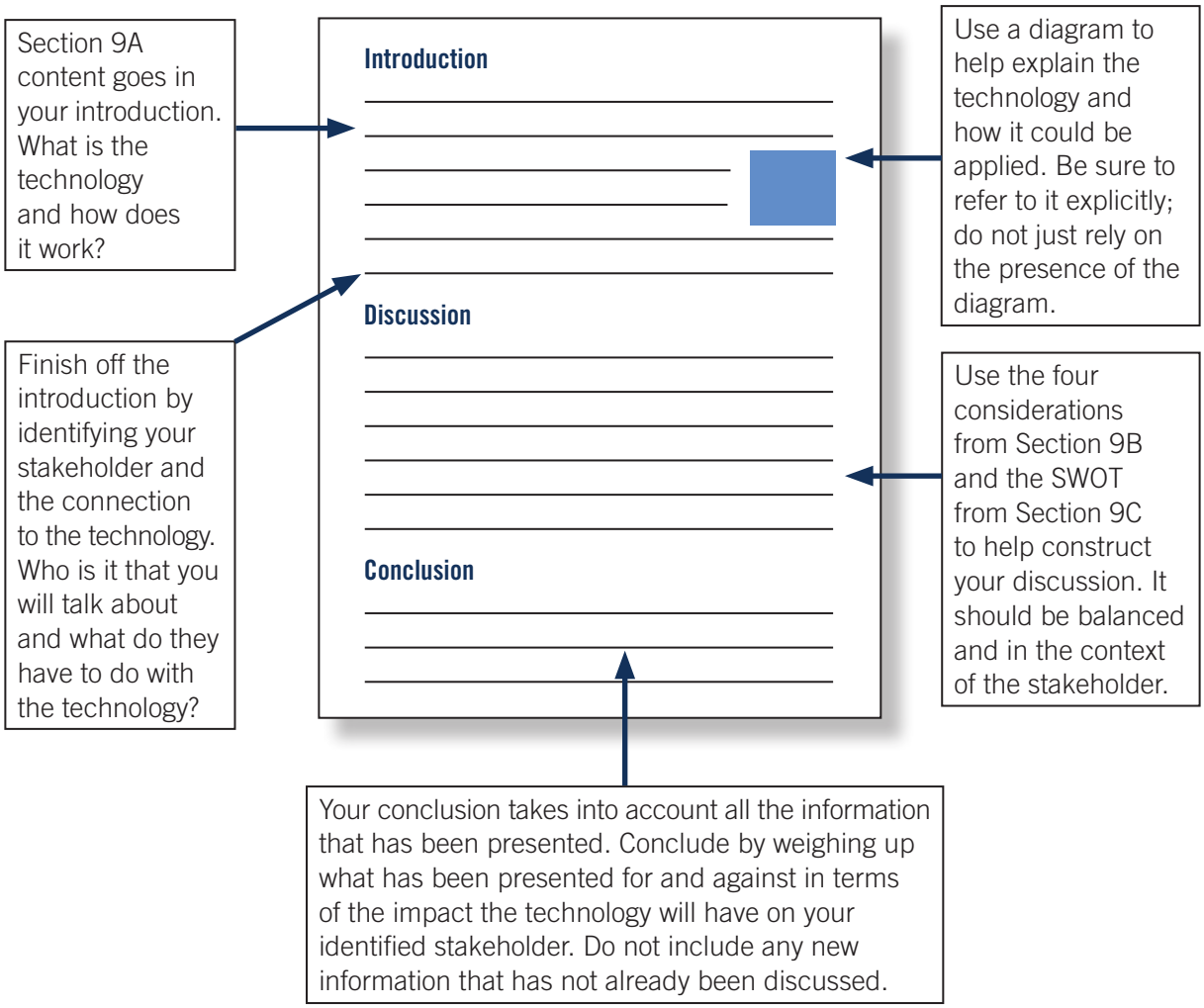
## Chapter review: Research report

LINK

**9B** ETHICAL, SOCIAL, LEGAL AND ECONOMIC CONSIDERATIONS

Instead of asking questions about the content in this chapter, this chapter review demonstrates how to lay out your research report. As you read in Section 9B, this review section provides a suggested way to construct your research report. It is important to consult with your teacher and look at the requirements that have been specified in the task sheet and the accompanying mark scheme (or rubric).

**DOCUMENT 9 REVIEW:** RESEARCH INVESTIGATION




There are three main sections in a research report: introduction, discussion and conclusion. When you are writing the report, it is important that you write in third person past tense. Any evidence or arguments presented should be based on research you have conducted (remember that Section 9C explains how to use CRAP detection to determine how reliable a resource is), not just your own opinion. Be careful of biased resources, as the technologies you are researching can have polarising agendas and opinions. Lastly, when you are using resources it is important to acknowledge where your information has come from, by referencing your sources in the APA style (see the online resources for details on how to do this).

ISBN 978-1-108-88711-3

# Unit 2 Revision exercise

## Multiple-choice questions

**1** Which of the following statements is correct?

**A** Only males can be carriers of a sex-linked allele.
**B** Meiosis increases the number of chromosomes in a cell from the diploid to the haploid number.
**C** All the genetic information in a cell or organism is referred to as the 'genome'.
**D** Cytokinesis is classified as a sub-stage of mitosis within the cell cycle.

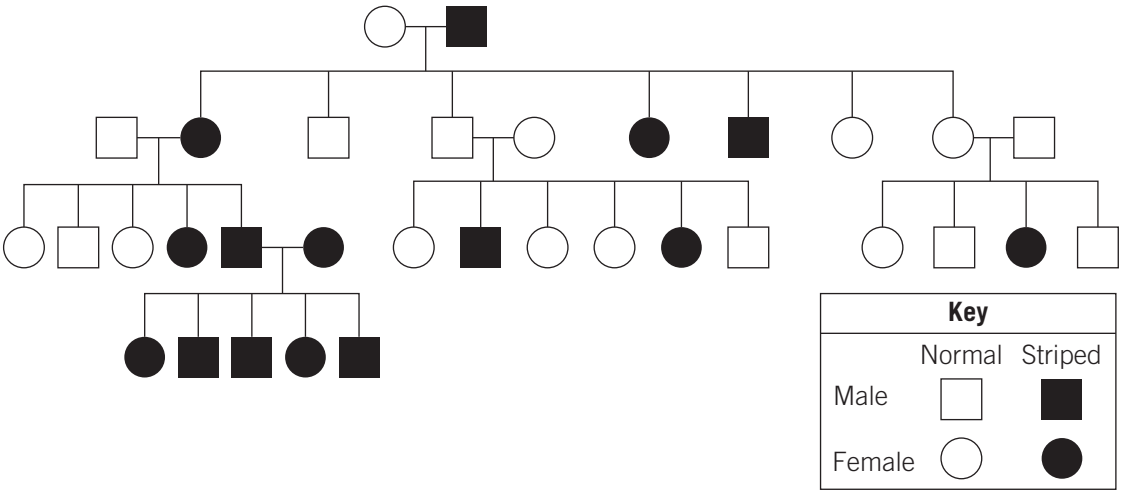
**2** In fruit flies, the gene for eye colour is located on the X chromosome, and the red eye trait (defined by allele $X^R$) is dominant to the white eye trait (defined by allele $X^r$). A female fly with genotype $X^RX^r$ is mated with a male fly with genotype $X^rY$. Which of the following statements best describes the expected outcome of the cross?

**A** The chance of an offspring having red eyes is 75%.
**B** The chance of an offspring having white eyes is 50%.
**C** The chance that a male offspring will have white eyes is 0%.
**D** The chance that a female offspring will have red eyes is 100%.

**3** The allele for an enzyme involved in the production of green pigment in geraniums is $C^g$. A mutant allele, $C^w$, codes for a defective enzyme, resulting in no pigment. A cross between two heterozygotes produced two phenotypes. These were pale green plants and dark green plants in the ratio of 2 : 1. What is the most likely explanation for this ratio?

**A** $C^wC^g$ is a lethal genotype.
**B** $C^g$ codes for a dominant trait.
**C** $C^w$ codes for a dominant trait.
**D** $C^wC^w$ codes for a lethal genotype.

**4** A pedigree showing the inheritance of a gold dorsal stripe pattern in ball pythons is shown below.




According to the pedigree, what mode of inheritance does stripe pattern follow?

**A** Polygenic
**B** Recessive
**C** Sex-linked
**D** Dominant

ISBN 978-1-108-88711-3

**5** In mice, the alleles for type of coat ('dappled' or 'plain') are located on the X chromosome. The dappled coat trait is dominant to the plain coat trait. The alleles for straight or bent whiskers are autosomal traits, and 'straight' whiskers (defined by allele 'W') is dominant to 'bent' whiskers (defined by allele 'w'). A male mouse with plain coat and bent whiskers was mated on several occasions to the same female and the large number of offspring consisted of the following phenotypes in equal proportions:

Dappled male with straight whiskers
Dappled female with straight whiskers
Dappled male with bent whiskers
Dappled female with bent whiskers
Plain male with straight whiskers
Plain female with straight whiskers
Plain male with bent whiskers
Plain female with bent whiskers.

If $X^D$ represents an X chromosome carrying an allele for dappled coat and $X^d$ represents an X chromosome carrying a gene for plain coat, what is the genotype of the female parent?

**A** $X^DX^dWw$
**B** $X^DX^DWW$
**C** $X^DX^DWw$
**D** $X^DX^dWW$

**6** Which one of the following phenotypic features can be affected only by genotype?

**A** Height
**B** Intelligence
**C** Skin colour
**D** Number of different blood group antigens

**7** What determines the sex of a child?

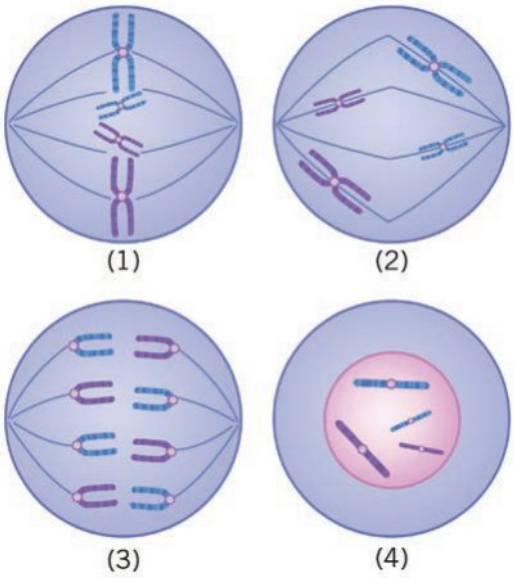
**A** Chromosome content of ovum
**B** Chromosome content of sperm
**C** Number of days between ovulation and fertilisation
**D** Number of days between fertilisation and implantation

**8** Which of the following are genetically identical?

**A** Brothers and sisters in the same family
**B** Cuttings taken from the same plant
**C** Mammals in the same litter
**D** Seeds produced by the same tree

ISBN 978-1-108-88711-3

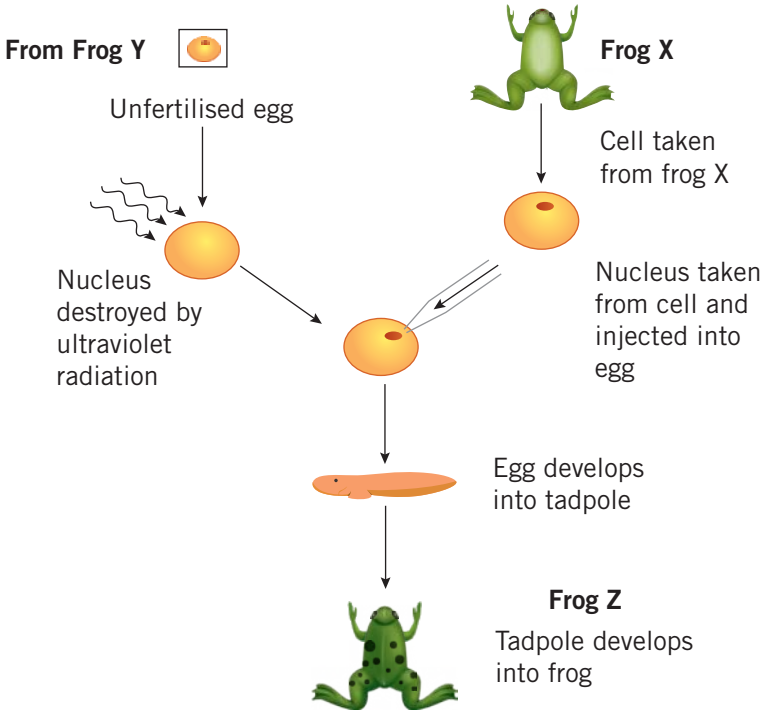
**9** The diagram shows the stages of cell division.




The correct order of these stages of cell division is

**A** (1), (2), (3), (4).
**B** (2), (4), (1), (3).
**C** (3), (1), (2), (4).
**D** (4), (2), (1), (3).

**10** The diagram below shows stages of an experiment in which the nucleus of each unfertilised egg, from Frog Y, was destroyed and replaced by a nucleus obtained from Frog X, to produce Frog Z.



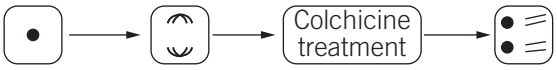

Which of the following statements is true?

**A** Frog Z is identical to frog X.
**B** Frog Z is identical to frog Y.
**C** Such a process is known as genetic engineering.
**D** An unfertilised egg from any species of frog can be used in this experiment.

ISBN 978-1-108-88711-3

## Short-answer questions

**11** An experiment was set up with growing onion roots to investigate the effects of colchicine, a medicine used to treat gout, on cell division. Gout is a complex form of arthritis. Onion roots were placed in 1% colchicine for 30 minutes. The scientists observed that cells in the final stage of cell division became binucleate (containing two nuclei), as the treatment inhibited microtubule polymerisation and inhibited the assembly of the mitotic spindle fibres. This is shown in the diagram below.




**a** By what process were the cells of growing onion roots dividing? (1 mark)

**b** What is the name of the final stage of division before division of the cytoplasm occurs? (1 mark)

**c** In onion cells, the chromosome number of a normal somatic cell is 16. Based on the image above, what is the chromosome number of the cell after the colchicine treatment? (1 mark)

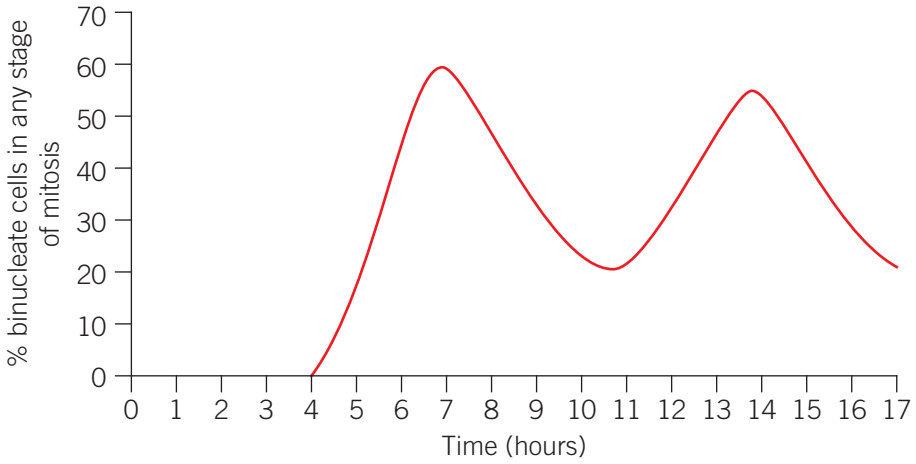
The relative numbers of binucleate cells were counted in samples of 2000 cells on three occasions after treatment with colchicine. All binucleate cells were at interphase.

| Hours after treatment | % of binucleate cells in tip region |
|---|---|
| 1 | 4.26 |
| 2 | 3.74 |
| 3 | 2.89 |

**d** Why were so many cells counted on each occasion? (1 mark)

**e** Referring to the data, describe the change in the percentage of binucleate cells during the 3-hour period. (2 marks)

The root tips were examined at 1-hour intervals for 16 hours following the 30-minute colchicine treatment. The percentage of binucleate cells formed from the suspension to cell division was determined. The results are shown below.

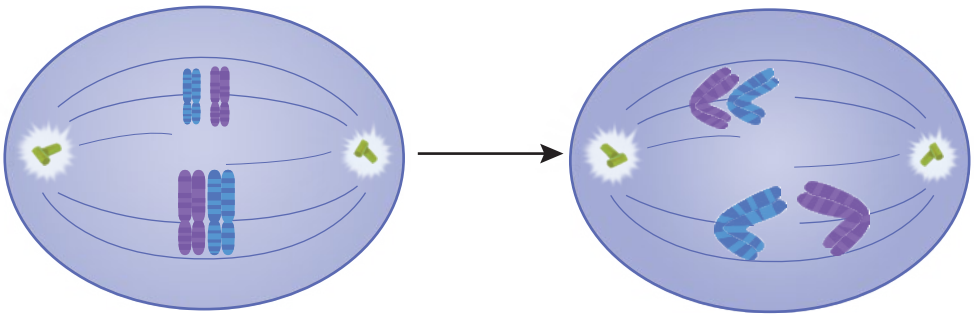



**f** Using the data, account for the difference in percentage of binucleate cells present at 4 hours and 7 hours after treatment. (2 marks)

ISBN 978-1-108-88711-3

**g** The *y*-axis label of the graph above states: '… cells in any stage of mitosis'. You will recall that the stages of mitosis also appear in the process of meiosis, which occurs during the production of gametes. Compare the appearance of chromosomes at prophase in mitosis and meiosis. (3 marks)

At a different stage of this process, a mistake occurred. This is shown in the image below.



**h** Draw all the resulting gametes from the cell division, as shown in the single cell on the right side of this diagram, indicating the number of chromosomes in each of the gametes. (2 marks)

**i** What is the name given to this error? (1 mark)

**12** *Drosophila melanogaster* flies are one of the most commonly studied organisms in biological research, especially in genetics. These flies are small and easy to grow in the laboratory and, once anaesthetised, their morphology is easy to observe. Characteristics such as shape of wing, colour of body, size and colour of eyes are frequently studied. The gene controlling eye colour is found on the X chromosome and has two alleles. It has been observed that the red eye trait is dominant over the white eye trait.

*Note*: Use the following symbols to represent the alleles in this question:

$X^R$ – red eyes, $X^r$ – white eyes

**a** What is the genotype of a white-eyed male? (1 mark)

**b** Construct a Punnett square showing the expected genotypic and phenotypic ratios of the offspring produced when a white-eyed female is crossed with a red-eyed male. (2 marks)

A geneticist investigated two other genetic traits: body colour and wing shape. The genes controlling both traits were found on autosomes. The geneticist did a test cross to test linkage between the genes.

The bodies of the *Drosophila* flies could be either a grey colour or an ebony colour.

A test cross was done between a heterozygous, normal-winged, grey-coloured male fly (double heterozygote) and a recessive, vestigial-winged, ebony-coloured female fly.

The following offspring numbers were produced from the test cross:

| Normal winged, grey body | Vestigial winged, grey body | Normal winged, ebony body | Vestigial winged, ebony body |
|---|---|---|---|
| 965 | 185 | 206 | 944 |

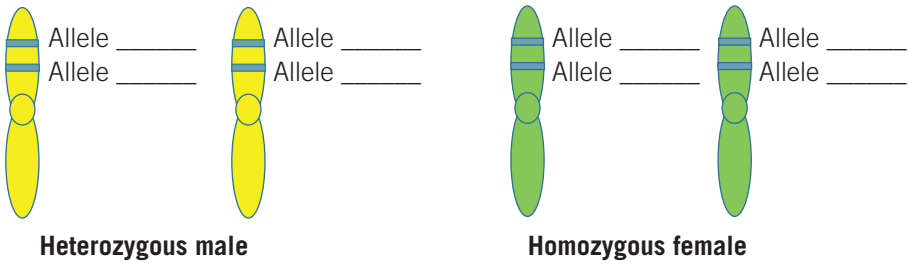
*Note*: Use the following symbols to represent the allele in this question:

N – normal winged, n – vestigial winged, G – grey body, g – ebony body.

**c** The genes are found be linked. Explain how the results obtained support this. (1 mark)

ISBN 978-1-108-88711-3

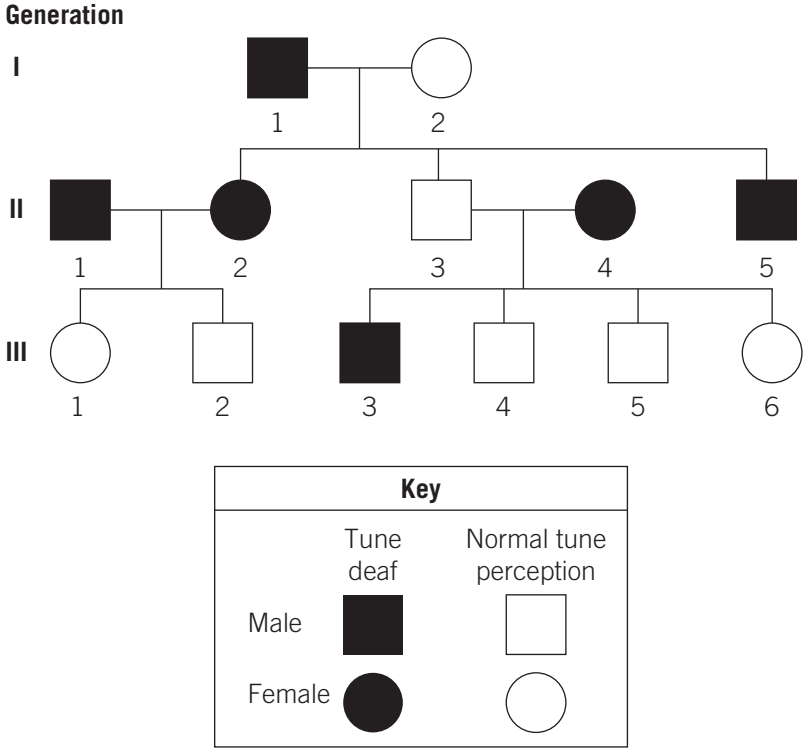
**d** Annotate the following diagrams of the parental chromosomes to indicate the arrangement of alleles in each of the parents' cells. (1 mark)




**e** Using key terminology, explain the difference between heterozygous and homozygous. (3 marks)

**f** In the diagram for part **d**, state two characteristics of chromosomes that are used to identify them when karyotyping.

**13** People who are tune deaf are unable to follow a melody. Scientists have evidence that tune-deafness can be genetic. The diagram below shows a pedigree that traces the inheritance of tune-deafness in a family. Individuals in the pedigree are numbered.




**a** Using the information from the pedigree above, determine the mode of inheritance of tune-deafness. Explain your reasoning. (3 marks)

**b** Identify the genotypes of individuals II-3 and II-4, using the alleles 'T' and 't'. (1 mark)

**c** Draw a Punnett square to show the cross between individuals II-3 and II-4, and state the expected genotypic and phenotypic ratios. (2 marks)

**d** Compare the expected percentage of each phenotype of the offspring in part **c** with the actual percentage of each phenotype observed in the children of individuals II-3 and II-4, and account for any difference. (2 marks)

ISBN 978-1-108-88711-3

**14** The image below shows a young harp seal on the beach at Long Island, New York, in winter.

**a** Adaptations occur over time to help make an organism or a population more 'fit' to survive in its environment. Identify one structural, one behavioural and one physiological adaptation that enables this seal to survive on land during the cold winter months. (3 marks)

**b** Explain how Aboriginal and Torres Strait Islander peoples have used their knowledge and observations of their land to understand the benefit of an adaptation to an organism to increase their likelihood of survival. (2 marks)

**c** The harp seal lives in the same environment as a type of fish called a cod. The harp seal's faeces are food for tiny organisms called phytoplankton and zooplankton, which then provide fresh oxygen for the cod to breath. As a result, the cod survives and is a source of food for the harp seal. What form of symbiotic relationship does this represent? Explain your answer. (2 marks)

**d** What are the other two types of symbiotic relationships and how do they differ from the relationship described in part **c**? (3 marks)

**e** It has been identified that harp seals hunt the weaker fish, securing the survival of the healthiest fish. What is the advantage of this for both the cod and, in turn, the harp seal? (2 marks)

**f** Do the harp seal and the cod living in the same environment represent a population or a community? Explain by identifying the difference between the two. (2 marks)

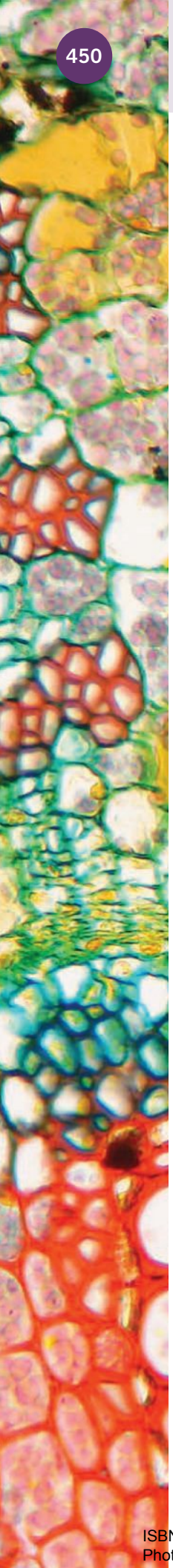
**g** Explain why sexual reproduction is important for the survival of a species such as the harp seal. (2 marks)

**15** In Question 14, phytoplankton were mentioned as providing extra oxygen for fish to use in order to survive. Phytoplankton are a type of microscopic marine organism, a protist called algae. They are autotrophs that use light to synthesise their own food by photosynthesis. They undergo different phases within their reproductive cycles, depending on environmental conditions.

**a** What is the name of the types of reproduction that these marine organisms would undergo? (1 mark)

**b** Marine organisms are very different from land plants, which have different ways of reproducing. Some of these methods of reproduction result in offspring that are genetically identical to the parent. Explain three different types of reproduction in land plants. (3 marks)

ISBN 978-1-108-88711-3



# Glossary

**abiotic**
not living

**absorption**
the movement of nutrients out of the digestive system and into the bloodstream for delivery to cells

**accuracy**
how close the measurements are to the 'true' value of the quantity being measured

**active transport**
the net movement of a substance from a region of low concentration to a region of high concentration, using a protein carrier and requiring energy input

**adaptation**
a change that makes an organism better suited to its environment

**ADP (adenosine diphosphate)**
a compound composed of adenosine and two phosphate groups that can store energy when another phosphate group is added, forming ATP

**adult stem cells**
undifferentiated cells that are found in certain tissues throughout the life of an individual

**aerobic cellular respiration**
cellular respiration that occurs in the presence of oxygen and involves the transformation of the chemical energy in glucose into ATP

**aim**
the main purpose of an investigation and what you hope to achieve

**allele**
an alternative form of a gene

**alternative splicing**
when a single gene codes for more than one protein

**anaerobic cellular respiration**
cellular respiration that occurs in the absence of oxygen and involves the transformation of the chemical energy in glucose into ATP; also known as fermentation

**anaphase**
a mitotic phase in which double chromosomes separate and the sister chromatids are pulled apart to opposite sides of the cell

**aneuploidy**
when cells contain one more or one less chromosome than normal

**angiogenesis**
the formation of new blood vessels

**apoptosis**
the systematic and controlled death of cells; occurs as a normal part of an organism's development (programmed cell death)

**apoptotic bodies**
membrane-bound vesicles that contain the intracellular contents of an apoptotic cell

**arteriole**
a small branch of an artery leading into capillaries

**asexual reproduction**
a type of reproduction in which only one parent is required to produce offspring, which are genetically identical to the parent

**ATP (adenosine triphosphate)**
the main immediate source of chemical energy in a cell, powering most cellular processes; energy is released when the last phosphate group is removed, forming ADP (adenosine diphosphate)

**authority**
the level of expertise and relevance of an author in relation to the information they provide

**autoantibodies**
antibodies that target and destroy the body's own cells ('self' cells)

**autoimmune disease**
a disease in which the immune system acts abnormally and begins to target and attack the body's own cells ('self' cells)

**autosomes**
chromosomes that do not determine sex; in humans, pairs 1 to 22

**autotroph**
an organism that synthesises its own organic materials (food), by taking in energy from its physical environment, to meet its energy needs (*auto* = self, *troph* = food)

ISBN 978-1-108-88711-3

**benign**
not cancerous; will not spread to surrounding tissue

**bile**
a substance produced by the liver that mechanically digests lipids

**binary fission**
a type of asexual reproduction in prokaryotic cells

**biotic**
living; made up of at least one cell

**blastocyst**
a stage of embryonic development, in which some differentiation of cells has occurred

**bleb**
a rounded structure that forms on the plasma membrane of a cell undergoing apoptosis

**bolus**
a ball-like mixture of food and saliva that forms in the mouth

**budding**
a type of naturally occurring asexual reproduction in which a small outgrowth (bud) develops on the surface of the parent organism and eventually detaches, forming a new organism

**bulk transport**
the movement of large particles (solid or liquid) through the plasma membrane, requiring the input of energy (ATP)

**C (cytokinesis) phase**
the portion of the cell cycle that includes cytokinesis

**cancer**
a disease that is the result of uncontrolled division of abnormal cells

**cardiomyocytes**
specialised cells making up the cardiac muscle tissue of the heart

**carrier**
an individual who has one copy of an allele for a trait but does not phenotypically express that trait

**carrier protein**
a transmembrane protein that binds to a specific substance (e.g. glucose) and changes shape to move that substance across the plasma membrane, releasing it to the other side

**caspases**
a class of protease enzymes that cleave (cut up) proteins; referred to as 'executioners' because they bring about the cascade of reactions that destroy the cell

**cell cycle checkpoints**
control points within the cell cycle that ensure accurate division of the cell

**cell plate**
a structure that forms during cytokinesis in plant cells and gives rise to the new cell walls of the daughter cells at the conclusion of division

**cell theory**
the theory that living (biotic) things are made up of at least one cell, and that these cells are the basic unit of life and came from pre-existing cells

**cell wall**
a structure that surrounds a plant cell and provides support and protection

**cellular respiration**
a chemical reaction in which the organic compound glucose is broken down, commonly in the presence of oxygen, to form the inorganic compounds carbon dioxide ($CO_2$) and water ($H_2O$), and energy in the form of ATP; occurs in the cytosol and mitochondria

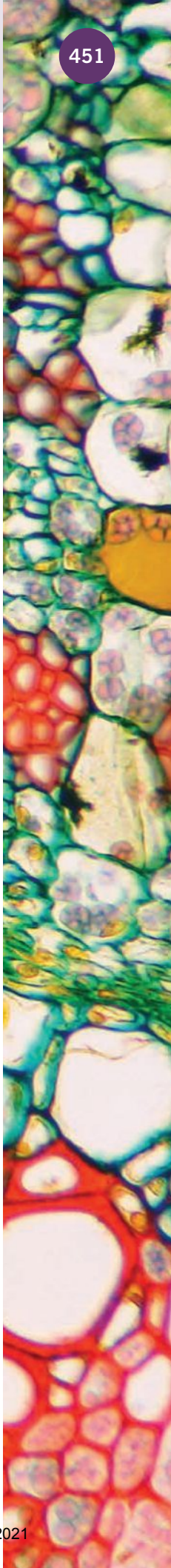
**centromere**
the structure in a chromosome where the two chromatids are held together; also the point of attachment of the kinetochore, which the spindle microtubules attach to

**centrosome**
an organelle from which spindle microtubules develop during cell division; contains the centrioles

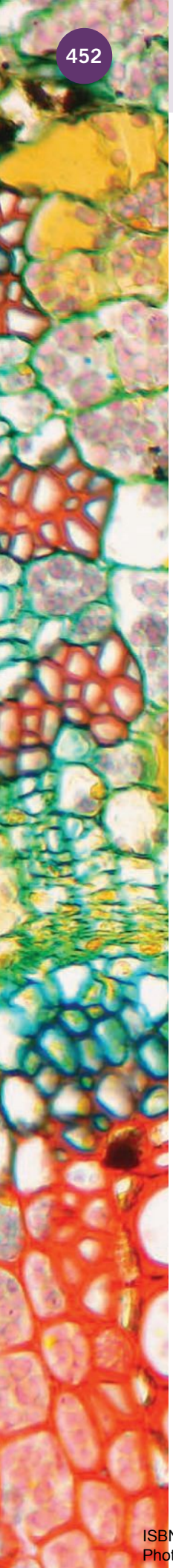
**channel protein**
a transmembrane protein that allows hydrophilic or polar substances to move across the plasma membrane from a region of high concentration to a region of low concentration

**chemical digestion**
the process of enzymes breaking down large complex substances into their simplest forms; occurs in several places along the digestive tract

**chemical energy**
energy from organic molecules in food



ISBN 978-1-108-88711-3



**chiasma**
the point of contact between non-sister chromatids in a homologous pair of chromosomes; the point at which crossing over may occur

**chlorophyll**
the green pigment found on the thylakoid membranes of the chloroplasts of green plants; absorbs light energy for photosynthesis

**chloroplast**
an organelle where photosynthesis occurs; contains chlorophyll

**chromatid**
one of two strands of a double chromosome formed when a single chromosome is replicated early in mitosis or meiosis; when two chromatids are joined at a centromere, they are called sister chromatids and are identical

**chromatin**
a condensed structure, made of DNA and protein, found in the nucleus of eukaryotic cells

**chromosomes**
the highly compact form of DNA that is visible in eukaryotic cells as they divide

**chyme**
a soupy mass of partly digested food and gastric juices

**cilia**
short microtubules projecting from a cell that move to provide motility (movement of the cell) or movement of fluid

**cleavage furrow**
the indentation of the cell's plasma membrane as it pinches inwards to split the cell into two

**clone**
an organism or a cell that is identical to another organism or cell

**cloning**
the process of creating genetically identical organisms or clones; can occur naturally or artificially

**co-dominant**
when both alleles are expressed in the phenotype of an organism

**coeliac disease**
an autoimmune disease in which an individual's own immune system attacks the cells of the small intestine

**commensalism**
a symbiotic relationship between two species, where one species benefits and the other one isn't affected

**community**
a number of different populations existing in the same location at the same time and interacting with each other

**complementary base pairing**
the pairing of nitrogenous bases in DNA, with adenine and thymine always paired and cytosine and guanine always paired

**complete dominance**
when the allele for the dominant trait completely masks (hides) the allele for the recessive trait

**concentration gradient**
the difference between the concentrations of a substance in two regions; if there is a large difference, the concentration gradient is steep; diffusion occurs from a region of high concentration to a region of low concentration, along a concentration gradient

**conclusion**
a summary of what you can deduce from the results of the investigation, including whether the tested hypothesis was supported

**consumers**
organisms that feed on another organism to obtain the energy/nutrients they require; heterotrophs

**continuous data**
data that is measurable and continuous, with infinite possible values; best represented by a line graph

**continuous variation**
when a trait does not have distinct phenotypes but instead shows a series of phenotypes on a continuum

**control group**
the set-up or group in an experiment that does not receive treatment; it is used as the 'standard of comparison'

**controlled variable**
anything kept constant, or monitored, so it does not affect the independent and dependent variables, and therefore the validity of experimental results

**CRAP detection**
a method of determining whether a source is reliable, based on the currency, reliability, authority and purpose of the information

ISBN 978-1-108-88711-3

**crenation**
the shrinkage of a cell that occurs when there is net movement of water out of the cell while it is in a hypertonic solution

**cristae**
the highly folded inner membrane of the mitochondria and site of the third stage of aerobic cellular respiration, the electron transport chain

**critical periods**
periods of time during an organism's development when it is more susceptible to developmental abnormalities

**crossing over**
the exchange of genetic material between non-sister chromatids of a homologous pair of chromosomes during prophase I of meiosis; occurs at the chiasmata and results in recombinant chromosomes, increasing variation between gametes

**culture**
the growth of cells in a nutrient medium, e.g. agar

**currency**
timeliness; how up to date information is

**cytokinesis**
the final stage of the cell cycle, in which the cytoplasm splits, giving rise to two genetically identical daughter cells

**cytoplasm**
all the contents inside the membrane of a cell, except the nucleus; includes cytosol and organelles

**cytosol**
the liquid inside a cell, between the organelles (doesn't include the organelles)

**decomposers**
organisms that obtain nutrients by secreting enzymes to break down the dead plant and animal material

**deoxyribonucleic acid (DNA)**
a type of nucleic acid that carries the organism's genetic information

**dependent variable**
the variable that changes in response to changes in the independent variable; the experimenter measures these changes

**detritivores**
organisms that obtain nutrients by ingesting dead plant and animal material

**diabetes**
a condition that results from an inability to maintain healthy blood glucose levels

**digestion**
the process of breaking food down into smaller molecules that can then be absorbed into the bloodstream and transported to cells

**dihybrid cross**
the study of inheritance for phenotypes of two different genes through the mating of organisms over generations

**diploid**
containing two complete sets of chromosomes, one set from the mother (maternal) and one set from the father (paternal); pairs of chromosomes are called homologous chromosomes

**discontinuous variation**
when a trait has only a few phenotypes or discrete categories

**discrete data**
data that is countable in discrete categories; contains distinct or separate values; best represented by a bar graph

**DNA packaging**
the process in which DNA is compacted and packaged into the nucleus of a eukaryotic cell

**dominant**
the trait expressed in a heterozygous individual

**double chromosome**
a highly condensed, replicated molecule of DNA consisting of two identical chromatids joined by a centromere

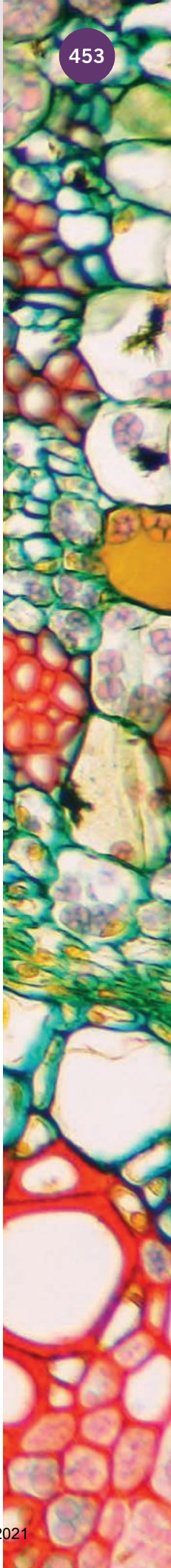
**ecosystem**
the combination of all organisms and their habitat

**ectoderm**
the outer primary embryonic germ layer

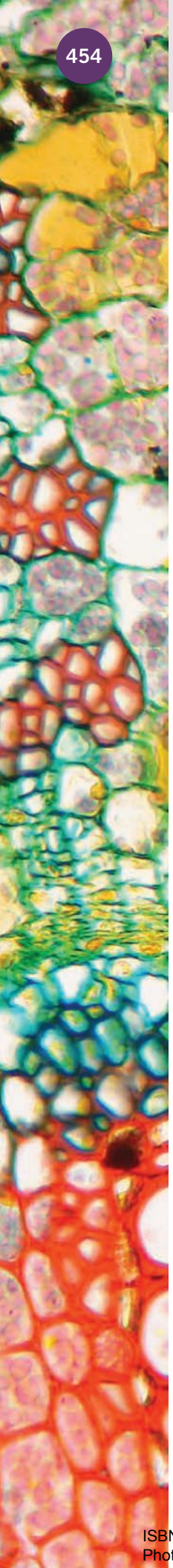
**effector**
the part of the body that is capable of responding to a stimulus

**egestion**
the removal of undigested food (waste) material from the body

**embryo**
an early stage of development from weeks 2 to 8 of pregnancy



ISBN 978-1-108-88711-3



**embryo splitting**
a type of artificial asexual reproduction in which offspring that are genetically identical to each other are produced by splitting the cells of an embryo early in development and implanting the cells in surrogate mothers to develop as normal

**embryonic germ layers**
the three layers of differentiated cells that the inner cell mass of the blastocyst gives rise to

**embryonic stem cell**
a type of stem cell that is found in an embryo, in the developmental stage prior to uterine implantation

**endocytosis**
the movement of large particles (or a large quantity of small particles) into the cell without directly crossing the plasma membrane, using vesicles and ATP

**endoderm**
the inner primary embryonic germ layer

**endosymbiosis**
symbiosis where one organism lives inside another

**enucleation**
the process by which a cell has its nucleus removed

**enzyme**
a biological catalyst that speeds up a chemical reaction by lowering activation energy

**epigenetics**
mechanisms that regulate gene expression, causing changes to the phenotype

**epithelial**
belonging to epithelium, a connective tissue forming skin and protective surfaces of organs

**ethics**
moral principles that guide our beliefs about what is right or wrong conduct

**eukaryote**
a single-celled or multicellular organism whose cells include membrane-bound organelles; includes protists, fungi, plants and animals

**excretion**
the process of eliminating waste matter

**exocytosis**
the movement of large particles (or a large quantity of small particles) out of the cell without directly crossing the plasma membrane, using vesicles and ATP

**extrinsic pathway**
the apoptosis pathway activated by an extracellular signal

**facilitated diffusion**
the net passive movement of a particular substance from a region of high concentration to a region of low concentration with the assistance of carrier protein molecules or channel protein molecules; also known as protein-mediated transport

**fermentation**
the process by which one molecule of glucose is broken down in the absence of oxygen to produce two molecules of ATP; also called anaerobic cellular respiration

**fertilisation**
the process by which the nucleus of an egg cell (or ovum) and the nucleus of a sperm cell fuse to form a zygote

**filtration**
removal of water and solutes from the blood into the nephron tubule

**first filial generation ($F_1$)**
offspring resulting from the parental cross/ generation

**fission**
a type of naturally occurring asexual reproduction in which the parent cell splits, forming two genetically identical cells

**flaccid**
refers to a plant cell that is not turgid or plasmolysed, but is limp due to lack of water and consequently the plant wilts

**flagella**
long microtubules projecting from a cell that move to provide motility (movement of the cell) or movement of fluid

**fluid mosaic model**
a model that represents the plasma membrane as a combination (mosaic) of phospholipids, proteins, cholesterol and carbohydrates that gives the membrane its fluid nature

**foetus**
the unborn offspring of a mammal more than 8 weeks after conception

**food chain**
a linear network of links (energy transfer) from producers through to consumers

ISBN 978-1-108-88711-3

**food web**
an interconnection between different food chains and organisms at the same or different levels

**fragmentation**
a type of naturally occurring asexual reproduction in which the parent breaks into two or more fragments and each fragment then regenerates to form a new daughter organism

**G0 phase**
the resting phase of the cell cycle that some cells may enter

**G1 checkpoint**
the first checkpoint of the cell cycle; commits the cell to the rest of the cycle

**G1 (first gap) phase**
the first period of cell growth in the cell cycle

**G2 checkpoint**
the second checkpoint of the cell cycle; ensures the DNA is suitable for entry into mitosis

**G2 (second gap) phase**
the second period of cell growth in the cell cycle

**gamete**
a haploid cell, or sex cell, involved in the creation of unique offspring in sexual reproduction; in humans, the male gamete is a sperm and the female gamete is an egg (ovum); in plants, the male gamete is a pollen grain and the female gamete is an ovum

**gastrointestinal tract**
a long hollow tube that connects the mouth to the anus

**gastrula**
an embryo at the stage following the blastocyst, when it has differentiated into three layers of cells

**gastrulation**
the process that results in the formation of the three primary embryonic germ layers

**gene**
a sequence of DNA that codes for the production of a polypeptide

**gene locus**
the position of a gene on a chromosome; plural: gene loci

**genetics**
the study of inheritance

**genome**
the complete set of genetic material in an organism/cell at a given time

**genomics**
the study of the genome and the relationship between genes

**genotype**
the combination of alleles that an organism has for a gene

**gestation period**
the time during which a foetus develops inside the mother's body, beginning at fertilisation and ending at birth

**gland (endocrine)**
an organ of the endocrine system that secretes hormones directly into the bloodstream

**glomerulus**
a network of capillaries that is the site of blood filtration in the nephron

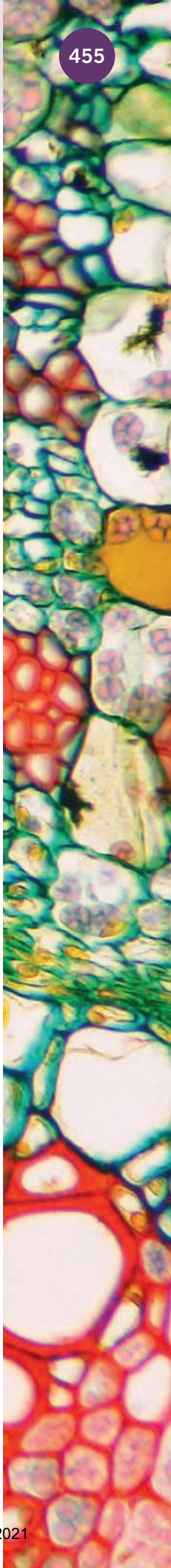
**glycolysis**
the first stage of cellular respiration, in which one molecule of glucose is broken down into two pyruvate molecules in the cytosol, producing two ATP molecules; does not require oxygen

**Golgi apparatus**
an organelle consisting of layers that modifies and packages proteins

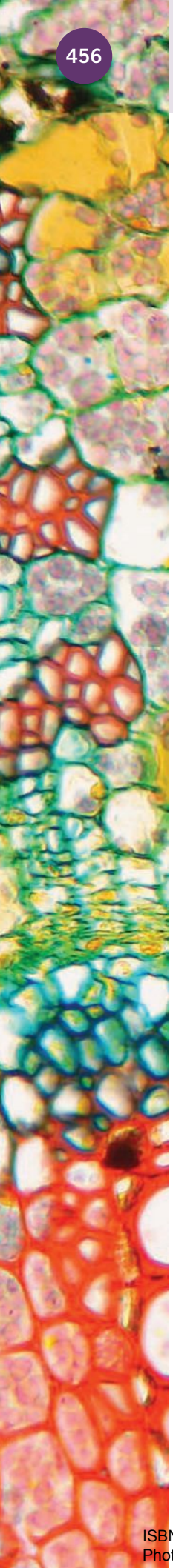
**gonads**
the sex organs responsible for carrying out meiosis and producing gametes; the testes in males and the ovaries in females

**grafting**
a type of artificial asexual reproduction in which the stem tissue of one plant is joined to the root tissue of another plant so they grow together as one plant

**grana**
stacks of thylakoid membranes inside the chloroplasts of plant and algal cells, where the light-dependent stage of photosynthesis occurs



ISBN 978-1-108-88711-3



**haematopoietic stem cell**
a type of multipotent stem cell found in bone marrow that can differentiate into any type of blood cell

**haemolysis**
the rupture or bursting of a red blood cell that occurs when there is net movement of water into the cell while it is in a hypotonic solution

**haploid**
containing nuclei with only one set of chromosomes

**heartburn**
a burning sensation in the chest caused by stomach acid rising into the oesophagus

**hemizygous**
when an individual, usually a male, has only one copy of an allele for a gene

**heterotroph**
an organism that ingests organic materials by feeding on autotrophs or on other organisms and their products, in order to make energy available in the form of ATP (*heteros* = other, *troph* = food)

**heterozygous**
having two different alleles for a gene

**homeostasis**
the maintenance of a constant internal environment despite changes in the external environment

**homologous chromosomes**
chromosomes that have matching structural features (size, banding pattern, centromere location) and gene loci, one from each parent

**homozygous**
having two copies of the same allele for a gene

**hormone**
a chemical messenger that travels through the blood to a target cell to initiate a response

**hydrophilic**
dissolves easily in water; also called lipophobic

**hydrophobic**
does not dissolve readily in water; also called lipophilic

**hyperthyroidism**
overproduction of thyroxine by the thyroid gland

**hypertonic**
refers to a solution that has a higher solute concentration than the cell's internal environment (*hyper* = higher)

**hypothesis**
a prediction of the outcomes, which are testable experimentally and form the basis of the methodology

**hypothyroidism**
underproduction of thyroxine by the thyroid gland

**hypotonic**
refers to a solution that has a lower solute concentration than the cell's internal environment (*hypo* = lower)

**incomplete dominance**
when the allele for the dominant phenotype does not completely mask the presence of the allele for the recessive phenotype, and a blend of both alleles occurs

**independent assortment**
the random arrangement of pairs of homologous chromosomes during meiosis, resulting in the random combination of alleles into gametes, thereby increasing variation

**independent variable**
the variable for which quantities are changed by the experimenter

**Indigenous**
the original or earliest known inhabitants of an area; also referred to as First Peoples or First Nations

**induced pluripotent stem cells (iPSCs)**
typical adult cells that have been genetically reprogrammed to revert to an embryonic stem cell state

**ingestion**
the entry of food into the gastrointestinal tract via the mouth

**inheritance**
how genetic material is passed on from one generation to the next

**inner cell mass**
the inner cluster of cells in a blastocyst

**integrity**
the commitment to searching for knowledge and understanding, and the honest reporting of sources and results

ISBN 978-1-108-88711-3

**interphase**
the period of the cell cycle that consists of the G1, S and G2 phases

**intrinsic pathway**
the apoptosis pathway activated by an intracellular signal

**introduction**
a brief but succint explanation of the reason for undertaking an investigation; includes key biological concepts, aim and hypothesis

**in-vitro fertilisation**
a medical procedure in which an egg is fertilised by sperm outside the body

**isotonic**
refers to a solution that has the same solute concentration as the cell's internal environment (*iso* = same)

**karyotype**
a pictorial representation of chromosomes in pairs, showing size, banding pattern, shape and number of chromosomes in an individual's somatic cell; allows for the determination of diploid number, gender and chromosomal abnormalities

**keystone species**
a species that has a much larger impact in an ecosystem than expected based on its size or numbers

**kinetochore**
a complex of proteins that assembles on the centromere and to which spindle microtubules attach during mitosis

**lacteal**
a lymphatic vessel within the villi of the small intestine that absorbs glycerol and fatty acids

**light-dependent stage**
the first stage of photosynthesis; occurs in the grana of the chloroplast and involves the splitting of water using light energy

**light energy**
energy from the Sun

**light-independent stage**
the second stage of photosynthesis; occurs in the stroma of the chloroplast and involves using carbon dioxide to create glucose

**lignin**
a component of the cell walls of vascular tissue that makes them rigid and woody

**line of best fit**
a line on a graph that shows the general trend of the data points; the distance to the points above the line should equal the distance to the points below the line

**linked genes**
two genes that are located on the same chromosome

**lipophilic**
dissolves easily in lipids; also called hydrophobic

**lipophobic**
does not dissolve readily in lipids; also called hydrophilic

**loop of Henle**
the part of a kidney tubule that forms a long loop, from where water and salts are resorbed into the blood

**lysosome**
an organelle containing enzymes that break down foreign matter or materials no longer required

**M (mitosis) phase**
the portion of the cell cycle that includes mitosis

**malignant**
cancerous; can spread to surrounding tissue or elsewhere in the body

**matrix**
the fluid component of the mitochondria and site of the second stage of aerobic cellular respiration, the Krebs cycle

**meiosis**
the process by which gonads produce haploid gametes, or sex cells, for sexual reproduction

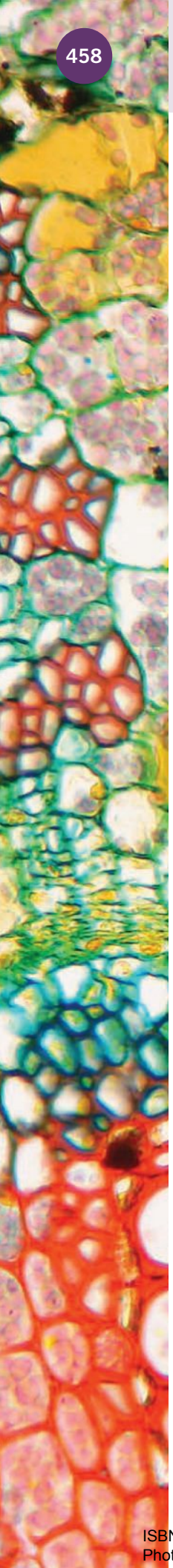
**mesoderm**
the middle primary embryonic germ layer

**metaphase**
the second mitotic phase; involves the lining up of chromosomes along the middle (equator) of the cell

**metastasis**
the spread of cancer cells from their point of origin to a new location in the body

**method**
a series of numbered steps describing the procedure

ISBN 978-1-108-88711-3



**micropropagation**
a type of artificial asexual reproduction in which large numbers of identical plants are produced rapidly by tissue culture techniques; occurs under controlled conditions

**microvilli**
minute projections that line the villi of the small intestine to further increase the surface area

**mitochondrion**
an organelle where respiration occurs, releasing energy (ATP)

**mitosis**
the division of a eukaryotic cell's nucleus

**monohybrid cross**
a genetic cross carried out to determine the possible genotypes and phenotypes of offspring inheriting one gene only

**morula**
a ball of 16 (to 32) cells that results from the cleavage of a fertilised ovum

**M checkpoint**
the final cell cycle checkpoint; ensures that spindle microtubules are correctly attached to chromosomes

**multicellular**
made up of more than one cell

**multiple alleles**
when there are three or more alleles for a gene

**multipotent**
able to differentiate into a variety of closely related types of cells

**mutualism**
a symbiotic relationship between two species, where both species benefit from the interaction

**necrosis**
cell death as a result of trauma or injury

**negative control**
a control group that isn't expected to produce a result

**negative feedback loop**
a process that regulates a variable within an organism, whereby the last step in the process (response) reduces the initial stimulus and so is self-limiting

**nephron**
the functional unit of the kidney

**non-disjunction**
when chromosomes fail to separate normally during anaphase

**non-sister chromatids**
a pair of chromatids, one from the maternal chromosome and one from the paternal chromosome

**non-vascular plant**
a plant that has no conducting tissue so cannot retain water or deliver it to other parts of the plant

**nuclear transfer**
a type of artificial asexual reproduction in which an adult cell nucleus is fused with an egg cell that has had its nucleus removed; the resulting cell is placed in a surrogate mother to develop as normal

**nucleoid**
an irregularly shaped area in a prokaryote where generic material is located

**nucleosome**
a set of eight histone proteins with DNA coiled tightly around them

**nucleotide**
the basic structural unit of nucleic acids

**nucleus**
a double-membrane bound organelle that contains genetic material (DNA, RNA)

**opinion**
a view or judgement that may be based on personal feelings, not necessarily on facts or research

**organ**
two or more types of tissue acting together to perform a specific role

**organelle**
a compartment within a cell that performs specific functions

**organism**
an individual that is living (biotic)

**osmoreceptors**
sensors in the body that detect changes in water balance away from homeostatic levels

ISBN 978-1-108-88711-3

**osmosis**
the net passive movement of free water from a region of high free water concentration to a region of low free water concentration across a semi-permeable membrane until equilibrium is reached

**outlier**
a reading that is very different from other results obtained for the same measurement

**p53 protein**
a regulatory protein that is vital to the division of healthy cells

**parasitism**
a symbiotic relationship between two species, where one species benefits at the expense of the other

**parental class**
offspring that display the combination of alleles that are also present together in one of the parent organisms

**parental generation (P)**
the first set of parents in a cross/pedigree

**parthenogenesis**
a type of naturally occurring asexual reproduction in which offspring are produced from the unfertilised egg of a female parent

**passive transport**
the net movement of a substance from a region of high concentration to a region of low concentration without the need for energy input; can also occur in non-living systems where there is no cell membrane

**pathogen**
a disease-causing agent

**pedigree chart**
a chart used to trace the inheritance of a phenotype over generations

**peristalsis**
involuntary contractions of muscles in the gastrointestinal tract that create a wavelike motion that pushes food through the tract

**peritubular capillaries**
a capillary network that wraps around the tubule and allows reabsorption and secretion between the bloodstream and nephron

**phagocytic cell**
a white blood cell of the immune system that engulfs and disposes of unwanted structures, such as dying cells

**phagocytosis**
a type of endocytosis in which a solid substance enters a cell via vesicle-mediated transport

**phenotype**
a physical characteristic in an organism, determined by the genotype and/or the environment

**phloem**
a component of vascular tissue responsible for the distribution of sugar throughout the plant

**photosynthesis**
a chemical reaction in which the Sun's light energy is used to convert the inorganic compounds carbon dioxide ($CO_2$) and water ($H_2O$) into the organic compound glucose; occurs in the chloroplast (*photo* = light, *synthesis* = build, put together)

**phototropism**
the process by which the growth and orientation of an organism occurs in response to a light stimulus

**physical digestion**
the process of breaking large chunks of food into smaller pieces

**pinocytosis**
a type of endocytosis in which a liquid or dissolved substance enters a cell via vesicle-mediated transport

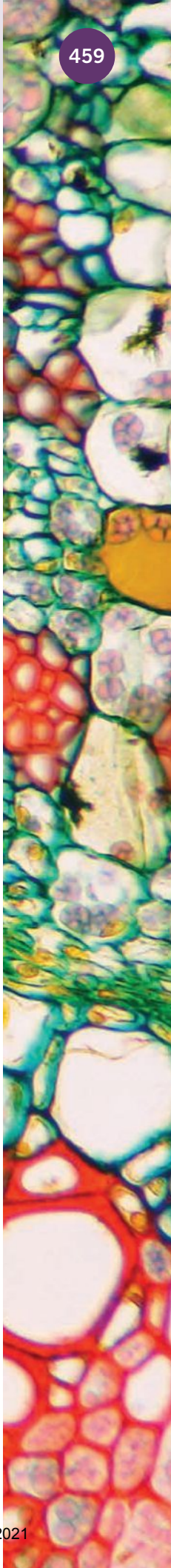
**placebo**
a substance that has no therapeutic effect but may have a psychological effect

**plasma membrane**
a membrane made up of two layers (known as a bilayer) of phospholipids that encloses the contents of a cell

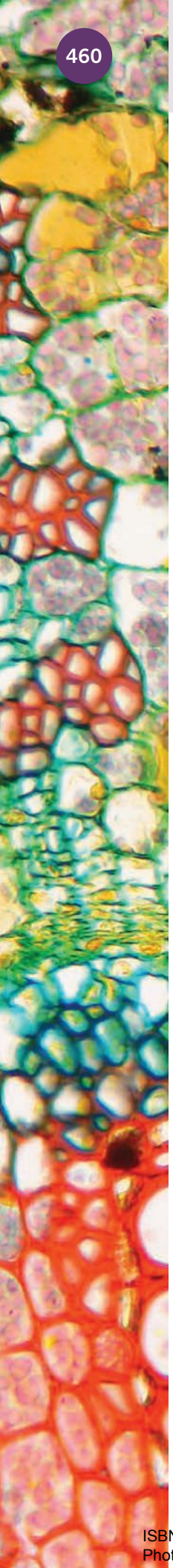
**plasmolysis**
the contraction of the plasma membrane and cytoplasm of a plant cell away from the cell wall when there is a net passive movement of free water out of the cell while it is in a hypertonic solution

**pluripotent**
able to differentiate into almost any type of cell

**polar**
describes a molecule that has different charged sides ('poles') and dissolves in water, which is also a polar substance



ISBN 978-1-108-88711-3



**polygenic trait**
a trait that is controlled by more than one gene

**population**
a group of organisms of the same species that are living in the same location at the same time

**positive control**
a control group that receives a treatment with a known response that can then be compared to the experimental group(s)

**positive feedback loop**
a process that controls a variable within an organism, whereby the last step in the process causes the action to be repeated

**precision**
how close all the measurements are to each other

**producers**
organisms that convert sunlight into their own chemical energy; autotrophs

**prokaryote**
a single-celled organism that does not have membrane-bound organelles; includes bacteria and archaea

**prophase**
the first mitotic phase; involves the breakdown of the nuclear membrane and the appearance of distinct chromosomes

**protein carrier**
a selective peripheral protein that uses ATP to move substances across a plasma membrane; also known as a protein pump

**protein-mediated transport**
when a transmembrane protein assists in the transport of a substance across a plasma membrane; also known as facilitated diffusion

**proteomics**
the study of proteins and their function

**Punnett square**
a diagram used to determine the expected genotypes and phenotypes of offspring from the genotypes of both parents

**purine**
a nucleotide with a two-ring structure (adenine and guanine)

**pyrimidine**
a nucleotide with a single-ring structure (cytosine and thymine)

**qualitative data**
data that is descriptive (not numeric)

**quantitative data**
data that is measured and represented numerically

**random error**
an unpredictable variation in the readings obtained, due to variables not all being controlled (extraneous variables), and resulting in the readings being higher or lower than expected

**reabsorption**
movement of water and solutes from the nephron tubule back into the blood

**receptor**
specialised proteins or glycoproteins in the cytosol or on the plasma membrane that receive a stimulus

**recessive**
the trait not expressed in a heterozygous individual

**recombinant class**
offspring that do not display the combination of alleles that are present together in the parent organisms

**reflex**
a response to a stimulus that doesn't require thought, as the nerve signal does not involve the central nervous system

**regenerative medicine**
a new field of medicine that replaces, regenerates or engineers human cells, tissues or organs to restore normal function

**regulatory proteins**
a group of proteins that operate at cell cycle checkpoints to allow healthy cells to progress in the cycle

**reliability**
the extent to which an experiment always yields the same results under the same conditions; or the degree to which information is accurate and dependable

**repeatability**
recording of results produced when the experiment is repeated in one lab by one operator under the same conditions

**reproducibility**
when the same results are obtained for the same experiment by different operators using different equipment

ISBN 978-1-108-88711-3

**reproduction**
the production of offspring

**respect**
giving consideration to the extent to which living things have an intrinsic value; giving due regard to the welfare, liberty, autonomy, beliefs, perceptions, customs and cultural heritage of individuals and the collective

**response**
a change in an organism resulting from the detection of a stimulus

**ribosome**
a non-membrane-bound organelle involved in synthesis of proteins

**root hairs**
elongated structures that grow from the outer layer of root cells and maximise the absorption of water and minerals from the soil

**root system**
the parts of a plant that lie below the surface of the soil

**rough endoplasmic reticulum**
an organelle that transports proteins in vesicles to the Golgi apparatus

**rubric**
a scoring guide; a set of criteria used to evaluate students' responses

**S (synthesis) phase**
the DNA replication phase of the cell cycle

**secretion**
active transport of solutes from the peritubular capillaries into the nephron tubule

**segregation**
in biology, the separation of two alleles during the formation of gametes

**self-renewal**
the ability of stem cells to regenerate by giving rise to exact copies of themselves

**semi-permeable**
allowing some substances to pass through while preventing the movement of others

**semi-permeable membrane**
a membrane that only lets certain substances cross it; also called partially permeable, differentially permeable and selectively permeable

**sensor**
a structure that detects a stimulus; a receptor

**sex chromosomes**
a pair of chromosomes in a diploid cell that determine the biological gender of the offspring; in humans, pair 23 is the sex chromosomes: males have an X and a Y chromosome, while females have two X chromosomes

**sex-linked gene**
a gene located on a sex chromosome (X or Y in humans)

**sexual reproduction**
a type of reproduction in which two parent organisms contribute gametes, containing genetic material, to the offspring

**shoot system**
the parts of a plant that are above the ground

**simple diffusion**
the net passive movement of a substance from a region of high concentration to a region of low concentration until equilibrium is reached; does not require energy

**single chromosome**
a highly condensed, single molecule of DNA

**single-variable exploration**
an investigation that contains only one independent and one dependent variable

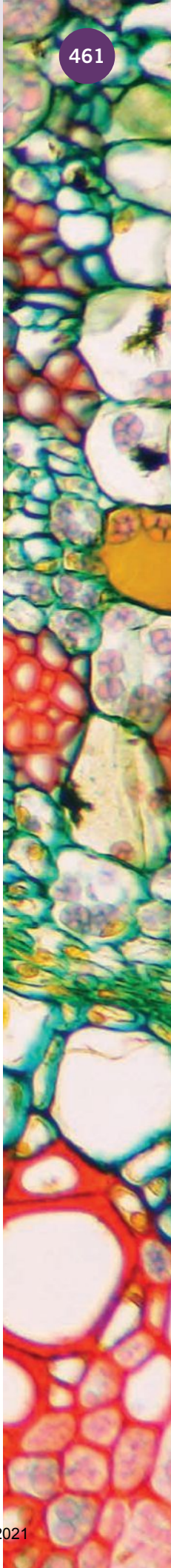
**sister chromatids**
a pair of chromatids (single arms of a double chromosome) from the same parent as a result of DNA replication

**smooth endoplasmic reticulum**
an organelle that synthesises and transports lipids

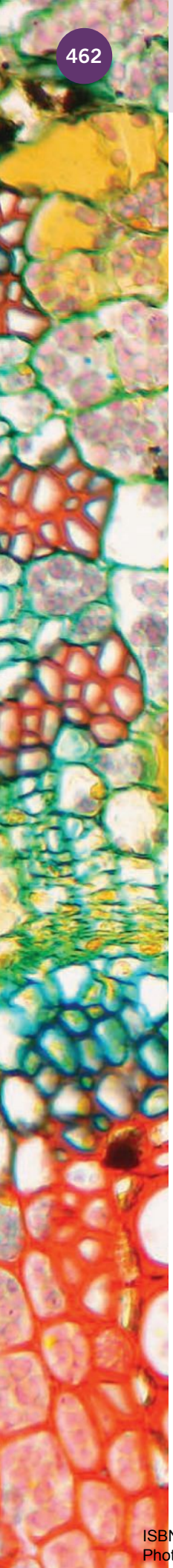
**social norms**
standards of what is considered socially acceptable within a community

**sodium–potassium pump**
the exchange of sodium and potassium ions across the plasma membrane of an axon by protein carriers, fuelled by ATP; leads to an action potential

**somatic cell**
a body cell containing a full complement of genetic information (diploid)



ISBN 978-1-108-88711-3



**specialised cell**
a cell with a specific function and structure within a multicellular organism

**species**
a group of organisms that are capable of interbreeding to produce fertile offspring

**sphincter**
a ring of muscle surrounding a tube that tightens to close it or relaxes to allow it to open

**spores**
small, lightweight capsules produced in large numbers by asexual reproduction; easily dispersed and can withstand tough environmental conditions

**stakeholder**
the person or organisation that will be affected by the factor under consideration

**stem cell**
a type of cell that is capable of differentiating into one of a range of specialised cells within an organism

**stem cell therapy**
the treatment and prevention of disease through the use of stem cells

**stimulus**
a change in the internal or external environment that can be detected

**stimulus–response model**
the pathway from a stimulus or change to response or action taken by a cell/organism

**stomata**
pores in the epidermis of leaves or stems in plants that allow the movement of gases and water vapour in and out of intracellular spaces; singular: stoma

**stroma**
the gel-like fluid inside a chloroplast that surrounds the grana and is the site of the light-independent stage of photosynthesis

**surface area**
the area on the outside of an object that is exposed to the external environment; in the case of a cell, this is the plasma membrane's surface

**surface area to volume ratio (SA:V)**
the relationship between the amount of plasma membrane that is exposed to the external environment (surface area) and the volume of the cytoplasm of the cell (volume)

**SWOT analysis**
a method of assessing an issue by considering strengths, weaknesses, opportunities and threats associated with the issue

**symbiosis**
a beneficial relationship between two organisms

**synapsis**
pairing of homologous chromosomes during prophase I of meiosis

**system (biological)**
a group of organs working together to perform a task vital for survival

**systematic error**
when the readings obtained from measurements differ from the 'true' value consistently in one direction every time

**target cell**
a cell with a complementary receptor for a signalling molecule/hormone

**telophase**
the final mitotic phase, in which two nuclei are formed and the cell prepares to divide

**test cross**
a genetic cross where an organism with the dominant phenotype (unknown genotype) is crossed with a homozygous recessive organism

**thylakoid membranes**
interconnected and folded membranes inside a chloroplast that make up the grana and are the location of the pigment chlorophyll

**tissue**
a group of similar cells that work together to carry out a specific function; organs are made up of different tissues

**title**
the research question under investigation; includes information about what is being tested

**tonicity**
how the concentration of solutes dissolved in an extracellular solution determines the direction and rate of osmosis and therefore the volume of a cell

**totipotent**
able to differentiate into any type of cell

**tracheid**
a hollow cell that tapers inwards at both ends and contributes to the structure of xylem in vascular tissue

ISBN 978-1-108-88711-3

**transpiration**
evaporative water loss through plant leaves that results in the movement of water through the plant

**transpiration stream**
the continuous column of water that forms inside the xylem as a result of evaporative water loss through the leaves

**trisomy**
a condition in which there is an extra copy of a chromosome in a somatic cell

**trophoblast**
the outer layer of cells in a blastocyst

**true value**
the value or range of values that would be obtained if the quantity could be measured perfectly

**tubule**
the tubular portion of the nephron that the filtrate passes through to become urine

**tumour**
an abnormal tissue mass that is the result of uncontrolled cell division

**turgid**
refers to a plant cell that has expanded or swollen when there is net passive movement of free water into the cell while it is in a hypotonic solution

**unicellular**
made up of only one cell

**unipotent**
able to produce only one type of cell, its own

**unlinked genes**
genes that are located on different chromosomes or very far apart on the same chromosome

**uterus**
an organ in females where offspring gestate before birth

**vacuole**
an organelle that stores substances; important in maintaining structure of plant cells

**validity**
the extent to which all variables in the experiment have been controlled, so that the independent variable is the only factor that changes

**variation**
differences that exist within a species

**vascular plant**
a plant that has tissue for conducting water and minerals throughout the plant

**vegetative propagation**
another name for asexual reproduction in plants; can occur both naturally and artificially; also called vegetative reproduction

**vesicle**
an organelle that transports materials between organelles and within the cell

**vesicle-mediated transport**
the movement of substances across the plasma membrane using membrane-bound structures within the cell; vesicles are formed from a section of cell membrane

**vessel element**
an elongated, hollow cell that contributes to the structure of xylem in vascular tissue

**vestigial**
smaller or undeveloped and not able to function (e.g. wings on a fruit fly)

**villi**
fingerlike projections that line the inner surface of the small intestine, increasing its surface area

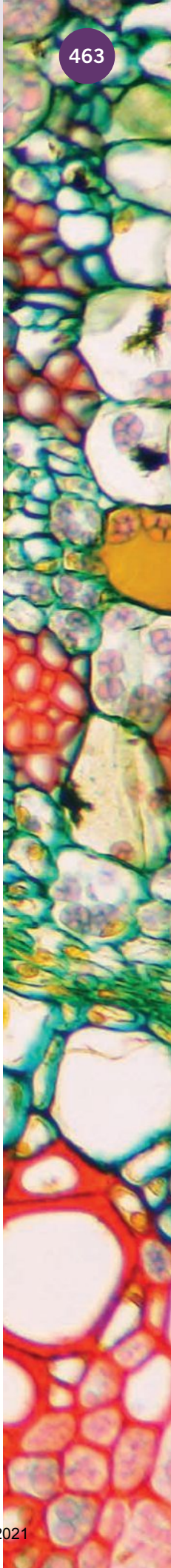
**volume**
the amount of space inside an object; in the case of a cell, this is the cytoplasm

**X-linked**
refers to a gene that is located on the X chromosome (in humans)

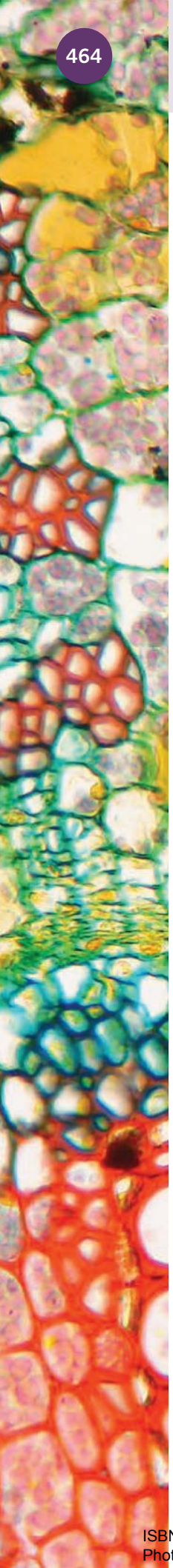
**xylem**
a component of vascular tissue responsible for the distribution of water upward from the roots

**Y-linked**
refers to a gene that is located on the Y chromosome (in humans)

**zygote**
a diploid cell formed when the nuclei of an ovum and a sperm fuse during fertilisation



ISBN 978-1-108-88711-3

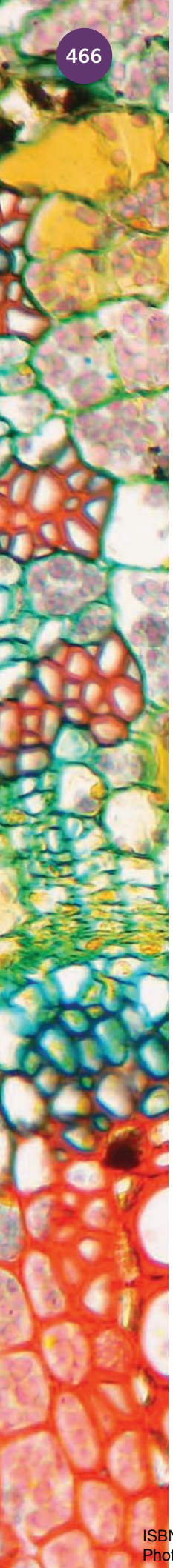


# Index



ISBN 978-1-108-88711-3

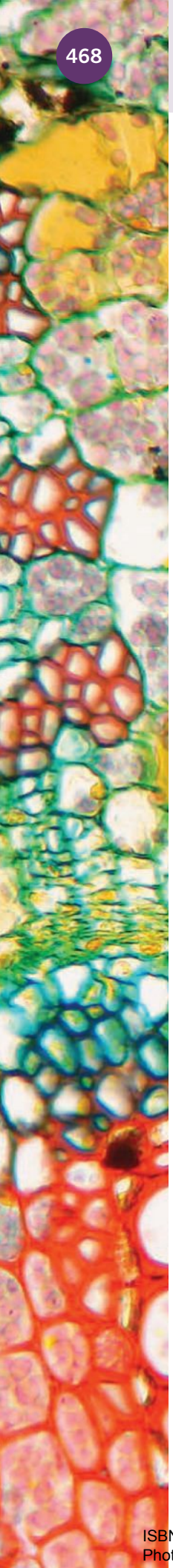
ISBN 978-1-108-88711-3





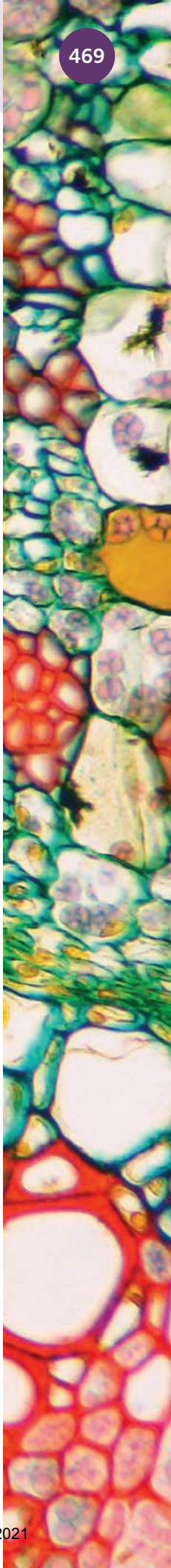
ISBN 978-1-108-88711-3

ISBN 978-1-108-88711-3

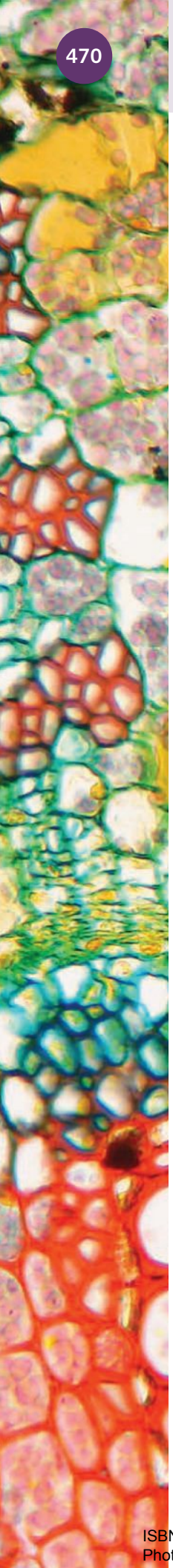




ISBN 978-1-108-88711-3



ISBN 978-1-108-88711-3



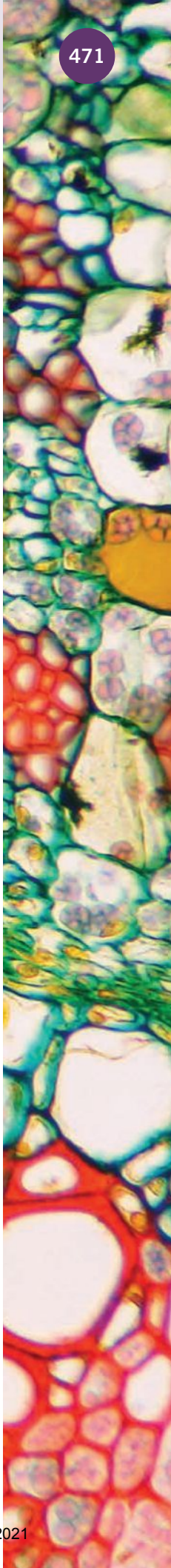
# Permissions acknowledgements

The author and publisher wish to thank the following sources for permission to reproduce material:

**Cover:** © Getty Images / Garry DeLong

**Images:** © Getty Images / Steve Gschmeissner, Chapter 1 Opener, 1C–4 (2), Chapter 3 Opener / Kateryna Kon / Science Photo Library, 1A (1), 1C–4 (3) / Rodrigo Friscione, 1A –1 / David & Micha Sheldon, 1A–2 / Reinhard Dirscherl, 1A–3 / jack0m, 1A–4 (1) / ttsz, 1A–4 (2) / Christoph Burgsted / Science Photo Library, 1A–4 (3) / Alfred Paseika, Science Photo Library, 1B / colematt, 1B–3 / Encyclopaedia Britannica/UIG, Table 1B–1 (1) / yxyeng, 1C–1 / Science Photo Library, 1C–2 / Don White, 1C–4 (1) / Jackie Bale, 1C–4 (5) / Mint Images, 1C–4 (5) / Amer Ghazzal, 1C–4 (6) / Wokephoto17, Ch 1 Check in Q–Set 1 / Science Picture Co, 1C–5 (1) / jack0m, 1C–5 (4–5) / ANDRZEJ WOJCICKI, 1C Skills A / snapgalleria, 1C Skills B / Keith Chambers / SPL, 1C Skills C / VectorMine, Table 1D–2 / FancyTapis, Table 1D–2 (5) / VectorMine, Table 1D–2 (9 & 10) / mariaflaya, Table 1D–2 (7) / BSIP/UIG, Table 1D–2 11 / TefiM, 1D–2 (1) / Encyclopaedia Britannica/UIG, 1D–2 (2) / toonishwarhead, 1D–4 / Santiago Urquijo, 1D–3, Chapter 1 Review Q (1) / Westend61, 1D Q (2) / Stocktrek Images, Chapter 1 Review Q (2) / Garry DeLong, Chapter 2 Opener / Claus Lunau, 2A, 2A–4, 2A–8 / blueringmedia, 2D / Aditi Gupta, 2A–1 (1) / Maria Casinos, 2A–1 (2) / Martin Leigh, 4E–14 / mariaflaya, 4E–15 / DR JEREMY BURGESS / SPL, 4E–16 / Claire Higgins, 4E Skills / Cexary Zarebsk, Section 4E Q (A) / Marisol Bogaard, Section 4E Q (B) / Rosemary Calvert, Section 4E Q (C) / Gunter Lenz, Section 4E Q (D) / Kateryna Kon/SPL, 8A–(L), 2A–1 (3), Ch2 Check–in Q Set 5, 4A–3 (1), 4A–6 (cell/tissue) / Olga Strelnikova, 2A–2 / FancyTapis, 2A–5 / Science Photo Library–Steve GschMeissner, 2A–7 (L), 2B–5, 3B skills, 3C–21, 3A–26, 4A From cells to systems, 4E–10 / FancyTapis, 2A–9, 2A–10 (L), 2A–10 (R) / tunart, Section 2A questions (1) / Mailson Pignata, 2B–1 / tunart, 2A Skills (3) / Mailson Pignata, 2B–1 / Dorling Kindersley, 2B–3 / VectorMine, 2B–6, 2D–2, 2D–4, 2D–6, 2D–11, 2D–15 / berkpixels, 2B–9 / RLS Photo, 2C–1 / Sciepro, 2C–4 / luxxtek, 2C–5 / Inner space imaging/SPL, 2C–10 / Dr. Kari Lounatmaa, 2D–5 / Kjohansen, 2C–12 / MarkMirror, 2D–1 / Sketchbook Designs, 2D–2 / Mark Newman, 2D–3 / Brian Hagiwara, Ch2 Review (image 4) / koya79, 3A–3 (L) / Dorling Kindersley, 3A–3 (R) / QAI Publishing, 3A–5 (R) / olando_o, 3A–6 / newannyart, 3 A–13 / Morsa Images, 3A–17 (L), 3A–17 (R) / Westend61, 3A–18 / Juan Gaertner/SPL, 3A–21, Westend61, 3A–22 / Paul Fleet, 3A–23 / Pasieka, 3B–1 / Hometowncd, Ch 3 Check in Q–Set 1 / Sarah Jones (Debut Art), 3B–7 (1) / Nastasic, 3B–7 (2) / ThomasVogel, 3B–7 (3) / Photographer, Basak Gurbuz Derman, 3B–7 (4) / BSIP, 3B–9 / Lester V. Bergman, 3B–14 / De Agnostini Picture Library, 3B–15 / Jonathan Wood, 3C–1 / BSIP, 3C–2 / Alfred Pasieka/SPL, 3C–4 / Matt Meadows, 3C–13 (R) / Callista Images, 3C–14 (T) / LEON NEAL, 3C–14 (B) / PASIEKA, 1B–4 / Steven McDowell, Chapter 4 Opener / Blueringmedia, 4A From cells to systems / Claudio Divizia, From cells to systems / stock_colors, From cells to systems / PIXOLOGICSTUDIO, 4A From cells to systems / Sebastian Kaulitzki, 4A From cells to systems / BSIP/UIG, 4A From cells to systems / De Agnosti Image Library, 4A From cells to systems / Blueringmedia, 4A From cells to systems / Dr. Keith Wheeler, 4A From cells to systems / Kei Uesugi, 4A From cells to systems / Leonello Calvetti, 4A From cells to systems / Danylyukk, 4A From cells to systems / Iuliia Morozova, 4A–1 (1–2) / Nnehring, 4A–3 (2) / RAZVAN CIUCA, 4A–3 (3) / Londolozi Images/Mint Images, 4A–3 (4) / Chris Ryan, 4A–8 (C) / xia yuan, 4A–8 (1) / Garry DeLong, 4A–8 (2) / xia yuan, 4A–8 (3) / Akesak, 4A–8 (4) / Iuliia Morozova, 4A–12 / xia yuan, 4A Skills / Nnehring, Section 4A Q (1) / Michael Duva, 4B–1 (2) / Andyworks, 4B–1 (4) / Altmodern, 4B–1 (1) / Satirus, 4B–1 (3) / Peter Macdiarmid, 4C–1 / Medicalstocks, 4C–2 / VectorMine, 4C–5, 4D–4 / medicalstocks, 4C–12 (L) / Andrew Holbrook, 4C–12 (R ) / Life on White, Section 4D Q (2), Steve West, 4D (1) /andegro4ka, 4D–2 / 7activestudio, 4D–3 / Owen Franken, 4D–7 / Javier Fernández Sánchez, Section 4D Q (1) / Carmen Martínez Torrón, 4E–1 (L) / Artur Debat, 4E–1 (R) / TED MEAD, 4E–2 / Atelopus, 4E–3 / ithinksky, 4E–3 / Selektor, 4E–3 /Pannonia, 4E–3 / Liliboas, 4E–3 / Tetra Images, 4E–3 / Emmanuelle Bonzami, 4E–3 / Zoonar/j.wnuk, 4E–3 / Dr. Keith Wheeler, 4E–5 / blueringmedia, 4E–6 / Jonathan Kantor, 4E–7 / ithinksky, Chapter 5 Opener / Lucie Wicker, 5A Homeostasis / Freder, 5B Homeostasis in animals / Terry Vine, 5C Homeostasis gone wrong / Aimee Lewis, 5A (1) / Neil Tapman, 5A (2) / Yaoinlove, 5B (1) / Siyatsky, 5A 2 / alla_snesar, 5A–4 / Klaus Vedfelt, 5A Skills / Peter Muller, 5C (1) / Maskot, 5C–3 / John P Kelly, 5C–4 / VectorMine, 5C–7 / Tharakorn Arunothai, 5C–6 / ablokhin, Chapter 5 Review (1) / Sellwell, Chapter 5 Review (2) / Vinco Computer, 5B–7 / Getty, 6A Engage (2), Check-in questions–Set 1 (1), Chapter 6 revision

ISBN 978-1-108-88711-3



exercise (2), 7A–6 / Jonathan Knowles, 6A Engage (3) / Westend61, Section 6A Q (1) / Arndt_Vladimir, Chapter 6 revision exercise (1) / Simon McGill, Chapter 6 revision exercise (3) / Pixologics Studios/SPL, Chapter 6 revision exercise (8–R) / Roger Harris/SPL, Chapter 6 revision exercise (7–L) / YasserBadr_Beenthere, Chapter 6 revision exercise (5) / Carmen Jiménez, Chapter 6 revision exercise (6) / Kevin Schafer, Chapter 7 Opener / tonaquatic, Concept map 7A / macroworld, Concept map 7B / Mark Weich, Concept map 7C / Holger Leue, Concept map 7D, 7C–9 / Tunatura, 7A–1 (R) / BeholdingEye, 7A–3 / Kumpanat Phewphong, 7A–7 / tverkhovinets, Table 7A–1 (2) / vavlt, Table 7A–1 (3) / Wrangler-JT, Table 7A–1 (4) / jskiba, Table 7A–1 (5) / mariaflaya, Table 7A–1 (6) / Robert Pickett, 7A–14 / buccaneership, 7B–14 / Philippe Bourseiller, 7C Skills / Graphic_BKK1979, 7A–12 / ZambeziShark, 7B–1 / tracielouise, 7B–2 / James Yu, 7B–3 / MaskaRad, 7B–5 / Olympia Valla, 7B–6 / Olympia Valla, 7B–11 / Westend61, 7C–1 / Arto Hakola, 7C–2 / Mark Weich, 7C–3 / Alicia Llop, 7C–4 (1) / ithinksky, 7C–4 (2) / Digital Vision, 7C–5 / Stocktrek Images, 7C–7 / Joao Paulo Burini, 7C–8 / Philip Dumas, 7D–1 (L) / Glow Images, 7D–1 (R) / Albert Wright, 7C–11 (R) / Connie Kerr, Table 7C–1 (2) / rockptarmigan, Table 7C–1 (3) / Mark Kostich, Table 7C–1 (4) / cmannphoto, Table 7D–1 (1) / Cat Gennaro, Table 7D–1 (2) / RAZVAN CIUCA, Table 7D–1 (3) / DonNichols, 7D–2 (5), 7D–3 (7) / GlobalP, 7D–2 (4), 7D–3 (4) / ithinksky, 7D–2 (3), 7D–3 (3) / PetlinDmitry, 7D–2 (2), 7D–3 (2) / GlobalP, 7D–2 (1), 7D–3 (1) / chengyuzheng, 7D–3 (6) / Andregric, 7D–3 (5) / PhotoStock-Israel, 7D–4 / Michael Cummings, 7D–5 (3), 7D–6 (1) / Mark Smith, 7D–5 (2), 7D–6 (centre) / ArtBoyMB, 7D–2 (R–1) / Jacky Parker Photography, 7D–6 (R–2) / Inigo G.–H. / 500px, 7D–6 (R–3) / Martin Ruegner, 7D–5 (1), 7D–6 (L–1) / Chase Dekker Wild-Life Images, 7D–6 (L–2) / Marcia Straub, 7D–6 (L–3) / Penny Tweedie, 7D–9 / Michael Carr, 7D–10 / Indianoceanimagery, 7D–13 / Ted Mead, 7D–11 / Paul Souders, 7C–13 / Fairfax Media via Getty Images Copyright: 2014 Fairfax Media, 7D–8 / Evgenii Kovalev, Chapter 8 Opener / Vaclav Hykes, 8A–3 / Yuji Sakai, 8A–1 (1) / Robyn Beck, 8A–4 / Fcafotodigital, 8B (Engage) / PeterHermesFurian, 8B–1 / yomogi1, 8B–2 / Etienne Jeanneret, Ch 8 Check-in Q–Set 2 / Dr_Microbe, 8C–5 / Chris_Paris, 8C–8 / Andrew Lucchesi, 8C–4 / Elizabeth Fernandez, 8C–4 / Jonathan Knowles, 8C–4 / dra_schwartz, 9A Explain (1) / VectorMine, 9A–2 / Tim Hale, Table 9A1, 9A–Genetic / AJ_Watt, 9C–1 / Graphic_BKK1979, 9A–3 / mikroman6, Section 9A Q / Mgkaya, 9B Concept map / Constantine Johnny, 9C thinking organisers / Sciepro/Science Photo Library, 3A–1, 3A–4 (1), 3A–2, 3A–4 (2), 3A–3, 3A–4 (3), 3A–4 (3A–4 (5), 3A–5, 3A–4 (6), 3A–5 (L) / 4A–6 (organ), 4B–8, ClusterX, 4B–13 / ttsz, Table 1B–1 (2), 1C–5 (2–3), 1C –6, Table 1D–1, Table 1D–3, Table 1D–2 (4), Table 1D–2 (8) / 2A–7 (R), 2B Osmosis (1), 2B Osmosis, 2B–7, 2D–9, 2D–12, Ch2 Review (image 5) / 3A–8 (cardiac muscle), 3A–11, 3A–24, 3 A–13, 3A–15, 4A From cells to systems, 4A From cells to systems/Check-in Q–Set 2, 4B–6, 4C–3, 4C–8, 4C–11, 4D–6, Chapter 6 revision exercise (4), Concept map 7D, 7B–5, 7D–7, 8A–1 (2) / 8A–5 / Ed Reschke, 2C, 2C–9, Ch2 Check-in questions–Set 1 (1), 2B–8, Section 2B Q, Table 3B–1 (R–2), 3B–18, Table 3B–1 (R–1) 3B–18, 3B–11, Table 3B–1 (R–4), 3B–18, Table 3B–1 (R–5), 3B–18, Table 3B–1 (R–6), 3B–18, 3B–16 (R ) 3B–18, CH3 Review Set of Images 1 (P&S), Q1, 1 (R), 4E–4, 4E–2, Table 7A–1 (1) / Encyclopaedia Britannica, 2C–7 (1), 2C–7 (2), 3B–5, Table 3B–1 (L–1), Table 3B–1 (L–2), Table 3B–1 (L–4), Table 3B–1 (L–5), Table 3B–1 (L–6), 3B–16 (L), 9A–1; William Barack 1898, NGV, Table 7C–1 (5) / photography by p.lubas, 5A–5, Ed Reschke, p.172; © Akarat Phasura / Dreamstime, Table 1D–2 (6) © Biology Pics / Science Photo Library, 1D–6 (L); © CNRI / Science Photo Library, D–6 (R), 2D–13; © Colors / Stockimo / Alamy Stock Photo, CH2 Review (image 6); © Douglas Blackiston CC BY 4.0, 3A (1); © Science Photo Library / Alamy, 3A–20; © Animated Health Care Ltd/SPL, 3C–16; © Biophoto Associates / Science Source, 3B–6; © Dr. Robert Calentine, Visuals Unlimited/SPL, 3B–17 (R); A Barrington Brown © Govnille & Caius College/SPL, 6A Engage (1); © Science Photo Library/Alamy Stock Photo, 7A–2.

**Text:** Quote by Bruce Pascoe: Dark Emu, Magabala Books, 2018, p.355; VCAA: Extracts from the VCE Biology Syllabus (2020) reproduced by permission; © VCAA. The VCAA does not endorse or make any warranties regarding this study resource. Current VCE Study Designs and related content can be accessed directly at www.vcaa.vic.edu.au. Readers are also advised to check for updates and amendments to VCE Study Designs on the VCAA website and via the VCAA *Bulletin* and the VCAA Notices to Schools.

Every effort has been made to trace and acknowledge copyright. The publisher apologises for any accidental infringement and welcomes information that would redress this situation.

ISBN 978-1-108-88711-3