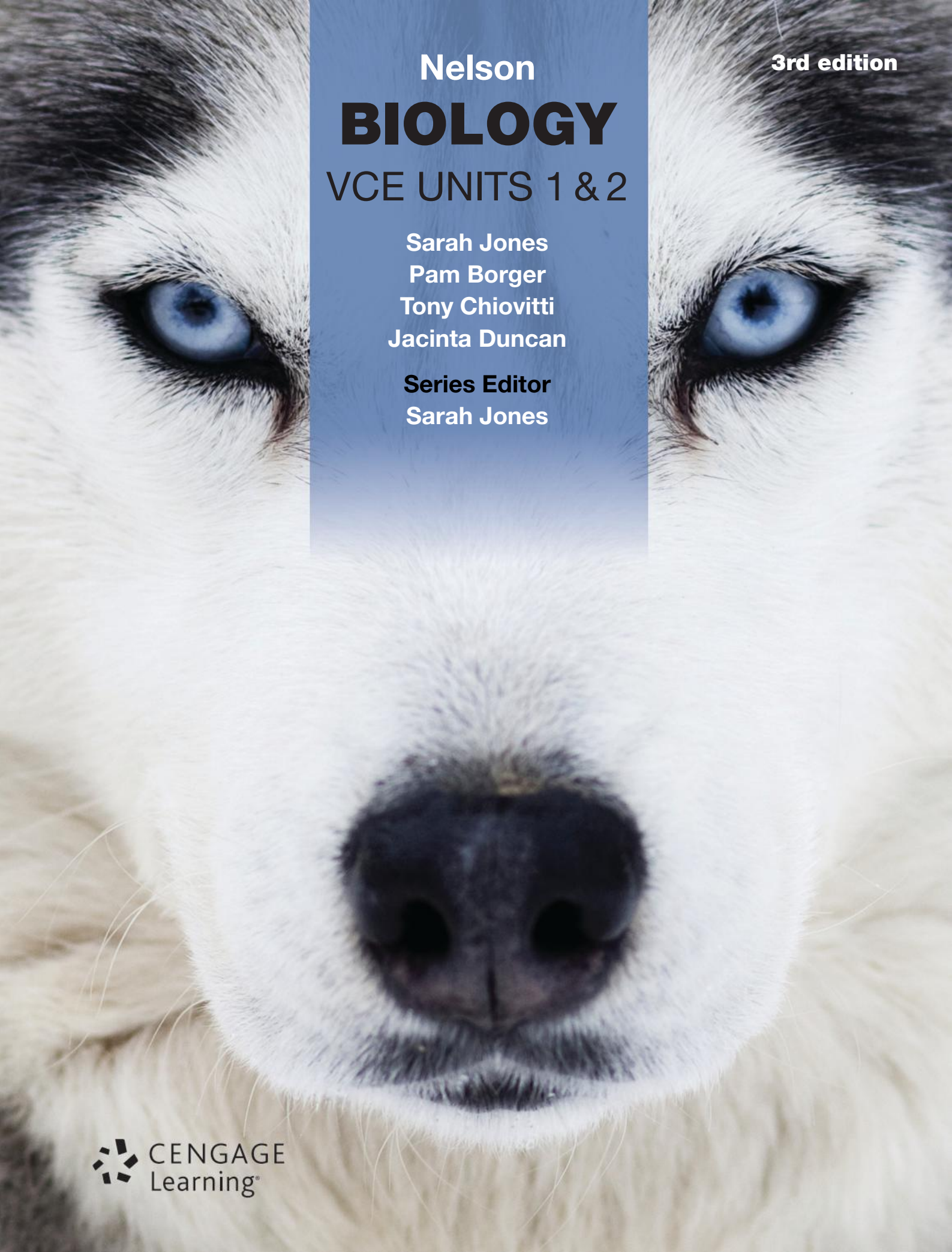


Nelson BIOLOGY

VCE UNITS 1 & 2

3rd edition

Sarah Jones
Pam Borger
Tony Chiovitti
Jacinta Duncan

Series Editor
Sarah Jones

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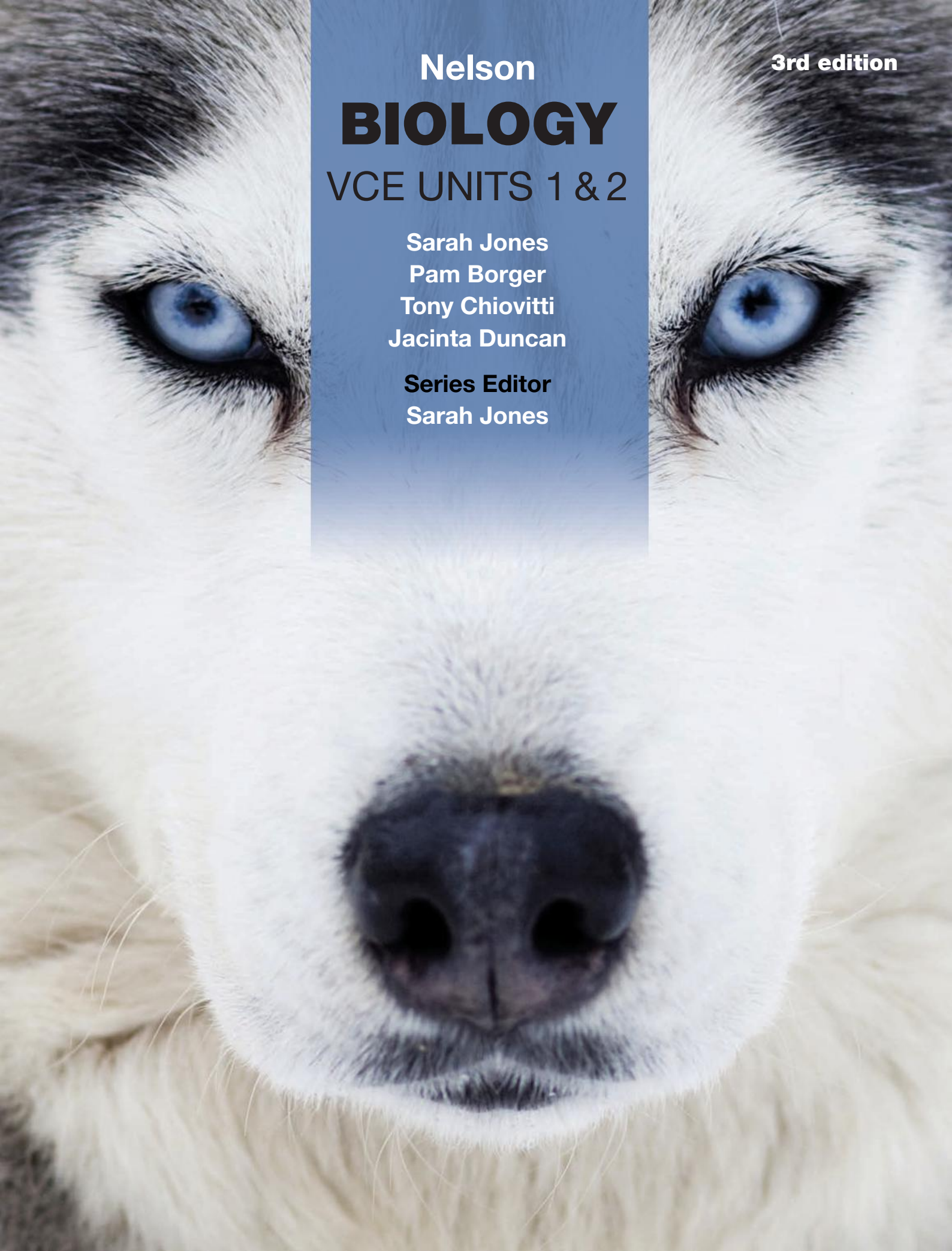
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Editor: Nadine Anderson-Conklin
Copyeditor: Kay Waters
Proofreader: Jane Fitzpatrick
Indexer: Russell Brooks
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Level 7, 80 Dorcas Street
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Cengage Learning New Zealand
Unit 4B Rosedale Office Park
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PREFACE

This third edition of *Nelson Biology VCE Units 1 & 2* has been structured to meet the requirements of the VCAA VCE Biology Study Design 2016–2021.

The text has been written to promote a high level of understanding while also presenting content in easy-to-understand language. The rationale and aims of the VCAA VCE Study Design have formed the basis of the approach for all of our authors. We are proud to have gathered a team of highly experienced subject experts from research, academia and secondary teaching. Our authors have been chosen for their comprehensive knowledge of biology and best teaching practice in biology education at secondary and tertiary levels. They are all dedicated to science communication and lifelong learning, and together they have produced an outstanding series.

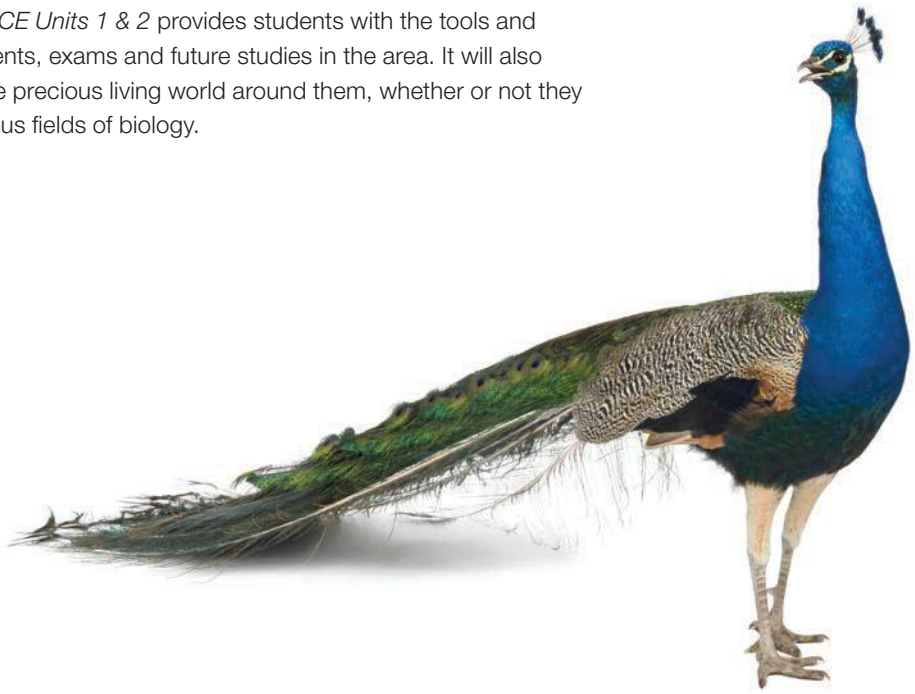
One of the goals of this text is to help students gain a wide perspective on the breadth and depth of Biology in both theory and practice. To understand the living world around us is the key role of a biologist, and a key goal of this text is to make that understanding possible. It is hoped that, through the study of living things, students will gain an appreciation of the complexity of life from the cellular level to the expansive ecosystems of the world, that they will better understand difficult bioethics situations, and will better evaluate the presentation of scientific issues.

The dedicated *Investigating an issue* chapter provides students with a comprehensive coverage of the key knowledge contained within Unit 2, Area of Study 3. There are also *Investigation of an issue* boxes throughout the text. These boxes scaffold and reinforce the critical thinking, analysis and communication skills that students require to succeed in the associated assessment task.

Scientific investigation is a key skill in biology. Activities and experiments included in the text introduce, reinforce and enable students to practise the key science skills. The dedicated *Scientific investigations* chapter thoroughly examines each of the key science skills and outlines how to develop, plan, conduct, analyse and communicate the results of a practical investigation task as required in Unit 1, Area of Study 3. Detailed information on how to develop and present a scientific poster according to VCAA requirements is also provided in this chapter.

Chapters 1–10 each conclude with a concept summary that pulls together all the ideas in the chapter in an easy-to-understand visual format. This summary will be invaluable to students as they try to assimilate all the concepts in the Biology course.

The third edition of *Nelson Biology VCE Units 1 & 2* provides students with the tools and knowledge to fully prepare for assessments, exams and future studies in the area. It will also give them a deeper understanding of the precious living world around them, whether or not they pursue further studies in any of the various fields of biology.



AUTHOR TEAM



Authors

Dr Sarah Jones – series editor

Sarah completed her PhD at the Walter and Eliza Hall Institute of Medical Research in Melbourne and held research positions at Harvard Medical School, Boston, and Trinity College, Dublin, before returning to Australia as a Research Fellow at Monash University. She was a medal-winning member of the Australian International Biology Olympiad Team before becoming a tutor then Acting Director of the program, designing theoretical and practical learning material and exams for Australia's highly successful Olympiad teams. Sarah is a member of and previous Project Manager for the Australasian Society for Immunology. She has authored multiple peer-reviewed scientific articles in leading journals and continues to research the causes of, and potential new treatments for, autoimmune diseases.

Pam Borger

Pam studied at the University of Melbourne, gaining a Bachelor of Science and a Diploma of Education. She went on to complete an Honours degree in genetics while undertaking work at the Murdoch Institute at the Royal Children's Hospital. Recently, Pam completed her Master's degree in School Leadership. She has taught Biology and developed curriculum for more than 30 years in various schools. Pam worked at regional level as a science project officer for the Science in Schools project, followed by a leading role in regional youth transitions and pathways. Pam is currently organising and delivering science outreach activities and leading educational projects in a number of areas. She has been actively involved in VCE Biology examinations as an assessor, exam setter and expert 'vetter' for many years.

Jacinta Duncan

Jacinta began her career as a molecular biologist investigating population genetics. After 4 years as a research scientist she completed her Diploma in Education at the University of Melbourne and has been teaching VCE Biology for 15 years. She worked for 2 years as a Lecturer in Science Education for the Masters of Teaching at the University of Melbourne, including coordinating Biology Method. She is now the Director of the Gene Technology Access Centre, a specialist science centre delivering programs for students and teachers in cell and molecular biology. Jacinta is currently completing a Masters of Education by Research. She was pivotal in introducing bioinformatics tasks into Victorian schools and designs educational resources that assist students in understanding Biology concepts.

Dr Tony Chiovitti

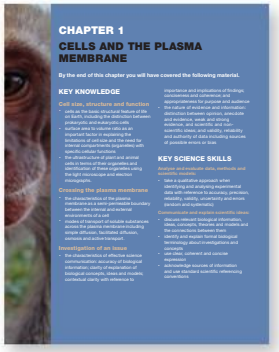
Tony Chiovitti attained a B.Sc. (Hons.) at the University of Melbourne in 1992. He completed a PhD at the School of Botany, University of Melbourne, in 1997, investigating the cell wall biochemistry of Australian red algae and algal evolution using gene sequences. He has 8 years of postdoctoral research experience in Australia and overseas with biochemical studies of bacteria and microalgae, including collaboration in the first phytoplankton genomes to be sequenced. He obtained a Dip. Ed. (2004) and joined the education team at the Gene Technology Access Centre (GTAC), Parkville, Victoria in 2007, and is now the Deputy Director. Tony has developed and delivered educational programs for students and professional learning programs for teachers on the themes of cell and molecular biology, health and disease, ecology and evolution.

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USING *NELSON BIOLOGY*

Nelson Biology VCE Units 1 & 2 has been crafted to enable you, the student, to achieve maximum understanding and success in this subject. Each page has been carefully considered to provide you with all the information you need without appearing cluttered or overwhelming. You will find it easy to navigate through each chapter and see connections between chapters through the use of linking icons. Practical work has been integrated within the text so you can see the importance of the interconnectedness between the conceptual and practical aspects of Biology.

Each chapter begins with a **Chapter opener**. This presents the key knowledge, investigation of an issue and key science skills from Unit 1 and Unit 2 of the Year 11 VCE Biology curriculum, which will be covered in the chapter. The text has been written and reviewed by experienced biology teachers, academics and researchers to ensure up-to-date scientific accuracy for learners.


CHAPTER 1

CELLS AND THE PLASMA MEMBRANE

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

KEY KNOWLEDGE

Cell size, structure and function

- cells as the basic structural feature of life on Earth; the size difference between prokaryotic and eukaryotic cells
- surface area to volume ratio as an important factor in explaining the limitations of cell size and the need for internal compartments (organelles) with specialised functions
- the ultrastructure of plant and animal cells in terms of their organelles and identification of these organelles using the light microscope and electron micrographs.

Crossing the plasma membrane

- the characteristics of the plasma membrane as a semi-permeable boundary between the internal and external environments of a cell
- the movement of molecular substances across cell plasma membranes including simple diffusion, facilitated diffusion, osmosis and active transport.

Investigation of an issue

- the 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; appropriateness and limitations of its application/relevance for purpose and audience
- the nature of evidence and information; distinction between opinion, anecdote and evidence; weak and strong evidence; and scientific and non-scientific sources of information; reliability and authority of data including sources of possible errors or bias.

KEY SCIENCE SKILLS

Analyse and evaluate data, methods and scientific models

- take a qualitative approach when identifying and describing patterns, trends and relationships in data; consider precision, reliability, validity, uncertainty and errors (random and systematic).

Communicate and explain scientific ideas

- discuss relevant biological information, ideas, concepts, theories and models and the connections between them
- identify and explain formal biological terminology about investigations and concepts
- use clear, coherent and concise expression
- acknowledge sources of information and use standard scientific referencing conventions

To optimise comprehension, a number of strategies have been applied to the preparation of our text to improve literacy and understanding. One of these is the use of shorter sentences and paragraphs. This is coupled with clear and concise explanations and real-world examples. New terms are bolded and highlighted as they are introduced, and appear in end-of-chapter glossaries as well as a consolidated end-of-book glossary.

Throughout the text, important ideas, concepts and theories are summarised in **Recall** boxes. This provides repetition and visual enhancement for improved assimilation of new ideas.

RECALL

After each Recall box in a chapter, a **Recap** box appears. Recaps are a set of questions that review and recap the recent concepts learned in the previous section.

RECAP

Mathematical relationships are presented in context. Step-by-step instructions on how to perform mathematical calculations are shown in the **Worked examples**. The logic behind each step is explained and approximate marks allocated so that you can see that you need to show your full working out. You can then practise these steps by attempting the related problems presented at the end of the worked example.

WORKED EXAMPLE

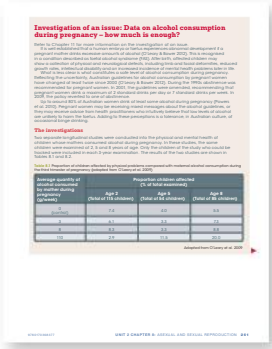
Biology is a science, so you need to be given the opportunity to explore and discover the living world through practical activities. **Activity** boxes provide the opportunity for short, hands-on tasks to clarify or reinforce a concept. The activity can be performed either individually or in groups.

ACTIVITY

The **Experiments** introduce and reinforce the key science skills. Experiments contain guided instruction on the materials, procedure, collection and analysis of results and discussion. In some cases, open-ended investigations are presented in the experiments. You have the opportunity to design and carry out your own scientific investigation, either individually or in a group. You are prompted to consider ideas for improvement and further investigation to illustrate that science is an ongoing and improving process.

EXPERIMENT

The **Risk assessment** table occurs within the experiment boxes. The table highlights the risks of the experiment and provides suggestions on how to minimise these risks – they are not comprehensive. Teachers are expected to amend this table in the case of substitutions or in the case of any additional risks. This may mean obtaining and following Material and Safety Data Sheets (MSDS) for certain chemicals. All teachers are required to follow the safety guidelines of their specific school and associated government legislation when students are in their care.


Investigation of an issue: Data on alcohol consumption during pregnancy – how much is enough?

The investigations

Margin note


CHAPTER REVIEW QUESTIONS

In this age of rapid scientific change and constant access to information, it is important that you are able to understand and evaluate the information presented in the media. In the first 10 chapters, the **Investigation of an issue** box is placed just before the chapter review section begins, and it presents a scientific text or media piece that encourages you to use evidence to evaluate the claims and conclusions presented. You can exercise your own reasoning and knowledge to construct a valid scientific argument.

Full understanding of a concept is often constructed from many pieces of information. Due to the sequential nature of a book, this information cannot always be presented together as it is best placed in other chapters. Links between concepts that occur on other pages and chapters are indicated using the **Margin notes**.

The end-of-chapter review provides a number of features.

- A concept summary, a visual and text-based summary of the most important concepts presented within the chapter, will be useful when you are revising for tests and exams.
- The chapter glossary provides definitions for all the highlighted terms introduced in the chapter.
- The chapter review questions revise understanding of concepts from the chapter, grouped under the headings Remembering, Understanding, Applying, Analysing, Evaluating, Creating and Reflecting.

Questions are ordered from lower to higher order thinking skills and also include reflection questions.

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NelsonNet is your protected portal to the premium digital resources for Nelson textbooks, located at www.nelsonnet.com.au. Once your registration is complete you will have access to a helpful suite of digital resources for each chapter to further enhance and reinforce learning.

The textbook is supplemented with the following digital resources.

- Practice unit exams and answers
- Lab notes
- Study design mappings for Unit 1 and Unit 2
- Teaching programs for Unit 1 and Unit 2
- Answers to questions from the textbook

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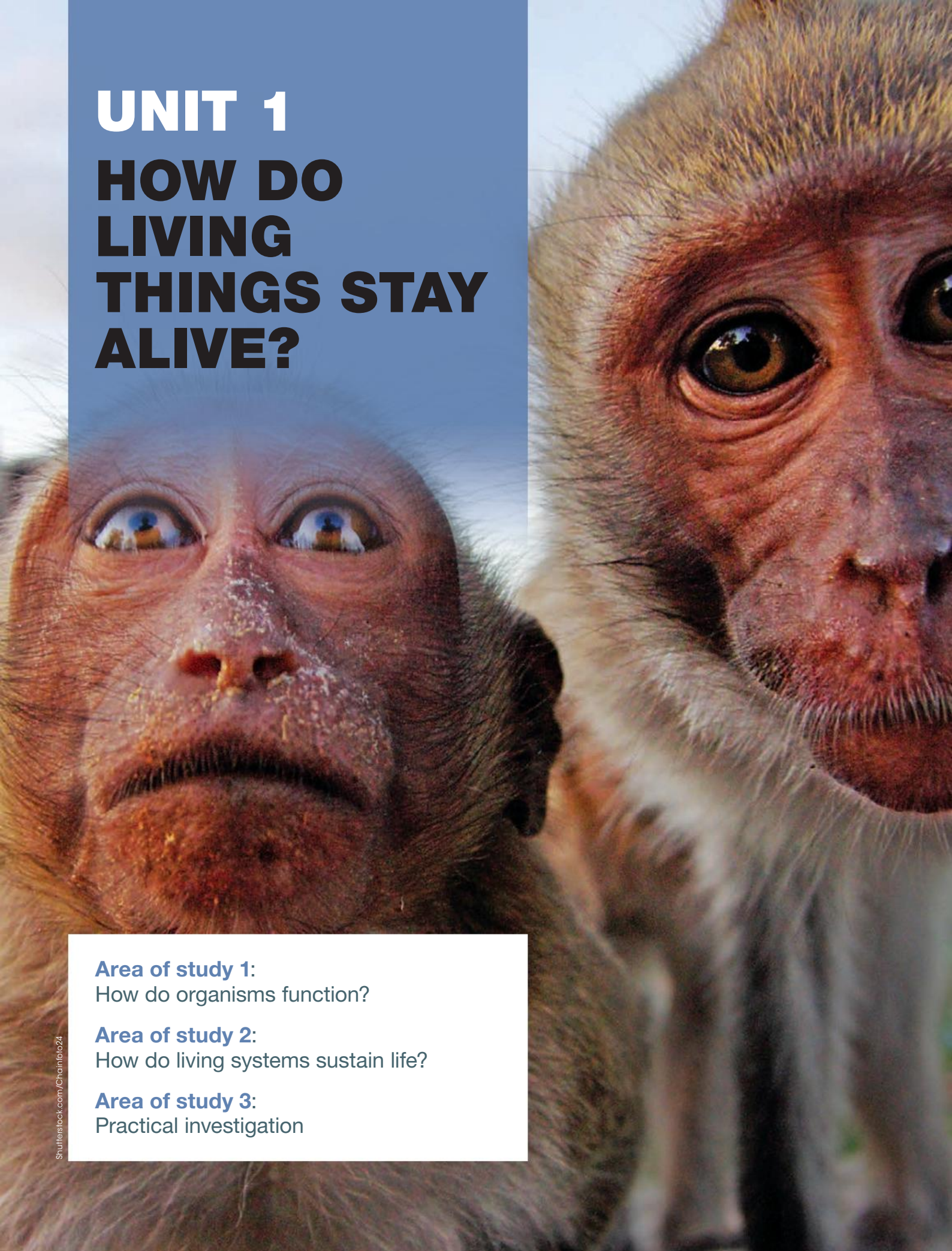
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STUDY DESIGN GRID

Unit	Area of Study	Chapters											
		1	2	3	4	5	6	7	8	9	10	11	12
1	1: How do organisms function? Students examine the structure and functioning of cells and how the plasma membrane contributes to survival by controlling the movement of substances into and out of the cell.	✓	✓	✓									
	2: How do living systems sustain life? Students examine the structural, physiological and behavioural adaptations of a range of organisms that enable them to survive in a particular habitat and to maintain a viable population size over time.				✓	✓	✓						
	3: Practical investigation Students are required to develop a question, plan a course of action to answer the question, undertake an investigation to collect the appropriate primary qualitative and/or quantitative data, organise and interpret the data and reach a conclusion in response to the question.												✓
2	1: How does reproduction maintain the continuity of life? Students consider the need for the cells of multicellular organisms to multiply for growth, repair and replacement.							✓	✓				
	2: How is inheritance explained? Students build on their understanding of the nature of genes and the use of genetic language to read and interpret patterns of inheritance and predict outcomes of genetic crosses.									✓	✓		
	3: Investigation of an issue Students apply and extend their knowledge and skills developed in Areas of Study 1 and/or 2 to investigate an issue involving reproduction and/or inheritance.											✓	

✓ All the AOS descriptions are taken directly from the Study Design.

UNIT 1
HOW DO LIVING THINGS STAY ALIVE?



Area of study 1:
How do organisms function?

Area of study 2:
How do living systems sustain life?

Area of study 3:
Practical investigation

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CHAPTER 1

CELLS AND THE PLASMA MEMBRANE

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

KEY KNOWLEDGE

Cell size, structure and function

- cells as the basic structural feature of life on Earth, including the distinction between prokaryotic and eukaryotic cells
- surface area to volume ratio as an important factor in explaining the limitations of cell size and the need for internal compartments (organelles) with specific cellular functions
- the ultrastructure of plant and animal cells in terms of their organelles and identification of these organelles using the light microscope and electron micrographs.

Crossing the plasma membrane

- the characteristics of the plasma membrane as a semi-permeable boundary between the internal and external environments of a cell
- modes of transport of soluble substances across the plasma membrane including simple diffusion, facilitated diffusion, osmosis and active transport.

Investigation of an issue

- the 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
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KEY SCIENCE SKILLS

Analyse and evaluate data, methods and scientific models:

- take a qualitative approach when identifying and analysing experimental data with reference to accuracy, precision, reliability, validity, uncertainty and errors (random and systematic)

Communicate and explain scientific ideas:

- discuss relevant biological information, ideas, concepts, theories and models and the connections between them
- identify and explain formal biological terminology about investigations and concepts
- use clear, coherent and concise expression
- acknowledge sources of information and use standard scientific referencing conventions

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Figure 1.1 ▲
These sea shells were produced by the molluscs that once lived in them.

Humans are one of 1.4 million different kinds of organisms that have been identified on Earth. This seems a large number but it probably represents only a third of all the species that exist on our planet.

Whether a bacterium, whale, fungus, tomato plant or snail, a living thing has fundamental characteristics in common with all other living things. Organisms grow and are able to replicate or reproduce themselves. They detect and respond to changes in their environment, they take in food or matter and process it in a variety of ways that involve controlled transformation of energy, and they remove the waste products of their activities.

Living things are not only made of cells but also the non-cellular products of cells: the slime on the back of a frog, the extraordinary exoskeletons of many insects, the bark of trees, the skin of grapes and the fingernails of your hand. All organisms produce substances that help them live. For example, bees produce the wax that forms their honeycombs, spiders produce the silk of their webs to trap their prey and ocean molluscs secrete the calcium carbonate material that forms a shell to protect and support them.

The cell is the basic unit of life

Over the past 150 years we have come to understand that all organisms are made up of **cells**, the basic structural and functional unit of an organism. A cell can be considered a discrete world in itself. It has many parts, each able to carry out specialised functions. It can take in simple nutrients and convert these into energy. Both oxygen and carbon dioxide can be taken in and used by some cells. A cell has the potential to reproduce itself and it even stores its own set of instructions for carrying out these activities. A cell is considered the basic unit of life because it is an easily recognised package. This is because every cell is surrounded by a **membrane**. This membrane is a boundary between the internal and external environment of the cell.

A cell's structure is highly organised and many chemical processes and reactions occur within it. A cell senses and responds to changes in its environment.

Figure 1.2 ▼
The various organisms on Earth can look very different but they are all made up of cells: (**a**) water flea, (**b**) octopus and (**c**) palm tree.



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Cells can be found in many shapes and sizes depending on where they are located in an organism and the job that they have to do. They arise from pre-existing cells. Some organisms consist of single cells, while others consist of millions upon millions of cells organised into functional groups that we know as organs or tissues.

Cells are classified into two different kinds depending on their internal structures. These two different cell types are characteristically found in different living groups. The simplest cells, called **prokaryotic** cells, are typically found in members of the Domains Bacteria and Archaea. These types of cells lack internal membrane-bound specialised structures or compartments called **organelles**. More complex cells, called **eukaryotic** cells, contain membrane-bound organelles that are suspended in fluid called the cytosol. Members of the Kingdoms Animalia, Plantae, Protista and Fungi are all composed of eukaryotic cells. Yet even these types of cells differ in the types of internal structures they possess.



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▲ **Figure 1.3** Bacterial cells take in materials from their environment such as water and nutrients. They produce wastes and in some cases products such as toxins.

The cell theory

In 1838, Matthias Schleiden saw that each individual cell within a whole plant developed as an independent unit. He thought that the obvious distinct area that we now know as the nucleus probably had something to do with the development of each cell. In 1839, Theodor Schwann used his extensive knowledge of zoology and animal tissues to theorise that 'Animals as well as plants consist of cells and cell products – and even though the cells are part of a whole organism, they have, to some extent, an individual life of their own'.

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

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

RECALL

- Living things are characterised by their ability to grow and replicate or reproduce themselves.
- The cell theory states that all living things are composed of one or more cells and all cells come from pre-existing cells.

RECAP 1.1

1 List the characteristics living things have in common.
2 'Living things are made up of cells and the products of cells.' Explain what this means.
3 Draw a timeline to show the development of the cell theory.

Seeing cells

We are indebted to the early microscopists for our knowledge of cell structure and function. Although their techniques were crude by today's standards, they paved the way for developments in understanding that they would never have dreamt of.

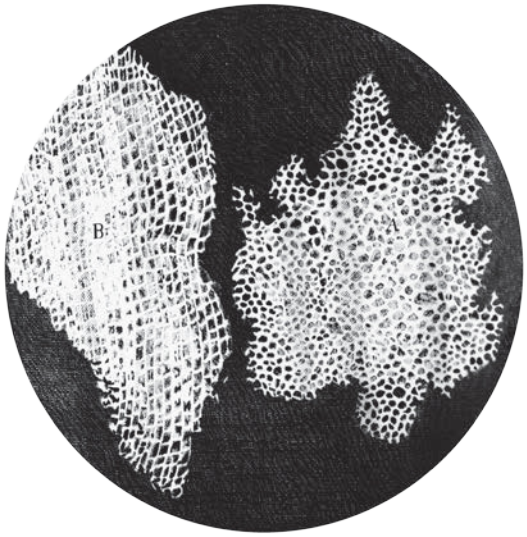
In the early 1600s, Galileo Galilei put together some glass lenses in a cylinder and found that they magnified objects. Across Europe, from Italy, then in France and England, scientists began to explore the microscopic world, the existence of which had never been suspected. By the middle of the 17th century, a curator of experiments for the Royal Society of London, Robert Hooke, used a microscope to observe thinly sliced cork from a mature tree. When you look at Figure 1.5 you might be able to see a resemblance to what Hooke described as small rooms. He used the Latin name 'cella' (small room) for these structures, not yet knowing that they were actually living components of the tree.

Anton van Leeuwenhoek used his skills in making lenses to improve microscope magnification and image clarity.



Corbis

Figure 1.4 ▲
An early compound microscope from Italy



Getty Images/Oxford Science Archive/Print Collector

Figure 1.5 ▲
Robert Hooke's drawing of cork cells

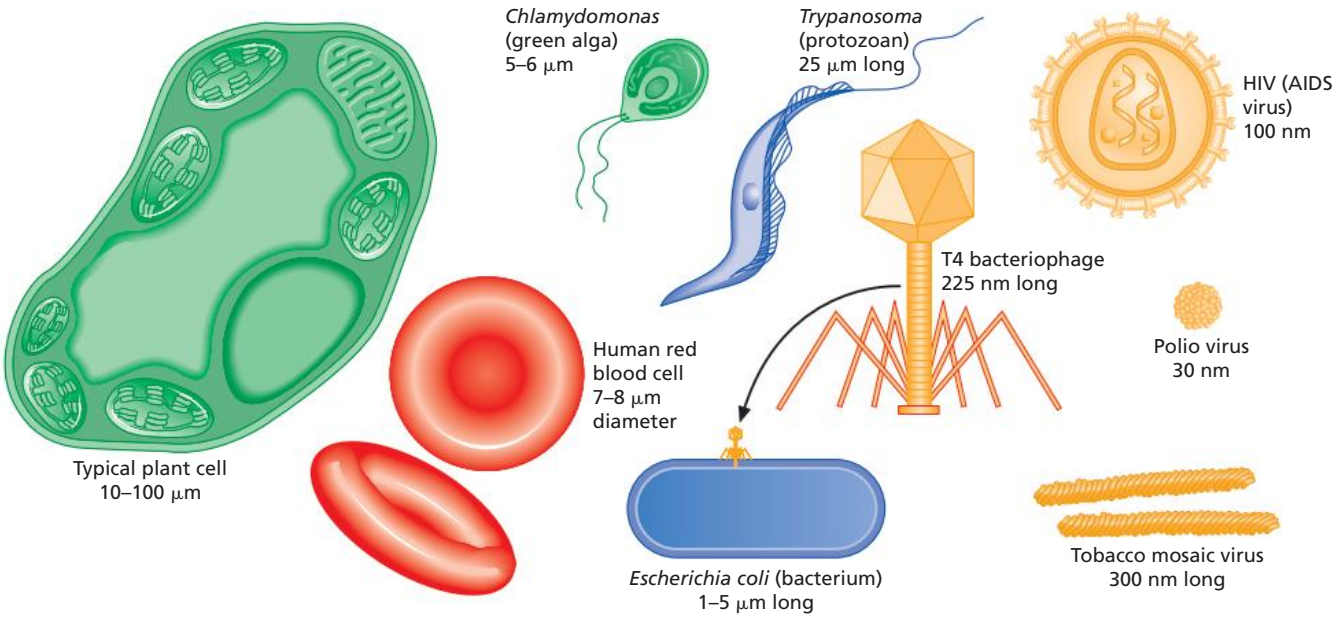
How small are cells?

Advances in biology over the last decades have pushed our view of the microscopic world to ever-decreasing sizes. Centimetres, millimetres and even micrometres or microns (μm) are often too large to measure objects. We are now in the 'nano age'. Cells are in the range of microns in size. Bacteria are around 2 μm long, while small eukaryotic cells are usually less than 10 μm. Larger cells can be up to 100 μm in size, which is one thousandth of a millimetre.

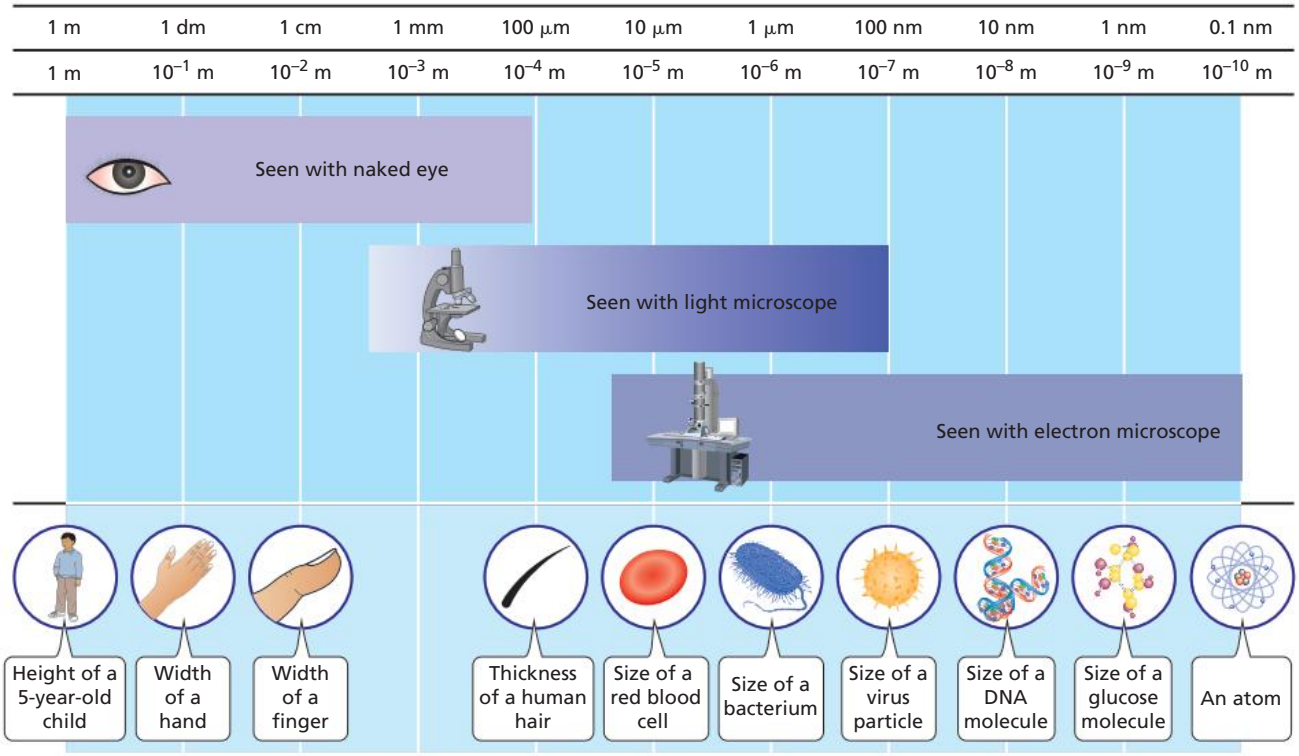
Different kinds of microscopes and microscopy

The type of microscope you use in your school laboratory is a light (or optical) microscope. This is the same type of microscope used by scientists when cells were first discovered. If you look at material with a simple light microscope, fine structures will not be visible. Light rays from a light source beneath the stage are transmitted through two glass lenses in series; the objective and ocular (eyepiece) lenses. Depending on their strength, these two lenses together provide magnifications of up to 400 times. More sophisticated technology is needed to view the smallest parts of cells.

Instructions on how to use a microscope are given in Chapter 12.



▲ **Figure 1.6**
Measurements of biological specimens (not drawn to scale)



▲ **Figure 1.7**
Resolving power of microscopes compared to what can be seen by the naked eye



Figure 1.8 ▲
A transmission electron microscope (TEM) currently used in biological research

Since the 1950s, microscopic studies have been revolutionised by the development of the electron microscope. This instrument uses an electron beam instead of light, and electromagnets instead of glass lenses. The interactions between the electrons and the object are recorded on a photographic plate, which then forms a viewable image on a screen.

The electron microscope can give clear pictures that are magnified 1 000 000 times or more. A cell with a diameter of 10 µm can be magnified up to a diameter of 5 m. Features as small as one-tenth of a nanometre (one ten-billionth of a metre) can be seen, including individual atoms.

The electron microscope shown in Figure 1.8 is called a transmission electron microscope (TEM) because the electrons pass through the specimen. In the scanning electron microscope (SEM), solid specimens are bombarded with a beam of electrons, which causes secondary electrons to be emitted from the surface layers of the specimen. The TEM is the most common form of electron microscope and has the best resolution. It can magnify up to 1 500 000 times. The SEM has poorer resolution, but gives excellent three-dimensional images of surfaces.

RECALL

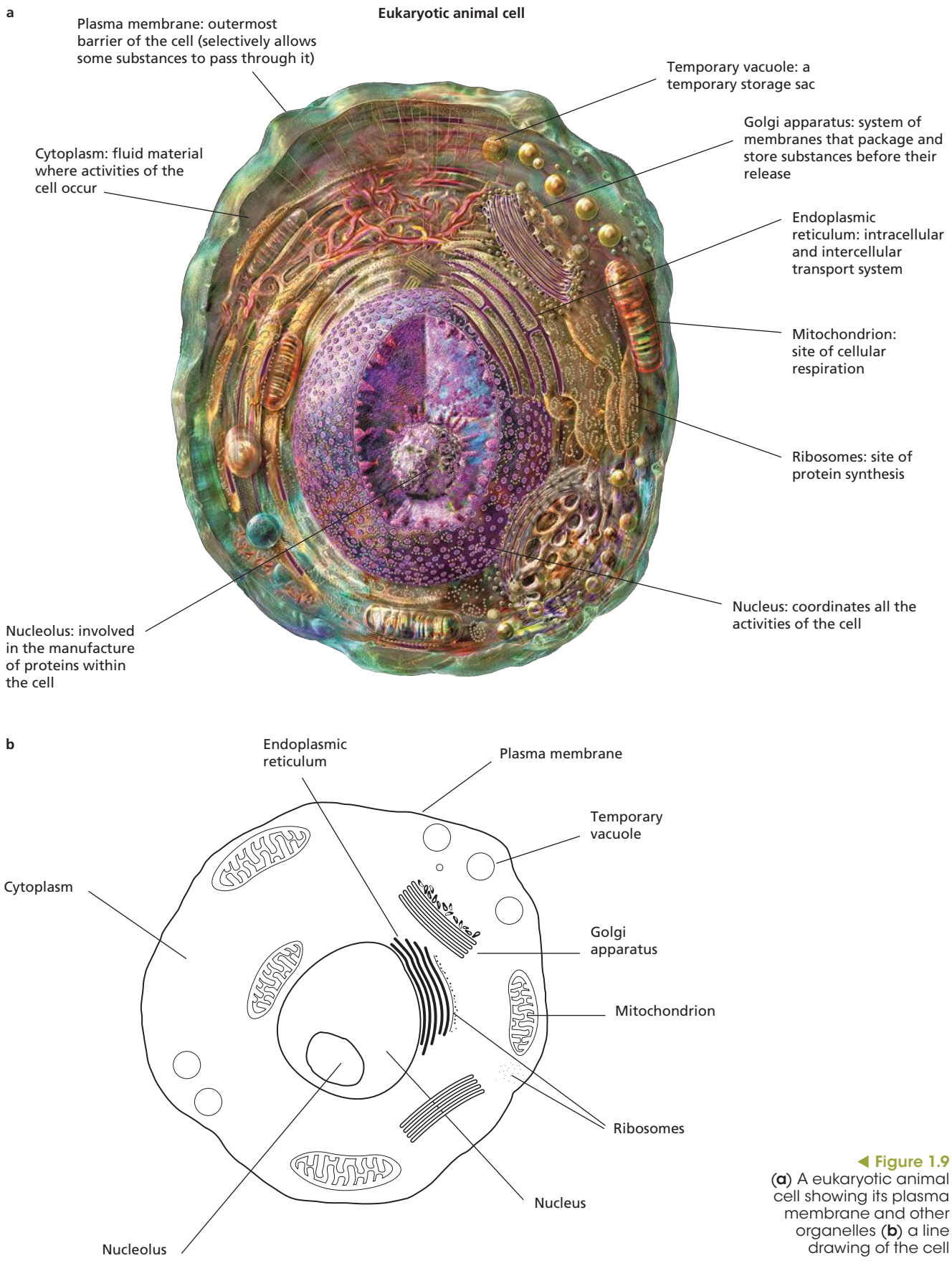
- Development of different kinds of microscopes has advanced our understanding of cell structure.
- Early microscopists opened the way for later developments and understanding of cell biology.
- Electron microscopes have allowed scientists to observe objects at nanometre sizes.

RECAP 1.2

1 Describe the contributions that Galileo Galilei and Robert Hooke made to the development of our understanding of cell structure.
2 Compare a light, TEM and SEM microscope, identifying differences between them.
3 List the resolving power range of the naked eye, a light microscope and an electron microscope.

Taking a close look within cells

The electron microscope has had a profound effect on biology. Materials that were formerly believed to have little or no structure have been shown to have an elaborate internal organisation. Eukaryotic cells contain internal compartments, which allow several activities to occur at the same time independently of each other. Special structures of different kinds described below, collectively called 'organelles', carry out specific functions within the cell, working together to ensure that all the cell's needs are met.



◀ **Figure 1.9**
(**a**) A eukaryotic animal cell showing its plasma membrane and other organelles (**b**) a line drawing of the cell

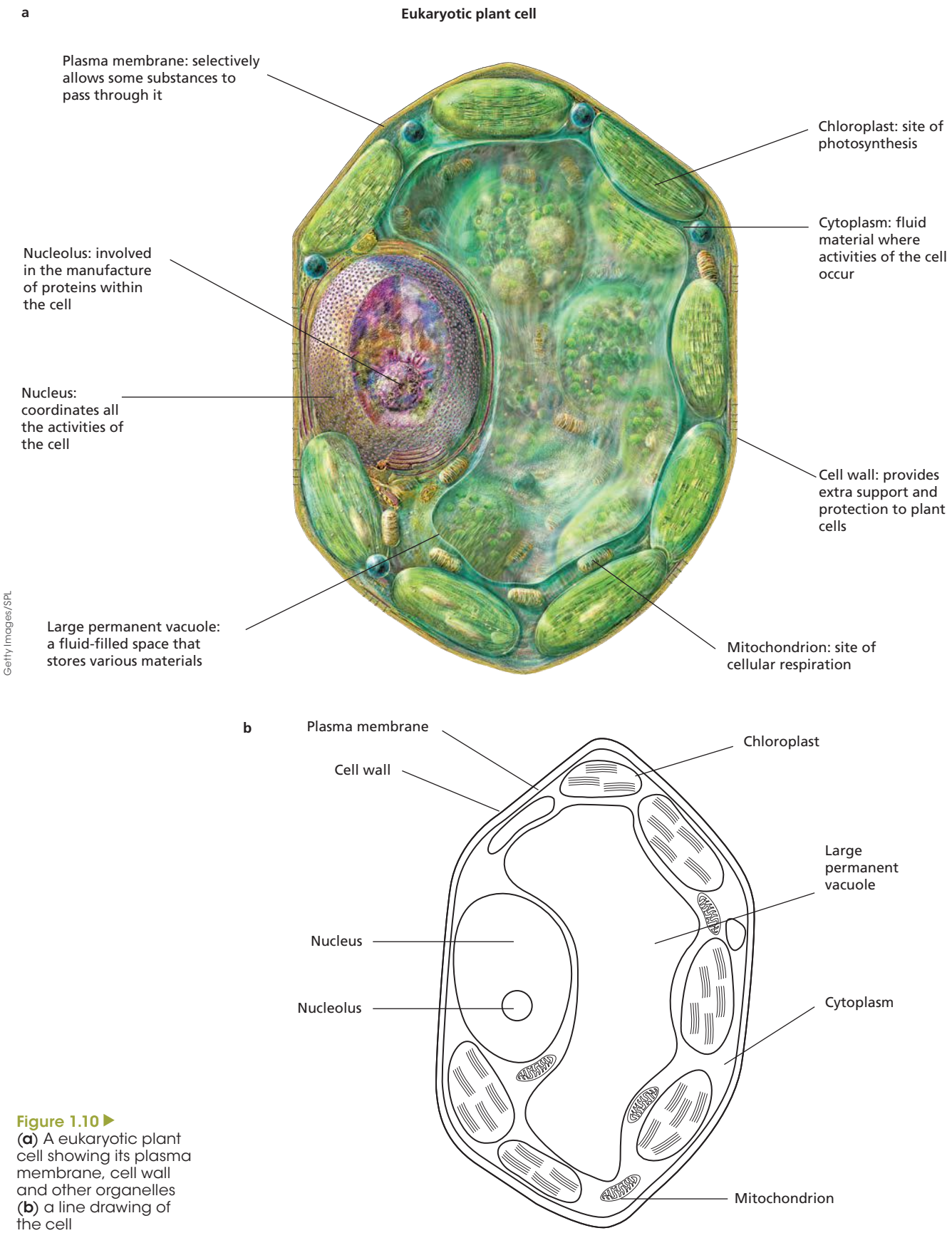


Figure 1.10 ▶
(**a**) A eukaryotic plant cell showing its plasma membrane, cell wall and other organelles (**b**) a line drawing of the cell

Keeping within boundaries: Plasma membrane

Each cell is an independent unit, separated from other cells and its environment by the **plasma membrane** (outer cell membrane), the outermost barrier of a cell. The plasma membrane is composed of lipid molecules that are interspersed with tiny protein channels. It is mainly through the protein channels that nutrients and water enter a cell and wastes are released. The structure and function of the plasma membrane are studied in detail later in this chapter.

Inside the boundary: Cytoplasm

If you observe prokaryotic cells such as bacteria using a light microscope, the granular or 'spotty' substance making up the internal bulk of the cell will be visible. This is the **cytoplasm**. The chemical reactions that enable the cell to live are carried out here. The **cytosol** is the fluid part of the cytoplasm that contains many dissolved substances. Collectively, the cytoplasm is made up of cytosol together with cell organelles.

Coordinating cell activities: Nucleus

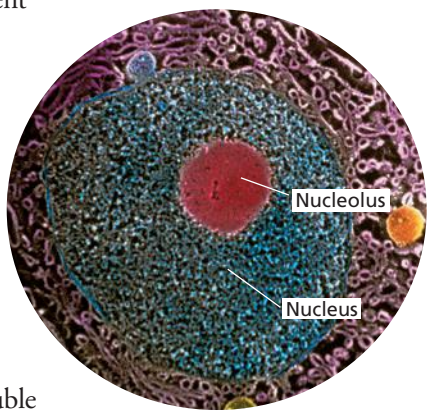
Cells carry out many and varied tasks, usually at the same time. To be an efficient system a cell needs to have some way of coordinating all of these activities. This is a main function of the **nucleus**. The nucleus is one of the most noticeable features you can observe in a eukaryotic cell. This is clearly visible using both light and electron microscopes.

DNA (deoxyribonucleic acid) is the main molecule found within the nucleus. DNA is bundled into **chromosomes** that code for the production of proteins that carry out a variety of activities within the cell. The nucleus is said to be the control centre of the cell. By coding for different proteins at different times and in different cells, the nucleus can coordinate the activities of a cell.

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

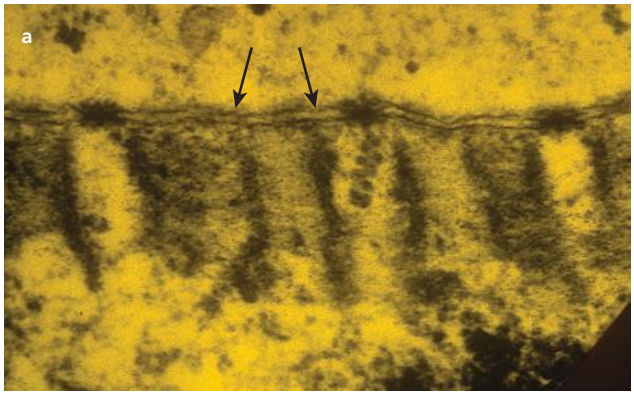
A dark-staining structure within the nucleus is called the **nucleolus**. One or more of these can be seen in cells when they are not dividing. The nucleolus is made of densely packed protein and a type of nucleic acid called ribosomal **RNA (ribonucleic acid)**. Nucleoli are the sites of **ribosome**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

▼ Figure 1.11
Transmission electron micrograph of the nucleus of a pancreas acinar cell (magnification 17 000x)

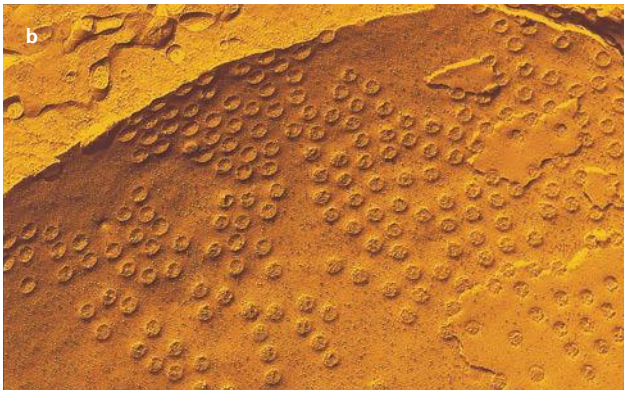


Science Photo Library/Professors P. Motta & T. Naguro

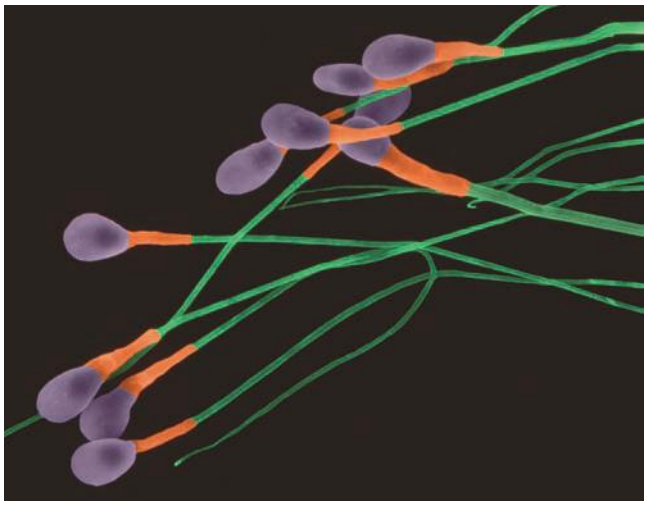
▼ Figure 1.12
Electron micrograph of a porous nuclear membrane (**a**) seen in section (arrowed) and (**b**) surface view (magnification 75 000x)



Visuals Unlimited, Inc./Dr. Kwang Jeon



Visuals Unlimited, Inc./Don W. Fawcett



Phototake Inc/Dennis Kunkel

Figure 1.13 ▲
Human sperm cells

The power supply: Mitochondria

An animal carries out many functions in order to survive: sleeping, eating, drinking and fighting, to name a few. In order to be able to perform these tasks it must have a supply of energy. For its species to survive, it must also be able to reproduce. Inside a male's reproductive system is an organ that produces the male sex cell, sperm. The task of the sperm cell is to fertilise the egg in the reproductive tract of a female. In order to get there it must swim – very fast.

If you could zoom in on an individual sperm cell you would see that at the start of the tail there are many tightly packed organelles called **mitochondria**. The rest of the tail thrashes rapidly to propel the sperm cell forward.

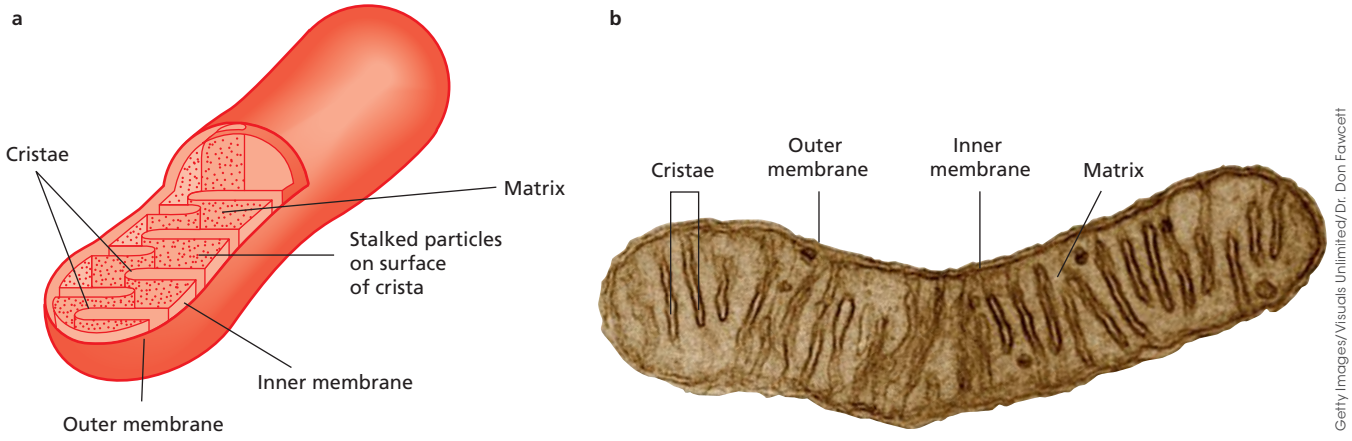
Mitochondria are found in the cytoplasm and are the sites of **cellular respiration**. Cellular respiration is a series of chemical reactions in which glucose and oxygen react to produce carbon dioxide, water and heat energy.

Cellular respiration is explained in Chapter 2.

During certain stages of these chemical reactions energy is released and this is used to form ATP molecules. ATP is an energy storage molecule that is used by the cell to power cellular processes. In the example of the sperm cell, this energy is used to move the tail and make the sperm cell move forward.

Mitochondria are small, oval-shaped organelles found scattered throughout the cytosol of a cell. Each mitochondrion consists of a smooth outer membrane and a highly folded inner membrane. The folds in the inner membrane are called **cristae** and they protrude into the inner space of the mitochondrion, a protein-rich fluid called the **mitochondrial matrix**. These cristae provide two important features to cellular respiration: the **enzymes** for cellular respiration are mainly embedded in the cristae, and the numerous folds of the cristae provide a large surface area for the chemical reactions to occur.

Figure 1.14 ▼
(**a**) A generalised sketch and (**b**) an electron micrograph of a mitochondrion in longitudinal section. The stalked particles on the surface of the cristae are the site of ATP synthesis.



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RECALL

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

RECAP 1.3

1. State where in cells you would find the cytoplasm.
2. Describe the relationship between the cytoplasm and cytosol.
3. Name the organelle that controls the functioning of eukaryotic cells. Describe the main molecule found in this organelle and explain how it controls the cell's functioning.
4. Draw a labelled diagram of a mitochondrion.

Building cell structures: Ribosomes

All cell types contain very small structures called ribosomes. You would not be able to see these clearly by using a light microscope. They are too small. You would need to make an image of a cell with an electron microscope before the ribosomes became visible.

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

How the digestive system breaks down foods such as proteins is explained in Chapter 3.

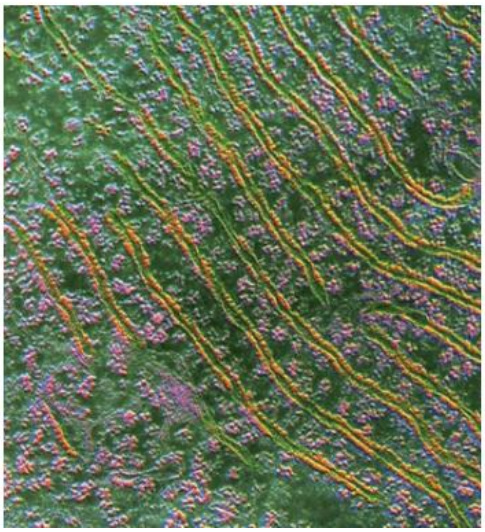
Transport within the cell: Endoplasmic reticulum

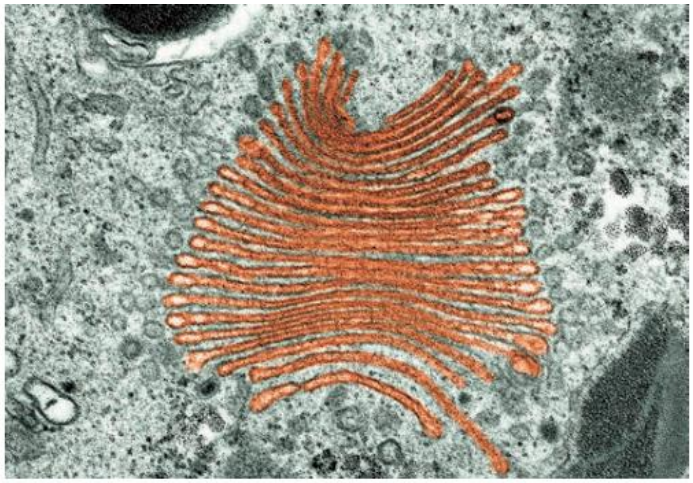
How do proteins produced in ribosomes move to other parts of the cell? Even though many substances move around the cell in the cytoplasm, other substances are able to move around the cell through the **endoplasmic reticulum (ER)**. The endoplasmic reticulum is an interconnecting system of thin membrane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

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

In certain parts of some cells, the endoplasmic reticulum has no ribosomes attached to it and is known as **smooth endoplasmic reticulum** (smooth ER). The amount and function of this smooth endoplasmic reticulum depends on the type of cell it is located in. Its main role is to transport proteins, synthesise lipids and assist in the manufacture of plasma membranes. In liver cells it also detoxifies

▼ **Figure 1.15**
Rough endoplasmic reticulum studded with ribosomes





Getty Images/Science Photo Library

Figure 1.16 ▲
Electron micrograph of the Golgi apparatus (magnification × 380000)

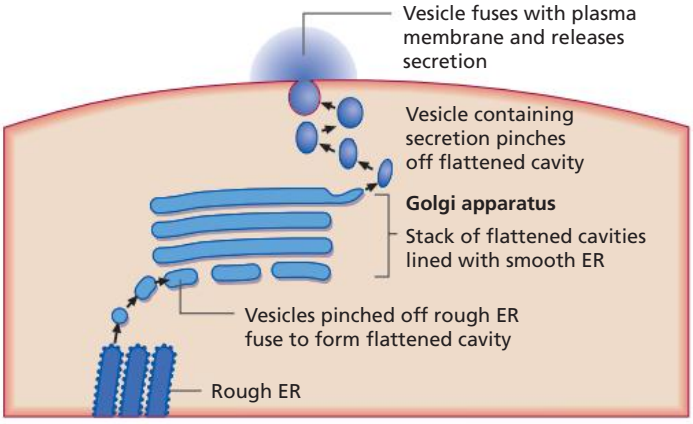


Figure 1.17 ▲
How the Golgi apparatus removes a secreted protein from a cell

drugs and in adrenal cortical cells it produces the steroid hormones. Some carbohydrates are produced on smooth endoplasmic reticulum. Smooth endoplasmic reticulum is a place for storage of calcium ions, which are necessary for muscle contraction and interactions between some membrane proteins.

Packaging and distribution: Golgi apparatus

Consider a grass-eating animal such as a kangaroo. The cells in grass have a tough cell wall. In order to be able to digest and absorb the nutrients from inside the grass cell, the cell wall must be broken down by enzymes. Cells in the digestive glands of the kangaroo produce such enzymes. Enzymes are types of proteins, and the digestive enzyme is produced initially by the ribosomes on the rough ER. It moves through the channels within the endoplasmic reticulum where it buds off into a vesicle. The vesicle moves to the **Golgi apparatus** (also known as Golgi body) and fuses to it, releasing the vesicle contents into the Golgi. Different enzymes put the final touches to the digestive enzyme, and then it is packaged and stored before being secreted from the cell to move into the intestines of the kangaroo. This is where it can begin its work digesting the cellulose in the cell wall of the grass.

The Golgi apparatus consists of a system of membranes within the cytoplasm. Parts of the Golgi apparatus membrane are able to pinch off into small vesicles. These vesicles move to the plasma membrane, where they join to the membrane and discharge their contents to the outside of the cell.

RECALL

- All cell types contain ribosomes that build up amino acids into proteins.
- Some substances are moved around the cell in the endoplasmic reticulum.
- The Golgi apparatus packages and stores substances into vesicles in preparation for their release from the cell.

RECAP 1.4

1 State the function of ribosomes. Explain why you would expect to find more ribosomes in a protein-producing cell.
2 Describe the main roles of the endoplasmic reticulum.
3 Explain the role of the Golgi apparatus in the transport of materials out of the cell.

Recycling and reuse: Lysosomes

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

Supporting cell structure: Cytoskeleton

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

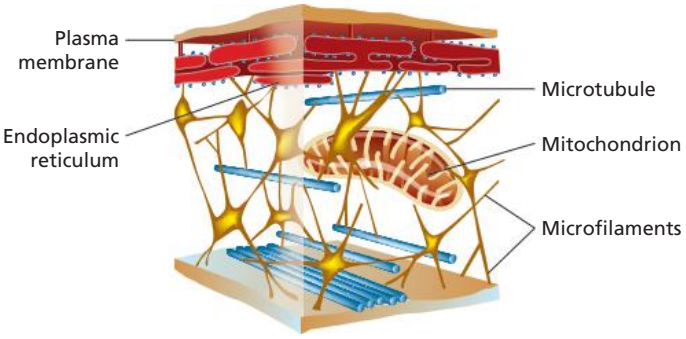
Microtubules are hollow, cylindrical tubes approximately 20 nm in diameter. They act as a scaffold to determine cell shape. They also provide a set of 'rails' for the cell organelles to travel around the cytoplasm. This allows the constant mixing and movement of the cytoplasm known as **cytoplasmic streaming**.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

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

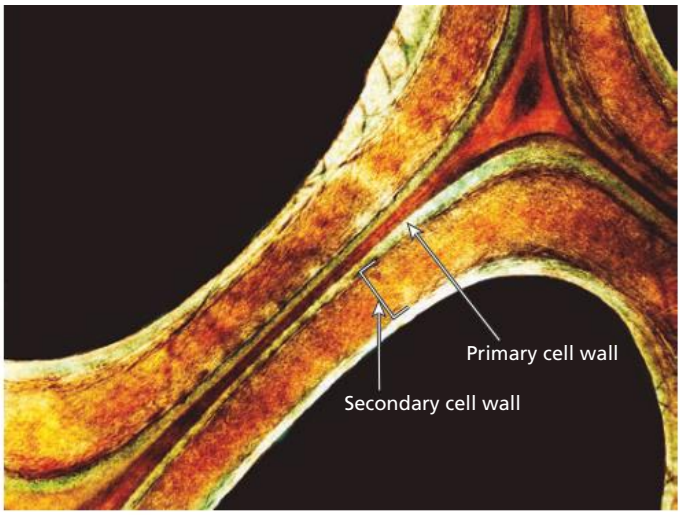
Animal cells contain two rod-like structures that are located at right angles to each other. These structures are called **centrioles**. One of the roles of centrioles is to organise and produce microtubules.

Centrioles are very prominent in animal cells that are about to divide. They replicate just before cell division begins to produce two pairs. They give rise to the **spindle fibres**, aggregates of microtubules onto which chromosomes attach. When the spindle fibres contract, the attached chromosomes can be moved around the cell.

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



◀ **Figure 1.18**
The cytoskeleton of a cell



Science Source/Biophoto Associates

Figure 1.19 ▲
A plant cell of the Canadian Yew showing the primary and secondary cell wall

Support and protection: Cell walls

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

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

Water transport in plants is discussed further in Chapter 2.

RECALL

- Lysosomes are formed by the Golgi apparatus and are responsible for splitting complex chemical compounds into simpler ones.
- The cytoskeleton provides shape to the cell.
- Microtubules and microfilaments are structures of the cytoskeleton.
- A cell wall, composed of cellulose, provides extra support and protection to some types of cells.

RECAP 1.5

1. Explain why lysosomes can be described as 'recyclers'.
2. Name the components of the cytoskeleton.
3. Describe the function of the cell wall.
4. State the groups of organisms in which cells that have cell walls are found.



Dreamstime.com/Ashley Whitworth

Figure 1.20 ▲
Snow gums

Making and storing food: Plastids

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

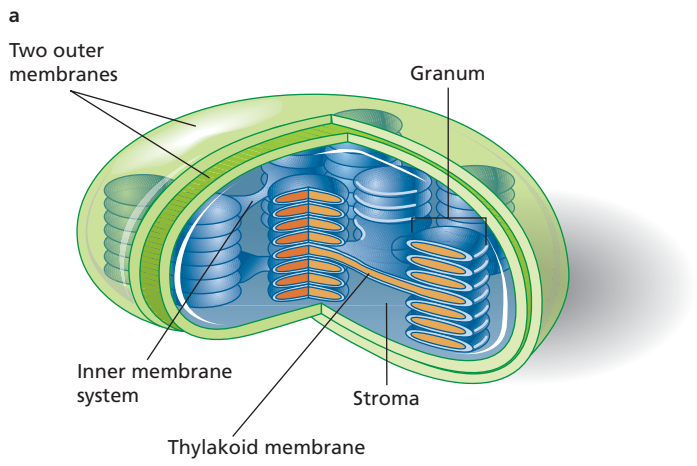
The colourful presentation of the leaves and flowers of these trees is caused by a group of organelles called **plastids**. Plastids are organelles that contain coloured pigments. The three general types of plastids are chloroplasts, chromoplasts and leucoplasts.

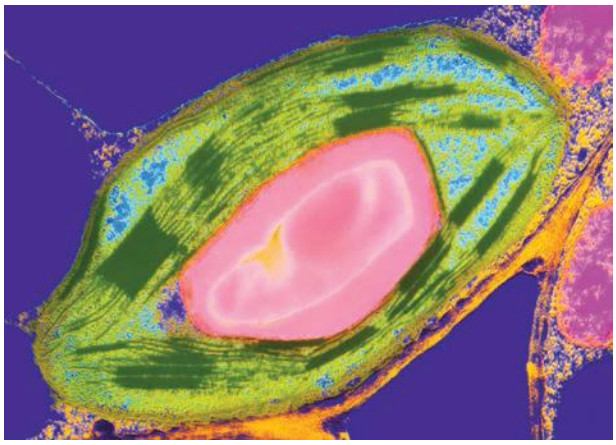
Chloroplasts

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

Photosynthesis is explained in Chapter 2.

Chlorophyll is able to absorb light energy and make it available for use in photosynthesis. Photosynthesis is a series of reactions that occur in the **stroma** and **thylakoid membrane** system of the chloroplast (see Figure 1.21). The internal thylakoid membranes of the chloroplast are folded many times to provide more surface area for chemical reactions of photosynthesis to occur. They are also associated with the enzymes necessary to speed up the chemical reactions involved.





Science Photo Library/Dr Jeremy Burgess

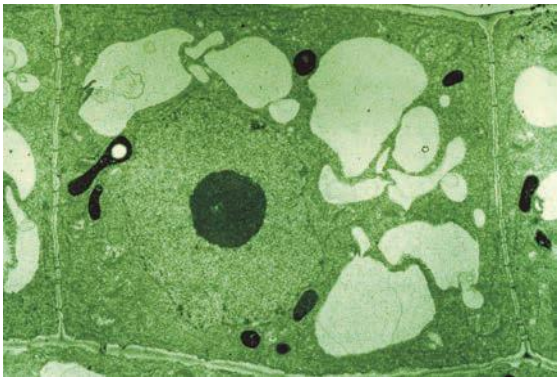
▼ **Figure 1.21** (**a**) Generalised sketch showing the grana and stroma of a chloroplast (**b**) False colour transmission electron micrograph of a chloroplast with a large starch granule (pink) (magnification 5000x).

Chromoplasts

The red Mallee gum has juvenile leaves that are red. It is the **chromoplasts** that contain coloured pigments (other than green), which give the red Mallee gum leaves their characteristic colouration. They have carotenoid but no chlorophyll pigments. They turn green as they mature and produce chlorophyll. Carotenoid results in the red-yellow colouration seen in some leaves, flowers, fruits and roots such as carrots.

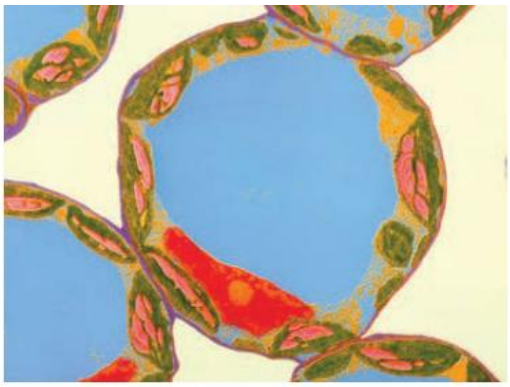
Leucoplasts

Leucoplasts do not contain any pigments; they are colourless plastids. They include **amyloplasts**, which often store starch grains (see Figure 1.22).



Visuals Unlimited/Dr David M. Phillips

◀ **Figure 1.22** Leucoplasts (the darker, smaller circles) in an onion root cell



Science Photo Library/Dr Jeremy Burgess

Figure 1.23 ▲
Plant cell showing vacuole (in blue). Notice how the cell wall is extended.

Storing fluid: Vacuoles

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

Table 1.1 Visibility of organelles using light and electron microscopes

Organelle	Visible using light microscope	Visible only using electron microscope
Plasma membrane	✓	
Cytoplasm	✓	
Nucleus	✓	
Nucleolus	✓	
Mitochondria	✓	
Ribosome		✓
Endoplasmic reticulum		✓
Golgi apparatus		✓
Lysosome		✓
Cytoskeleton		✓
Plastid	✓	
Vacuole	✓	
Cell wall	✓	

RECALL

- Chloroplasts, chromoplasts and leucoplasts are three types of plastids.
- Chloroplasts contain chlorophyll, a green pigment. They are the site for photosynthesis.
- The fluid in the vacuole serves as a storage space for sugars, minerals, proteins and water.

RECAP 1.6

1 Name three types of plastids.
2 Describe the structure of a plastid.
3 Distinguish between the pigments in chloroplasts, chromoplasts and leucoplasts.
4 Describe the effect on a cell when a vacuole fills with water.

EXPERIMENT 1.1

INVESTIGATING CELLS

Living cells have a range of different structures that enable them to meet their needs for energy production and to carry out their specialised tasks. How do prokaryotic organisms, such as bacteria, compare in their basic structure to plant and animal cells?

Aim

To compare and contrast the structure of eukaryotic and prokaryotic cells, and plant and animal cells

Materials

- light microscope
- microscope slides
- coverslips
- mini-grid
- onion
- sharp knife or single-edged razor blade
- tweezers or mounted needles
- eye dropper (optional)
- methylene blue stain with eye dropper
- paper towelling
- large beaker of water for used microscope slides and coverslips
- *Elodea* plant (or an alternative freshwater oxygenator available from the local aquarium or biological supplier)
- prepared slide of human cheek cells
- prepared slide of bacteria
- prepared slides of plant and animal tissues
- oil immersion lens
- oil immersion

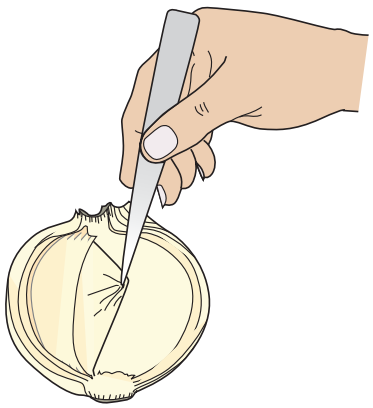
What are the risks in doing this experiment?	How can you manage these risks to stay safe?
The knife or razor blade is very sharp.	Take care when using the knife or razor blade and handle it carefully.
Cover slips break easily and can cut.	Take care with coverslips and do not push hard when placing them.
Elodea is a noxious weed.	Dispose of *Elodea* safely, away from waterways.

Procedure

Plant cell: Onion

Use the onion provided and cut off a piece. Peel a section of membrane from between the two layers of onion. The membrane will be about as thin and flexible as plastic wrap.

1. Use the knife or razor blade to carefully cut the membrane until it is about the size of a quarter of a fingernail. Try not to squash the membrane piece that you will mount onto the slide.
2. Have a microscope slide ready with a drop of cold water on it.
3. Place the small piece of membrane in the drop of water, making sure that it stays flat. You can stop it from curling or doubling over on itself by using tweezers or mounted needles.
4. Carefully place a coverslip on top of the onion membrane on an angle to push out any air bubbles. This is known as a 'wet mount'. Check that there is enough water to surround the onion membrane (which should sit well within the boundaries of the coverslip). The water will seep under the coverslip by itself.



▲ **Figure 1.24**
Preparing onion tissue

5 Focus on onion cells under low power and then switch to high power. Draw a diagram of a few cells, labelling the nucleus, cell wall and cytoplasm.

6 Put one drop of methylene blue stain next to one side of the coverslip (Figure 1.25). Use some paper towelling on the other side of the coverslip to absorb liquid and so draw the stain across under the coverslip.

7 Focus on the cells again and identify whether the stain has made any structures more visible.

8 Make a careful diagram of a few cells. Label the nucleus, cell wall and cytoplasm.

9 Use a mini-grid to measure the dimensions of an onion cell.

Plant cell: *Elodea* (or alternative)

10 Repeat steps 1 to 5 in the procedure using an *Elodea* leaf from the tip of the plant instead of the onion membrane. Float the tissue in warm water instead of cold water.

11 View the *Elodea* leaf on low and then high power. Watch it for a few minutes. What do you see happening to the cell contents? What does this suggest?

12 Make a careful diagram of one cell. Label the cell wall, nucleus, chloroplasts and cytoplasm.

13 Stain the *Elodea* cell using methylene blue by following the instructions in step 6 above. What differences do you see occurring within the *Elodea* cell? What does this suggest?

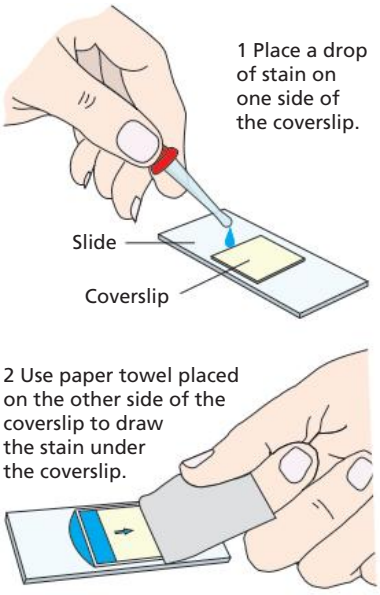


Figure 1.25 ▲
Staining a slide

Animal cell

14 Examine the prepared slide of a cheek cell under low power then high power. Make a careful diagram of one of the cells. Label the plasma membrane, nucleus, cytoplasm and any other structures that you can identify.

15 Your teacher may have prepared other animal and plant tissue slides for you. Take a look at each slide using the light microscope and see if there are any different cell structures that you can identify.

Prokaryotic cell

16 Place a prepared slide of bacterial cells onto your microscope stage.

17 An oil immersion objective lens may be used to give a higher magnification (useful for observing bacteria). A drop of oil is placed on the coverslip above the specimen and the oil immersion objective lens is centred over the oil. Only use the fine adjustment for focusing.

18 Draw a bacterial cell.

Results

1 Draw labelled diagrams of onion cells, an *Elodea* cell and a bacterial cell. Include the magnification used and size of the cell (in micrometres, μm).

2 Describe the similarities and differences between the three types of cells.

Discussion

1 Describe what effect adding the methylene blue stain had on your ability to see different parts of the onion cell.

2 List what sorts of substances would need to be able to pass through the walls of onion cells.

3 Describe what you observed happening to the chloroplasts inside the *Elodea* cell. Name this process and explain why it is happening.

4 Note any differences you noticed in the *Elodea* cell once the cell had been stained with methylene blue. Account for these differences.

5 Compare the size of a bacterial cell to the plant and animal cells you have seen so far.

6 Outline what cell detail you can see inside the bacterial cells.

7 State two limitations of using a light microscope.

8 From your observations, suggest two differences between prokaryotic and eukaryotic cells.

9 Describe how the prepared slides that you used in this activity compare to the ones that you had to prepare using fresh materials. Explain whether one was better to use than the other.

10 Describe how the oil immersion technique assisted you in seeing the internal structure of the cell.

Size and shape of cells

There are many different cell types in your body, each carrying out a specialised function. Yet **unicellular** organisms survive successfully as an independent single cell. No matter where they are from, almost all cells are very small. Why are there no large unicellular organisms? Why is it that cells divide rather than continue to increase in size? There must be an advantage for **multicellular** organisms to consist of many, smaller, specialised cells. The main reason for this is that it improves the ability of a cell to obtain its nutrients and remove its waste products.

Surface-area-to-volume ratio

An important concept related to exchange across membranes is the **surface-area-to-volume (SA : volume) ratio**. This ratio may be expressed as a single number (e.g. 3), or a ratio (e.g. 3:1). It represents an important relationship between the area of the membrane surrounding a cell and the volume of its cytoplasm.

The uptake of materials from the external environment into a cell occurs via its plasma membrane. These materials are then used to fuel the chemical reactions that occur throughout the volume of the cytoplasm. For a cell to be able to supply the cytoplasm with its metabolic requirements and remove wastes, it needs a large surface area in relation to its volume. That is, it needs a large surface-area-to-volume ratio, where the surface area is the area of membrane around the cell and the volume is the amount of cytoplasm.

As a cell grows larger, both its surface area and volume increase, but its volume grows faster than its surface area. This is shown in Table 1.2. Cell A has a volume of 0.52 cm^3 and a surface area of 3.14 cm^2 to service it. This is a surface-area-to-volume ratio of 6:1. Cell C, however, has a volume of 14.14 cm^3 and a surface area of 28.28 cm^2 to service it, a surface-area-to-volume ratio of only 2:1.

Table 1.2 Surface-area-to-volume ratios of three hypothetical cells

	Cell A	Cell B	Cell C
Diameter (cm)	1.0	2.0	3.0
Surface area (cm^2)	3.14	12.57	28.28
Volume (cm^3)	0.52	4.19	14.14
SA : volume ratio	6:1	3:1	2:1

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

How big can cells grow?

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

Such cells have special ways to offset the low surface-area-to-volume ratio that comes from their large size. In giant algal cells, an inert vacuole fills the majority of the cell. This pushes the metabolically active cytoplasm towards the edge of the cell, just beneath the plasma membrane. This has two benefits. It means that the distance materials need

to diffuse when moving into or out of the cell is much less. It also has the effect of reducing the active volume of the cytoplasm and so reducing the amount of exchange that must occur across the membrane.

Shape of cells

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

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

Figure 1.26 ▼
Scanning electron micrograph of root hairs in oregano, *Origanum vulgare*. They greatly increase the surface area for absorption of water.



Getty Images/Science Photo Library/Andrew Syred

Cells often have specific features that ensure they have the highest surface-area-to-volume ratio possible. Long, thin or flat cells have relatively more membrane for a certain volume compared with spherical cells. A good example is seen in the root hairs that cover the root tips of most plants. The long, thin extensions of the single cells that form root hairs are able to significantly increase the surface area over which water and mineral salts can be absorbed (Figure 1.26).

WORKED EXAMPLE 1.1

Calculate the surface-area-to-volume ratio of a cube 1 cm × 1 cm × 1 cm. (3 marks)

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

Try these yourself

1 Calculate the surface-area-to-volume ratio of a cube 2 cm × 2 cm × 2 cm. (3 marks)
2 Calculate the surface-area-to-volume ratio of a cube 3 cm × 3 cm × 3 cm. (3 marks)

Compartmentalisation

To compensate for increasing cell size and decreasing surface-area-to-volume ratio, eukaryotic cells have become compartmentalised. Organelles are surrounded by membranes. The presence of these membranes results in a greater surface area, allowing for more cellular functions. Together, the total area of a cell's internal membranes far exceeds that of its plasma membrane.

ACTIVITY 1.1

CAN YOU MAKE SQUARE SOAP BUBBLES?

Aim

To explore shape and surface area

You will need

- 250 mL beaker (or large glass)
- two 30 cm pipe cleaners
- liquid dishwashing detergent

What to do

1. Place approximately 200 mL of cold water into the beaker.
2. Add about 10 mL of detergent, being careful not to let it froth. If froth does appear, scrape it off.
3. Bend each pipe cleaner to form a square, one with sides 3 × 3 cm, the other 5 × 5 cm.
4. Dip the pipe cleaners into the soapy mixture and gently blow to form bubbles. Observe the shape changes that occur as the bubble forms and floats away.
5. If you can get bubbles to land on a surface, measure their diameter. Find their radius and then calculate their surface area, volume and surface-area-to-volume ratio.

What did you discover?

1. Were you able to blow square bubbles?
2. Explain your observations in terms of surface-area-to-volume ratio.

RECALL

- Cells with a larger surface-area-to-volume ratio can obtain nutrients and remove wastes more efficiently.
- The shape of a cell can significantly change its surface-area-to-volume ratio.
- Membrane-bound organelles increase a cell's surface area, allowing for more cellular functions.

RECAP 1.7

1. Explain why individual cells tend to be very small.
2. Explain how the shape of a cell affects its surface-area-to-volume ratio.
3. Describe advantages in having membrane-bound organelles in a cell.

The plasma membrane: The boundary of cells

How do cells obtain their requirements, rid themselves of wastes and communicate? The plasma membrane plays a vital role in the life of cells. Both the physical and chemical properties of the plasma membrane enable it to control the exchange of materials and messages. Many factors both within the cells and in their environment affect this sensitive balance.

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

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

Structure of the plasma membrane

The ability of the plasma membrane to keep the concentration of substances inside cells fairly constant and very different from the external environment depends on its structure. The fluid mosaic model describes membranes as a double layer of lipids, a lipid **bilayer**, with the ability to flow and change shape, like a two-dimensional fluid. Specialised protein molecules are embedded in the lipid in various patterns like a mosaic. Some of these proteins can move laterally, and others are fixed in position. Both proteins and phospholipids help to control the exchange of materials between the external and internal environments.

Phospholipid bilayer

The lipid bilayer is composed of subunits called phospholipids. Each phospholipid can be represented by a head and two tails (Figure 1.27). A phosphate group on the head makes this end **hydrophilic** (able to absorb water or dissolve in water) and the fatty acid tails are **hydrophobic** (water avoiding or unable to dissolve in water). This means that while the heads are attracted to water, the tails are repelled. When these molecules spontaneously form a bilayer, the fatty acid tails turn inwards, away from the watery environment and cytoplasm, and towards each other (Figure 1.27), rather like oil forming a film on the surface of water.

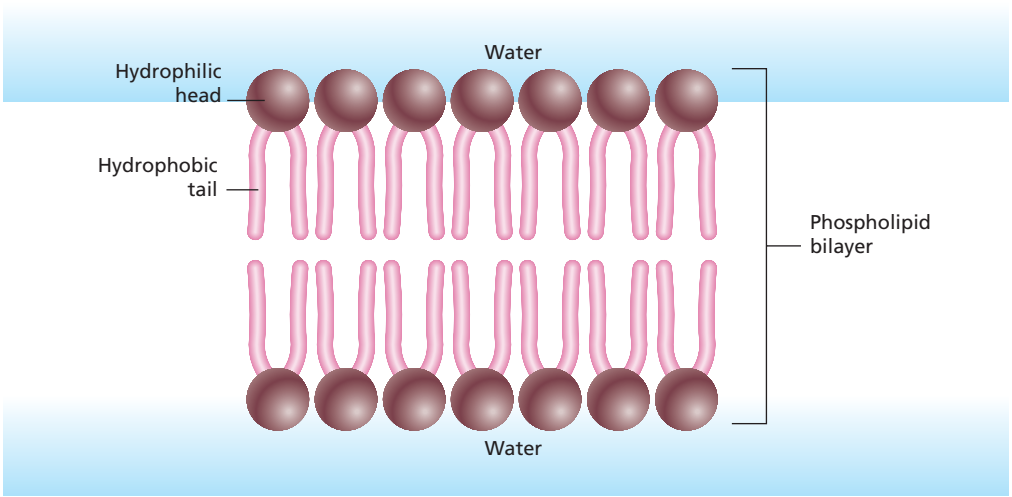
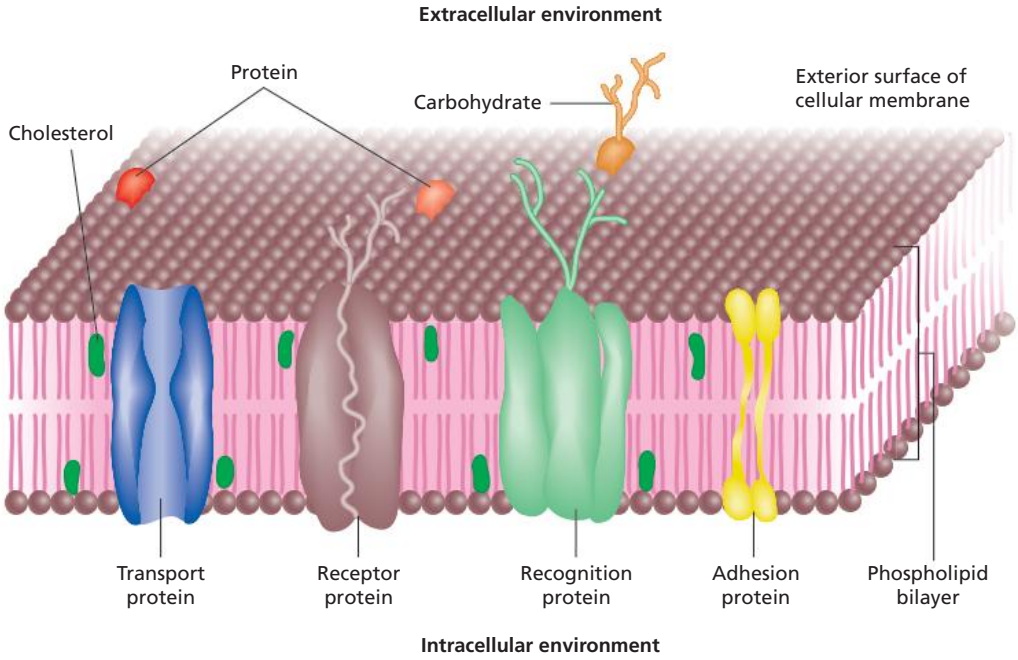


Figure 1.27 ▶ Representation of the way phospholipids form a bilayer in membranes

Membrane proteins

A range of different proteins are embedded in the phospholipid bilayer, with many penetrating from one side to the other (Figure 1.28). These proteins have evolved to enable cell–cell interaction and communication, and the exchange of substances with the external environment. For example, in multicellular organisms, **adhesion proteins** link cells together to maintain both the three-dimensional structure and the normal functioning of tissues.



◀ **Figure 1.28**
A view of part of the plasma membrane showing embedded proteins

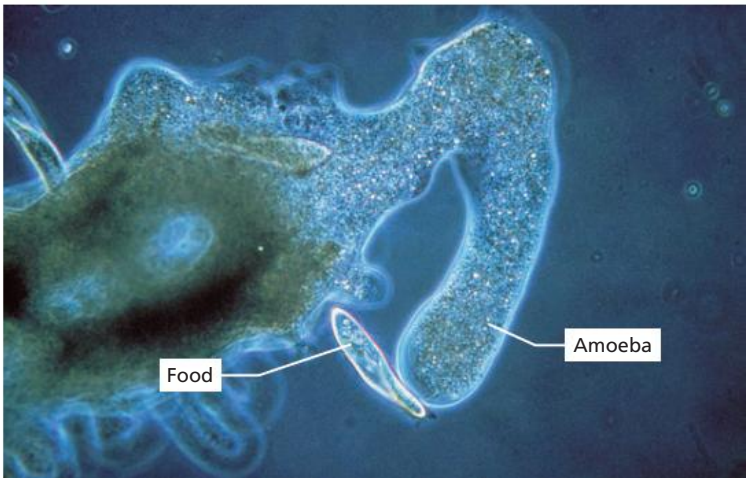
Transport proteins act as passageways that allow specific substances to move across the membrane. Membrane proteins are also involved in cellular communication. **Receptor proteins** bind hormones and other substances that cause changes to the cell's activities. Different types of cells have different receptor proteins, enabling them to respond to only certain signals and so carry out specific functions.

Membrane **recognition proteins** act as markers, called antigens, which allow the immune system to distinguish between the body's own 'self' cells, and foreign invaders ('non-self' cells).

The immune system is discussed in more detail in Unit 3 Biology.

An *Amoeba* is a unicellular freshwater organism, meaning the whole organism consists of a single cell. It is continuously interacting with its pond environment via its plasma membrane. When feeding, an *Amoeba* can sense food particles, ignoring silt and other indigestible material. As a protective boundary, its membrane allows the entrance of some molecules such as oxygen, but excludes others, some of which could damage the cell's contents. The plasma membrane is a very flexible structure, flowing like a liquid when the *Amoeba* moves or engulfs food (Figure 1.29).

▼ **Figure 1.29**
An *Amoeba* engulfing food demonstrates the flexibility of the plasma membrane.



Getty Images/Science Photo Library

Multicellular organisms, whether they are plants or animals, are made up of many cells, each surrounded by a plasma membrane. These cells also exchange substances with their external environment, which for most cells is the **extracellular fluid**. Extracellular

fluid bathes the outside of the plasma membrane, providing the liquid medium through which nutrients are supplied and wastes are removed. Each of the cells in tissues communicates via the plasma membrane with many other types of cells. This communication can cause cells to grow or become specialised or die.

The internal and external environment of cells

The internal environments of organisms are distinct and very different from their external environments. For example, almost 99% of the mass of an average human body is made up of only six elements: oxygen, carbon, hydrogen, nitrogen, calcium and phosphorus. Table 1.3 shows that the proportions of these elements are very different in the human body compared with the external environment in the earth, sea water and atmosphere.

Table 1.3 Comparison of the proportion of different elements in the human body, earth, sea water and atmosphere

Element	Symbol	Percentage in human body	Percentage in earth	Percentage in sea water	Percentage in atmosphere
Carbon	C	18	0.03	0.0028	0.039455
Oxygen	O	65	47	86	21
Hydrogen	H	10	0.14	11	0.000055
Nitrogen	N	3	trace	negligible	78
Calcium	Ca	1.5	3.6	0.04	negligible
Phosphorus	P	1.1	0.07	negligible	negligible

Unicellular organisms often live in dynamic environments, such as freshwater ponds, where conditions may change quickly. An *Amoeba* living in a freshwater pond could experience a significant increase in salinity if run-off from the land carries minerals into its pond environment. An organism living in brackish (slightly salty) water could have the opposite problem after heavy rain. Unicellular organisms must control the movement of substances across their plasma membrane to cope with rapid changes like these.

The cells in multicellular organisms are more protected from the swings of environmental change because they are surrounded by extracellular fluid. In humans, the contents of this liquid are kept fairly constant by the workings of various organs such as the lungs, kidneys and liver. Nevertheless, the internal cellular environment has very different concentrations of some substances compared with the extracellular environment (Table 1.4).

Table 1.4 Comparison of the concentration of various ions inside and outside the cell

Type of ion	Extracellular concentration (mmol/L)	Intracellular concentration (mmol/L)
Sodium	145	15
Potassium	4.5	120
Chloride	116	20
Calcium	1.2	10

Table 1.4 shows that the level of potassium ions is more than 26 times greater inside a cell compared with extracellular fluid. Other ions are significantly more concentrated outside the cell. The plasma membrane is responsible for maintaining this concentration difference. It can do this because it is selectively permeable, allowing some substances through the membrane, but not others.

RECALL

- The plasma membrane forms a barrier between the internal and external environments of cells.
- The plasma membrane regulates the internal environment by allowing some molecules but not others to pass across it.

RECAP 1.8

1. Describe the differences between the cell wall and plasma membrane in terms of movement of substances into and out of cells.
2. List the components of the plasma membrane.
3. Explain why unicellular organisms are more likely to experience bigger changes in their external environment compared with cells in multicellular organisms.

Passive movement across membranes

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

Diffusion

Why does a spoonful of sugar dissolve rapidly in a cup of tea, especially when it is stirred? Why can you smell gas escaping from a gas stovetop? Part of the reason is that the particles of sugar and gas are constantly moving.

If you were to drop a crystal of potassium permanganate ($KMnO_4$) into a beaker of water, and you did not stir or move the beaker, what would happen? You will find that, over time, the purple colour of the permanganate spreads through the water until eventually it is evenly distributed. As the crystal dissolves, the potassium and the permanganate particles separate from the crystal and move through the water (Figure 1.30 on page 28).

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

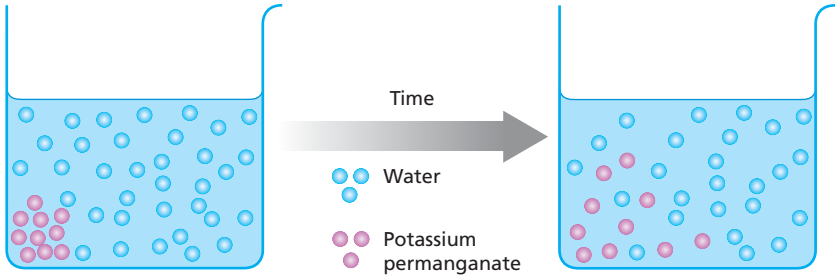


Figure 1.30 ▶
Diffusion of potassium permanganate in water over a period of time

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

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

ACTIVITY 1.2

OBSERVING DIFFUSION

Aim

To explore the movement of particles within a liquid

You will need

- a glass jar or tall beaker
- warm water
- tea bag
- stirring rod

What to do

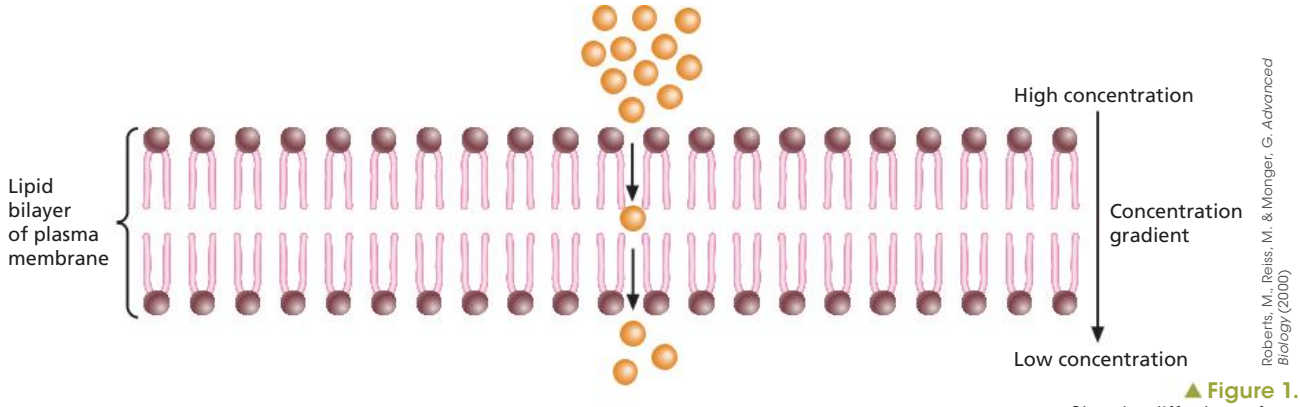
1. Fill the beaker with warm water.
2. Tie a tea bag to the stirring rod and place the rod across the top of the beaker. Place the tea bag so that it enters the water with minimal disturbance.
3. Record the changes you observe in the water over the next 10 minutes.

What did you discover?

1. Describe the change in colour of the water over the 10 minutes.
2. Explain your observations, ensuring you use the term 'concentration gradient'.
3. Predict what difference you would observe with hot water rather than warm water. If you have time, test this prediction.

Diffusion across membranes

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

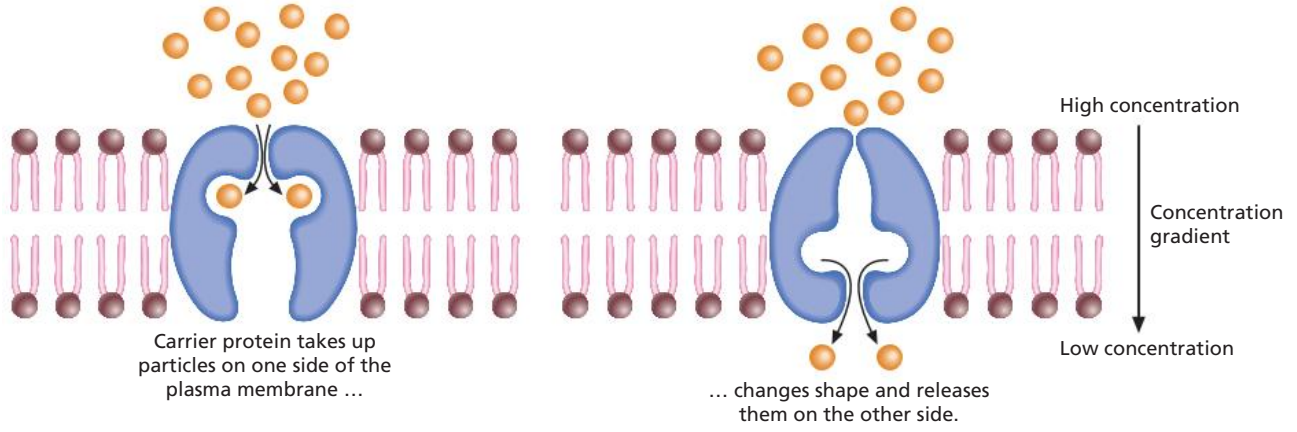


▲ **Figure 1.31** Simple diffusion of small molecules through the plasma membrane is dependent on the concentration gradient.

Facilitated diffusion

Charged particles (such as sodium and chloride ions) and relatively large molecules (such as glucose and amino acids) do not pass through the phospholipid bilayer readily. There must be some way to help them enter the cell. In the plasma membrane, certain proteins assist such particles to diffuse into the cell. This process is called **facilitated diffusion**.

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



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

Channel proteins form narrow passageways through which small ions can diffuse rapidly from a high ion concentration to a lower ion concentration (Figure 1.33 on page 30). Only ions of a specific size and shape can pass through a particular channel protein.

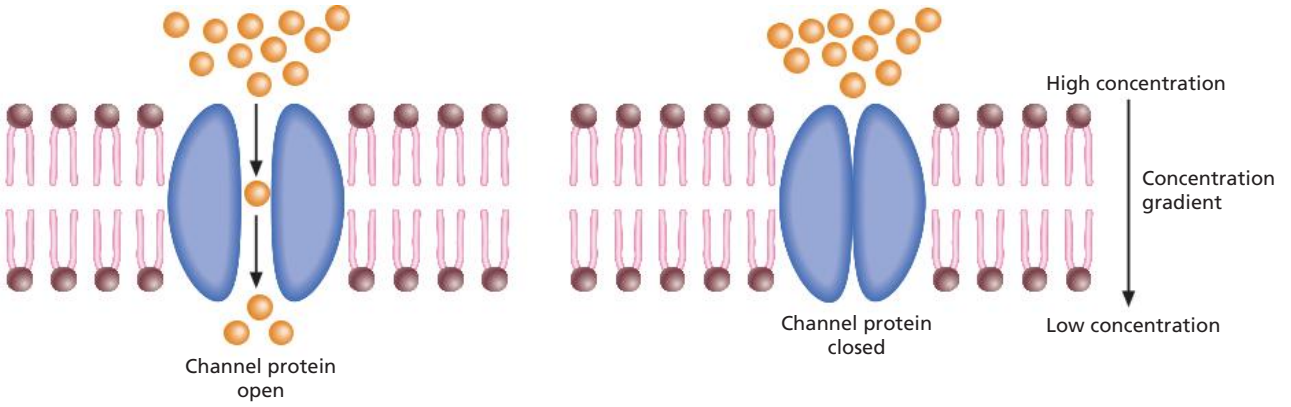


Figure 1.33 ▲
Facilitated diffusion through a channel protein in the plasma membrane of a cell. Movement is always down the concentration gradient.

RECALL

- Movement of particles down a concentration gradient, from where they are in high concentration to where they are in low concentration, is passive and does not require energy.
- The greater the concentration gradient of a substance across a membrane, the faster it will diffuse.
- Carrier proteins and channel proteins assist particles to diffuse into a cell. This process is called facilitated diffusion.

RECAP 1.9

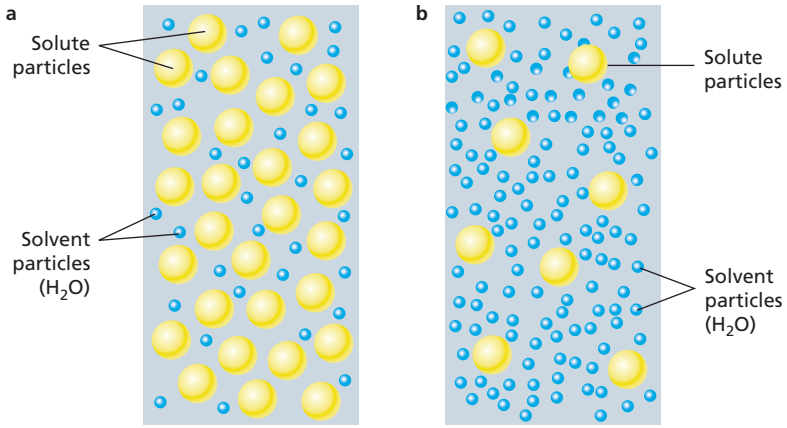
1 Define diffusion.
2 List two factors that increase the rate of diffusion.
3 Explain how carrier proteins and channel proteins assist in facilitated diffusion.

Osmosis: A special type of diffusion

When injured wildlife are received by wildlife recovery staff, they check to see if the animal is dehydrated by pinching the skin and seeing how quickly it returns to its usual position. The skin will stay bunched for longer in a dehydrated animal. A lack of water in cells and extracellular fluid means that the tissues are slack and do not keep their firmness. The equivalent in plants is **wilting** but it is usually more obvious. If the weather is extremely hot or we fail to water pot plants, they may droop because of lack of water in their cells.

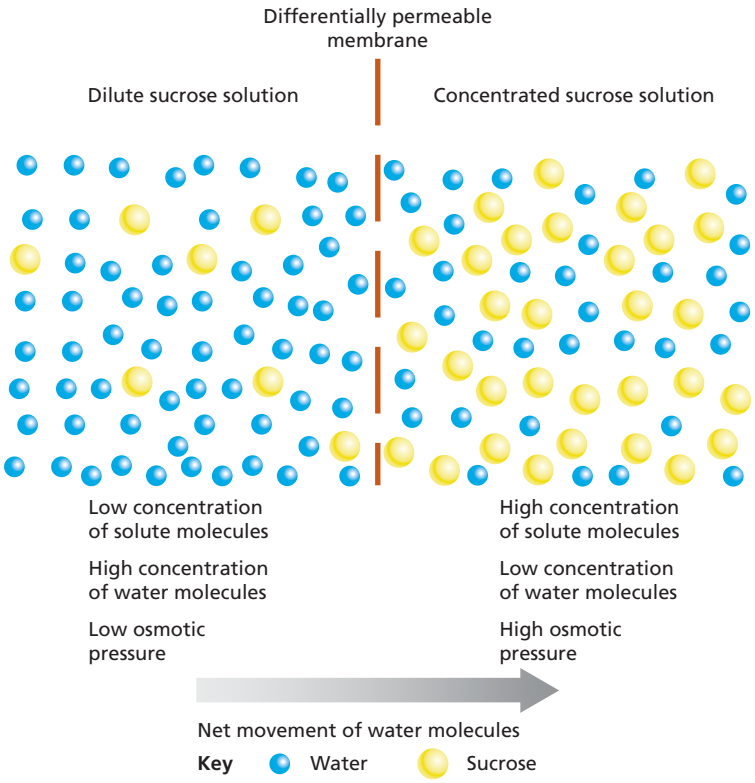
Without water, no life can survive, although some organisms can survive with less water for longer than others. Water is the medium in which biochemical processes take place. Water also transports materials in **solution**, helps keep cells in shape and forms the fluid that bathes tissues. Water is described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

Plasma membranes are selectively (differentially) permeable, meaning that water molecules pass through them easily but solutes do not. If the concentration of water molecules inside a cell is lower than the concentration outside, more water will diffuse



◀ **Figure 1.34**
Making solutions: (**a**) a concentrated solution and (**b**) a dilute solution.

into the cell than leave the cell until a balance or equilibrium is reached (net movement of water is into the cell). This process is called **osmosis**. By definition, osmosis is the diffusion of water across a selectively permeable membrane from an area of high water concentration (low solute) to an area of low water concentration (high solute). Osmosis is a special type of diffusion. Similar to diffusion, osmosis requires no input of energy as water is moving down its concentration gradient (Figure 1.35).



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

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

Osmosis in animals

The cells of unicellular eukaryotes and multicellular organisms, such as animals, are surrounded only by a plasma membrane. Hypertonic solutions, such as fresh water, pose a special problem for these organisms. Water moving into their cells by osmosis could cause the fluid plasma membrane to swell and eventually burst, killing the organism. Unicellular organisms such as *Amoeba* that live in fresh water have important regulatory mechanisms to combat these problems. They are able to remove excess water by forming pools of water in cytoplasmic organelles called **contractile vacuoles** (Figure 1.36). When these vacuoles stretch to a certain point, they contract and expel the water.

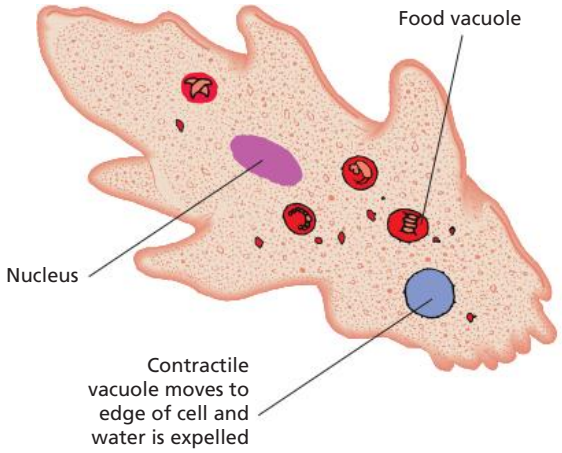


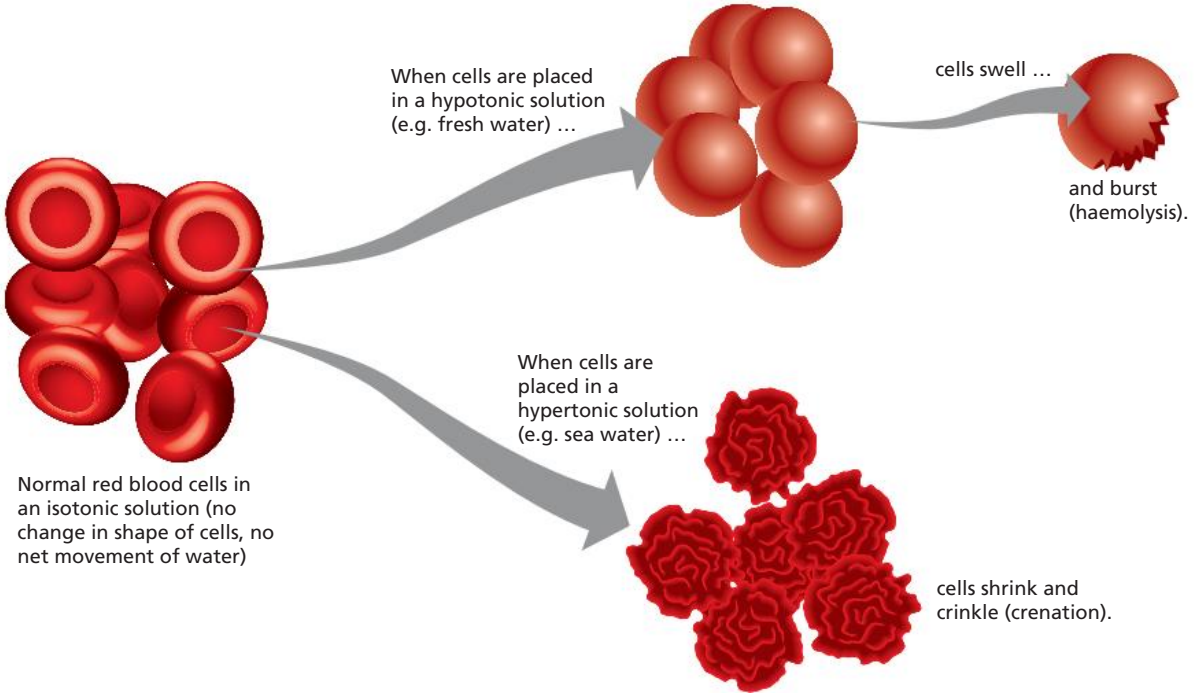
Figure 1.36 ▲
Amoebas are able to remove fresh water using organelles called contractile vacuoles.

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

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

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

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

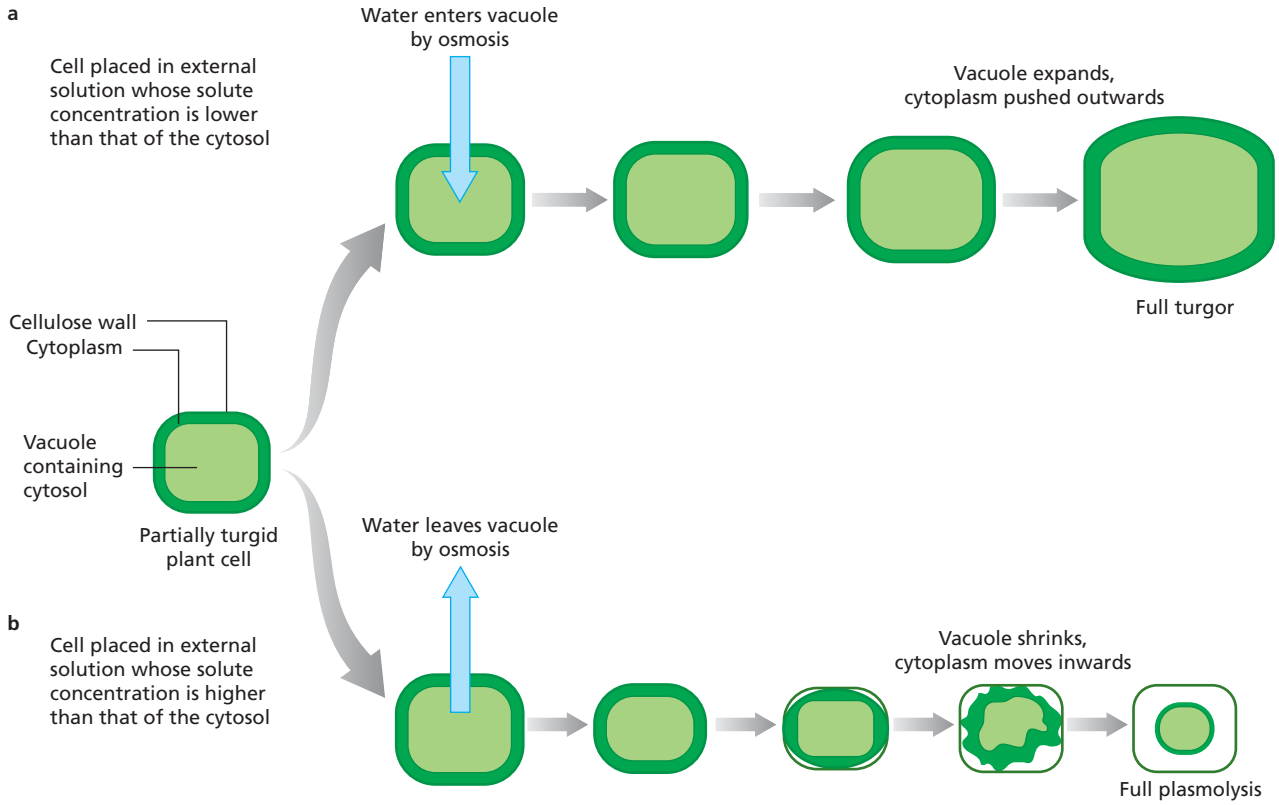


It is equally dangerous for an intravenous solution to be hypotonic. If the blood plasma is diluted by water, the blood cells will swell and burst. This condition is called **haemolysis** and it can seriously reduce the amount of oxygen being transported to body tissues. Because of these effects of osmosis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

Osmosis in plants

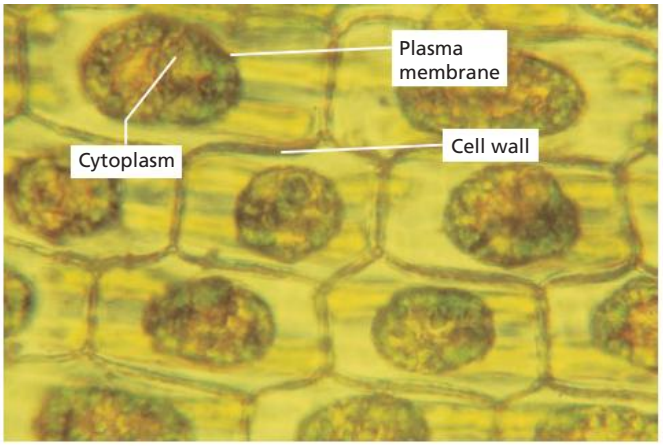
Did you know that soaking limp vegetables like celery in water restores their crispness? Unlike animal cells, the celery cells will not burst when soaked in fresh water (hypotonic solution), even though water moves into the plant by osmosis. How can you explain this difference?

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



▲ **Figure 1.38** The effect of immersing a partially turgid plant cell in (**a**) pure water and (**b**) a high solute concentration.

Turgor is very important for plants. It supports them and maintains their shape and form. The stems of non-woody plants are kept erect by the turgid, tightly packed cells that fill them. Turgor is also responsible for holding leaves in a flat, opened-out position. Certain plant cells are able to undergo quite rapid changes in their solute concentration



Corbis/Visuals Unlimited

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

with consequent changes in turgor. This allows such cells to change their shape. Stomatal guard cells behave this way, as do cells responsible for the leaf movements of insectivorous plants (the Venus flytrap).

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

RECALL

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

RECAP 1.10

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

Movement across membranes using energy

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

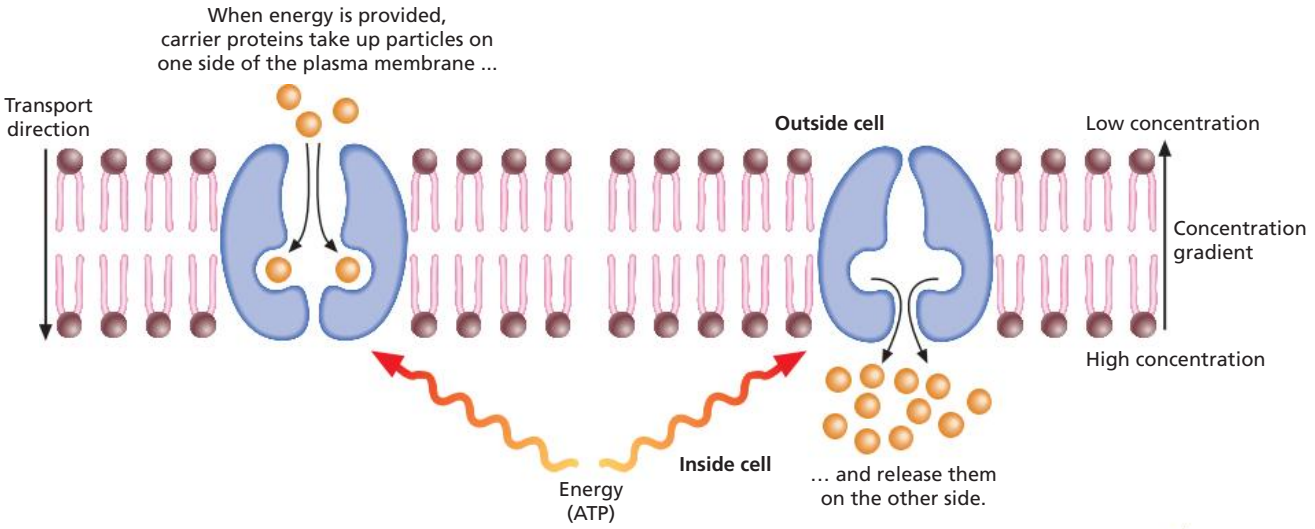
Active transport

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

small intestine even when its concentration is lower outside the cell. Cells appear to pump glucose in through their plasma membranes.

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

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



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

Without active transport the kidneys could not reabsorb useful materials, muscles would not contract and impulses would not be able to travel along nerves. As we saw in Table 1.4, animal cells contain high concentrations of potassium ions but low concentrations of sodium ions. The mechanism responsible for this is the **sodium–potassium pump**, which moves these two ions in opposite directions across the plasma membrane. The sodium–potassium pump has a particular significance for excitable cells, such as nerve cells, which respond to stimuli. Other substances such as amino acids and hydrogen ions are also pumped across membranes by active transport.

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

Bulk transport: Movement of large molecules across membranes

At times, very large particles have to be moved into a cell across its plasma membrane. In other circumstances, relatively large molecules have to be exported from a cell. The large size of these particles makes their movement through the membrane by diffusion or active transport impossible. In these cases of bulk transport, membranes



Corbis/Visuals Unlimited

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

and cytoplasmic vesicles have an important role to play in **endocytosis** and **exocytosis**. These are active processes, requiring energy in the form of ATP to move vesicles around the cytoplasm and to change the shape of the cell.

Endocytosis

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

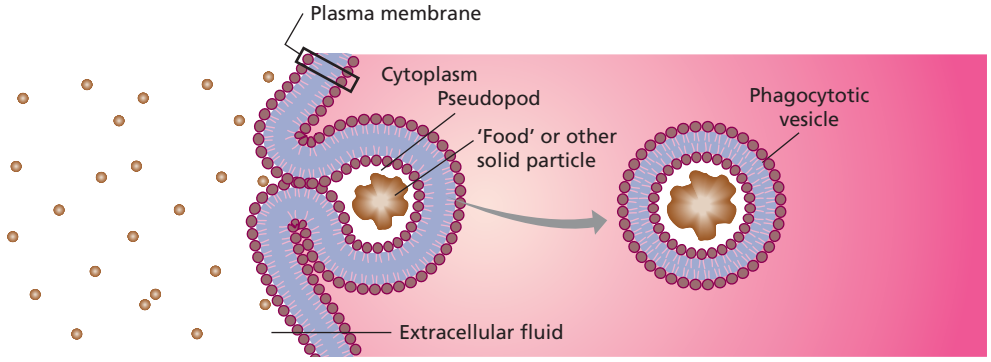
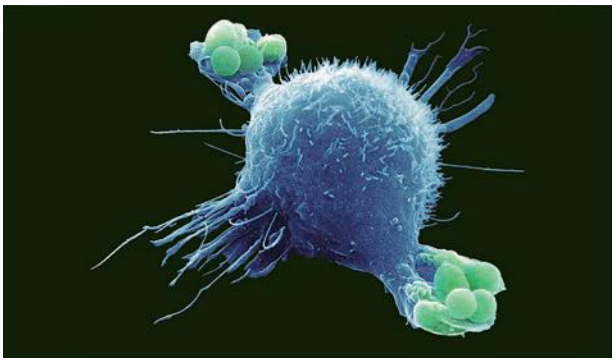


Figure 1.42 ▶
The process of phagocytosis

Human macrophages (a type of white blood cell) are called phagocytes because, in defending the body against disease, they engulf bacteria by phagocytosis (Figure 1.43). Macrophages use recognition proteins in the plasma membrane of the cells they encounter to discriminate between invading bacteria and body cells. This demonstrates that phagocytosis is a selective process.

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



Corbis/Visuals Unlimited/Dr. David Phillips

Figure 1.43 ▲
A macrophage engulfing cells by phagocytosis

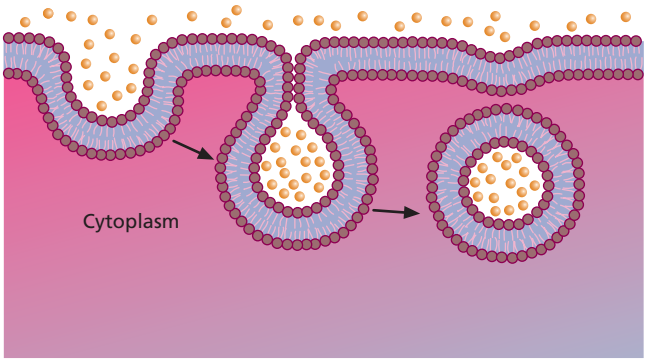
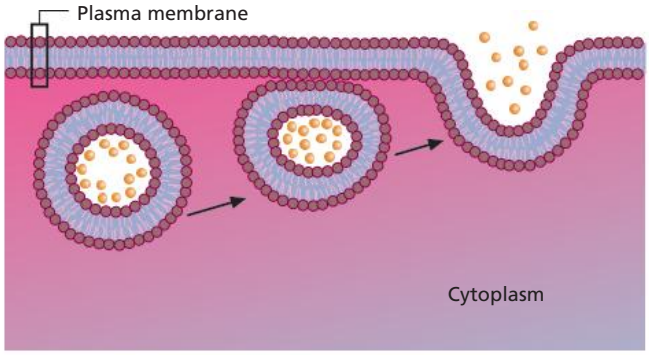


Figure 1.44 ▲
The process of pinocytosis

Exocytosis

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

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



▲ **Figure 1.45**
The process of exocytosis

RECALL

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

RECAP 1.11

1 Distinguish between active transport and simple diffusion.
2 Compare and contrast the passive and active cellular uptake of glucose molecules and ions.
3 Explain how the plasma membrane is involved in the processes of endocytosis and exocytosis.

Investigation of an issue: Organ-on-a-chip: a valuable technology for medical research

Refer to Chapter 11 for more information on the investigation of an issue.

Why medical research is important for society

We are made up of a community of cells that work together to maintain life. At times cells may be damaged or start misbehaving. This causes disease, as body function is impaired. To treat diseases we need drugs that target damaged cells and fix the problem. Medical research helps us to understand cell systems better and to discover new drugs to treat disease. Drug discoveries improve the health of our community. They increase our lifespan and that is good for the economy as we can work longer. They also reduce the cost burdens of healthcare.

Issues associated with drug discovery through medical research

Discovering medical drugs is costly. Drug development takes a long time and often ends in failure. Matthew Herper is an investigative science journalist with Forbes. His research reveals that approximately 95% of drugs trialled are found to be ineffective or not safe when tested in humans (2013). He calculates that the cost of getting a drug to market ranges from $350 million to $5 billion.

Current methods for drug development involve testing them on cells grown in culture and on cells in animal models. While these methods provide us with valuable information, they do not always reveal how the drug will work on cells in the human body.

Cells in culture do not experience the mechanical forces at play in the body. Think about the beating cells of the heart or the movement experienced by cells in the lungs. This is hard to replicate in a dish. Cells grown in culture are generally all of the same type, such as skin cells or nerve cells. The body is a very complex system with many interactions between different cells and molecules. In cell culture systems in the lab, most of these interactions and communication with other cell types is lost.

Using animal models helps overcome some of these problems as new drugs can be tested in a complex whole-animal system that much more closely resembles the human body. However, the structure and function of proteins and cells in the animal model can vary from that in a human. Many potential drugs that work in mouse models do not work when trialled in humans. Moreover, the use of animals in medical research is an issue that requires great ethical consideration.

New technologies offer hope for reducing the cost of medical research

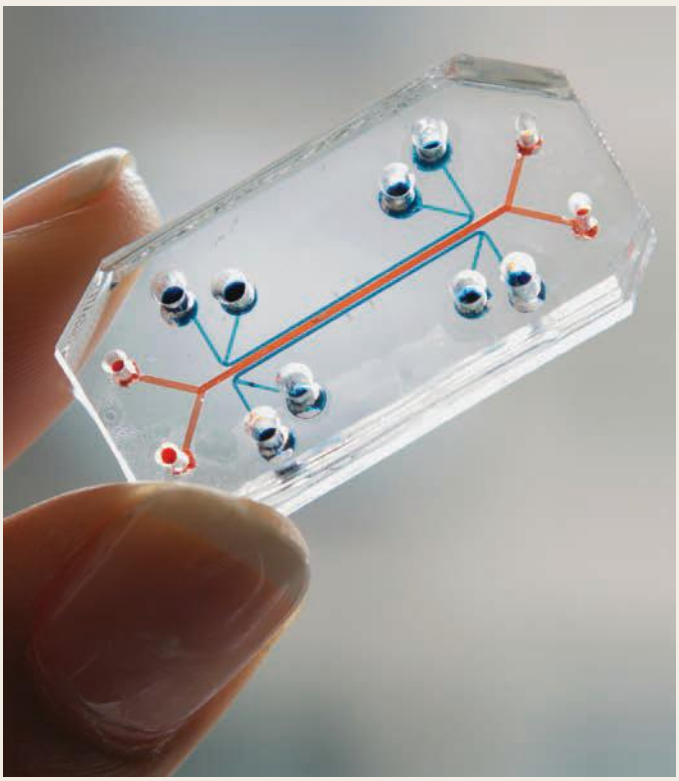
Scientists at the Wyss Institute for Biologically Inspired Engineering at Harvard University, Boston, United States, are proposing an alternative method for drug discovery. They have designed organs on a chip, such as the lung chip shown in Figure 1.46. The human cells on these chips experience a chemical and physical environment similar to that in the body. The chip is engineered so mechanical forces can be applied to cells. The chip is also designed so layers of different cell types can be grown, allowing for interaction between these cell types that more closely resembles the natural interactions in the human body. Geraldine Hamilton, a senior scientist at the Institute, states that organs-on-a-chip will improve drug discovery by making it faster and cheaper, by reducing the need for animal testing and by reducing the number of drugs that fail in human clinical trials, because the drugs will have already been tested in these manufactured human systems (2013).

Over to you: Characteristics of effective science communication

Task 1: When discussing an issue, its importance, authority and implications should be made clear to the audience. This information provides **contextual clarity**. That is, it helps the reader to understand precisely what the situation is, any problems potentially arising from the situation, and why we should be concerned about the situation. The passage above describes the **importance** of the issue – we need faster, cheaper and more effective methods for discovering and testing medical drugs. The **implications** if we ignore this problem are:

- considerable financial burden of getting drugs to market as most drugs fail in clinical trials
- missed opportunities for improvement to healthcare as we can't maximise discovery of treatments for disease
- continued use of animals in research.

Authority refers to the source of the information and how reliable it is. Look at where quotes and citations have been used to provide authority. Reflect on why they make the argument more convincing. For example, consider a new drug that is being sold to treat rheumatoid arthritis. Use the table on page 39 to rank, in order of reliability (with 1 the most reliable), the information provided by the sources listed.



Huh, Dongeun, Donald E. Ingber, et al. "Micro fabrication of human organs-on-chips." Nature Protocols 8. 2135–2157 (2013)

Figure 1.46 ▲
A lung on a chip designed by the Wyss Institute. It offers an in vitro approach to drug screening by mimicking the mechanical and biochemical behaviours of a human lung.

Rank of reliability	Information source
	A news article in a popular newspaper
	A media press release from Arthritis Australia
	A peer-reviewed scientific article containing primary data on the drug's effectiveness in patients, with authors who have no financial conflict of interest with the company selling the drug
	An advertising leaflet from the company selling the drug
	A peer-reviewed scientific article containing primary data on the drug's effectiveness in patients, with authors who are employed by the company selling the drug
	A government website containing information for patients

Task 2: A problem statement is a concise and accurate summary of the issue, which gives the reader information on the context, importance, implications and potential solutions to the issue. Read the following problem statement, which captures the context of this issue. Identify the vision, the problem and the proposed solution.

> The discovery of drugs through medical research provides treatments for disease and drives a healthier community and economy. However, drug development is costly and 95% of trialled drugs prove to be ineffective in clinical trials. This is largely due to pre-clinical studies being conducted on cells that do not replicate the situation in the human body. Organ-on-a-chip provides a new model for testing drugs on human cells in vitro. It may increase the success rate of new drugs through clinical trials, by providing more accurate conditions for pre-clinical testing.

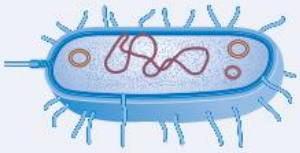
Task 3: **Clarity of expression** makes it easier for the audience to understand the issue. A Flesch-Kincaid (FK) scale measures the simplicity of written expression. Each paragraph in the organ-on-a-chip article above has an FK grade level score close to 8, except for the final two paragraphs, which have a score above 11. Re-write the last paragraph in the article to achieve a simpler, more easily understood paragraph that maintains scientific accuracy. You can do this by shortening sentences and using simple words and sentence structures, but use scientific terminology wherever possible. Use an online FK readability program to test your work. Try to get the grade level score to less than 8.
Task 4: When writing about scientific information, there are ways you can make your ideas stand out to the audience. Reflect on the article above. Subheadings have been used to provide structure and help the audience navigate through the piece. Working backwards you can produce an outline similar to that used by the author to develop this piece. For each subheading list the major ideas presented. This reveals how the author attempted to keep the work focused and concise.
Task 5: Now review the work. Identify any areas where text or sections can be removed without losing the point of the article. Can text be replaced by diagrams or graphs that explain concepts, summarise ideas or demonstrate the correlation between ideas? This will make the work more concise.

References

Hamilton G. (2013, June) *Body parts on a chip* [Video file]. Retrieved from https://www.ted.com/talks/geraldine_hamilton_body_parts_on_a_chip/
Herper M. (2013) *The cost of creating a new drug now $5 billion, pushing big pharma to change.* Forbes media group. Retrieved from www.forbes.com/sites/matthewherper/2013/08/11/how-the-staggering-cost-of-inventing-new-drugs-is-shaping-the-future-of-medicine/

CONCEPT SUMMARY

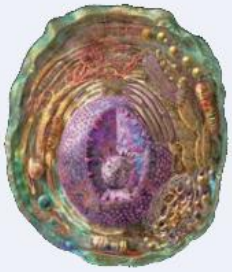
Types of cells



Prokaryotic



Eukaryotic



Types of organisms



Single-celled organisms

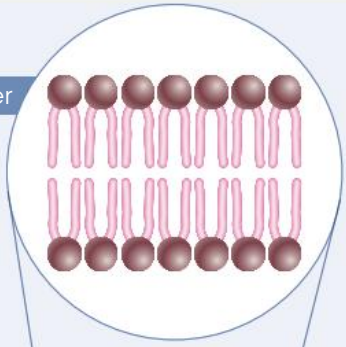


Multicellular organisms

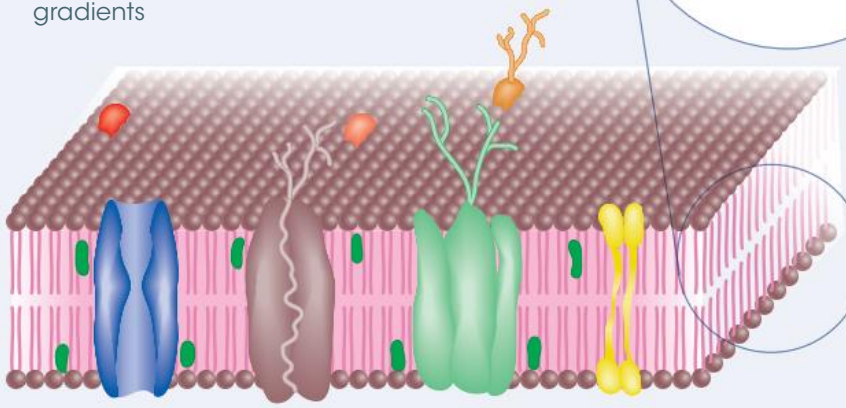
The plasma membrane

Features of membranes

Phospholipid bilayer

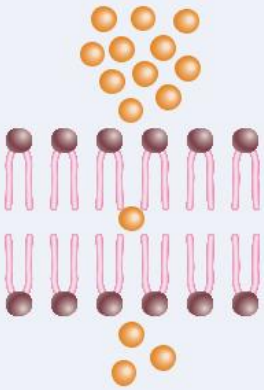


- Contains proteins, cholesterol and carbohydrates
- Maintains concentration gradients

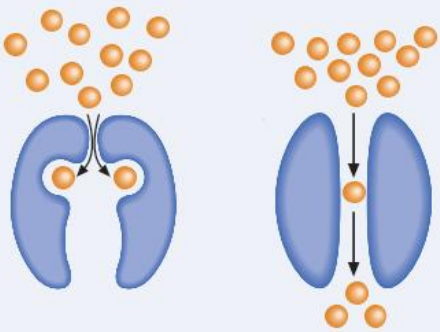


Movement across membranes

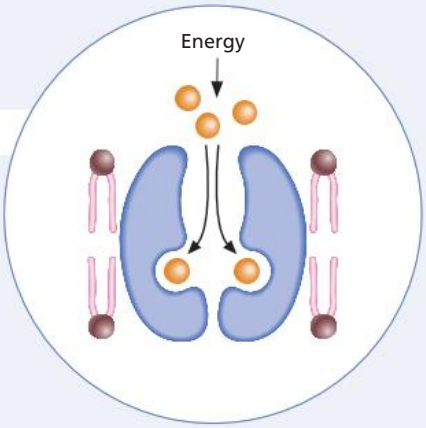
Diffusion



Facilitated diffusion



Active transport



- Endocytosis
- Exocytosis

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Features of cells

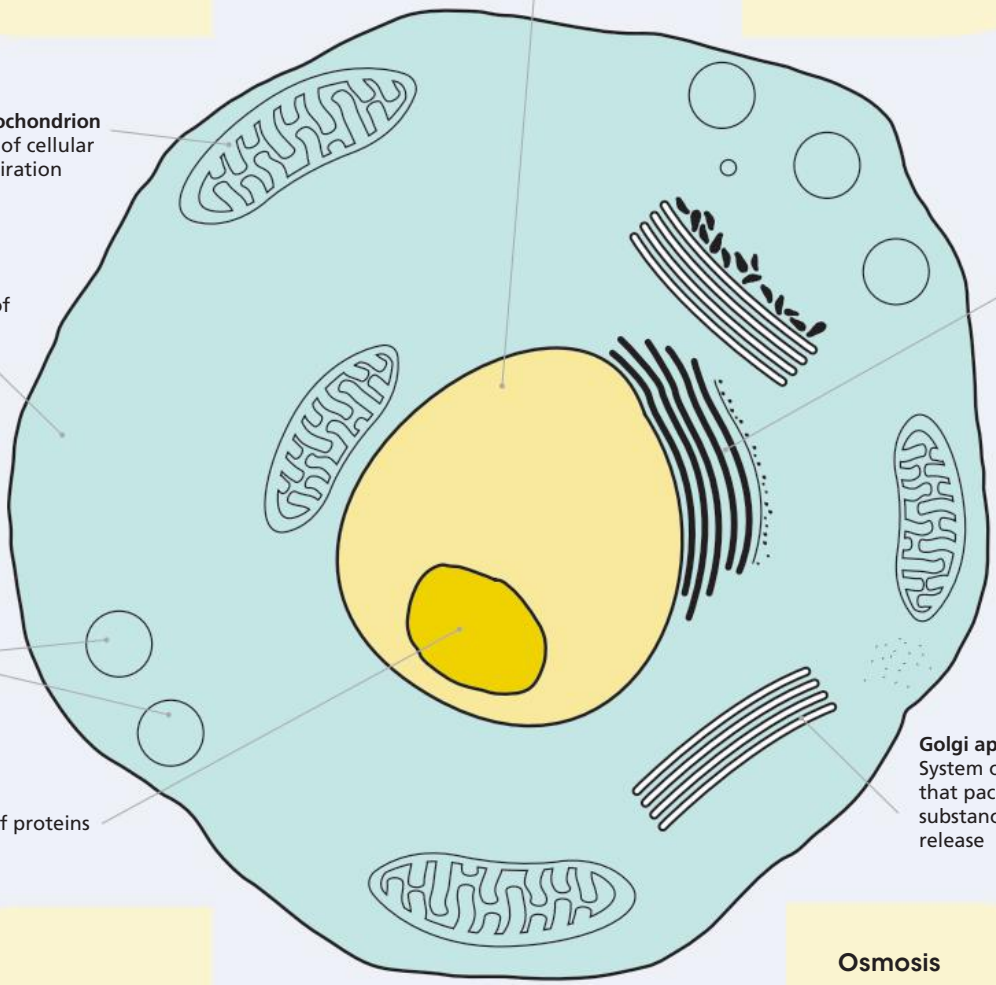
For example, an animal cell

Cell theory

All living things are composed of one or more cells and all cells come from pre-existing cells.

Surface-area-to-volume ratio

Cells with a larger surface-area-to-volume ratio can obtain nutrients and remove wastes more efficiently.



Concentration gradient

The difference in particle concentration between the two regions

Osmosis

The movement of water across a selectively permeable membrane from regions of low solute concentration to high concentration

CHAPTER GLOSSARY

active transport the process whereby cells actively transport substances across a membrane from low to high concentration using ATP

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

adhesion protein a membrane protein that helps link cells together

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

amyloplast a type of leucoplast that often stores starch

bilayer a double layer

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

cell the basic structural unit of all life forms on Earth

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

cellulose a complex carbohydrate molecule found in cell walls

centriole a structure in animal cells that produces and organises microtubules

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

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

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

chromoplasts a type of plastid containing coloured pigments other than green

chromosome a structure made of a DNA molecule

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

contractile vacuole the vacuole found in some freshwater unicellular organisms that maintains osmotic balance by collecting water and emptying it from the cell

crenation the crinkling of red blood cells when they lose water

cristae the folding of the inner membrane into the matrix of the mitochondria, thus increasing the total surface area of the inner membrane

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

cytoplasmic streaming the mixing and movement of the cytoplasm

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

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

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

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

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

endoplasmic reticulum (ER) an organelle in eukaryotic cells consisting of an interconnecting system of thin membrane sheets dividing the cytoplasm into compartments and channels; lipid synthesis occurs here

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

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

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

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

external environment the environment surrounding a cell outside the plasma membrane

extracellular fluid the fluid that bathes the outside of cells in multicellular organisms

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

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

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

haemolysis the bursting of red blood cells

hydrophilic tending to interact with and dissolve in water

hydrophobic avoiding association with water

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

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

intercellular occurring between cells

internal environment all material contained within the plasma membrane

intracellular occurring within a cell

isotonic describes fluid with an equal solute concentration to another fluid

leucoplast a colourless plastid not containing pigments

lysosome an organelle within the cytoplasm containing digestive enzymes

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

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

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

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

mitochondrial matrix a gel-like material occupying the space enclosed by the inner membrane of a mitochondrion

multicellular describes an organism consisting of more than one cell

nuclear membrane the membrane surrounding the nucleus

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

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

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

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

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

permeable able to pass through

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

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

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

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

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

plastid an organelle in a plant cell containing coloured pigments

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

receptor protein a protein that binds hormones and other signal molecules

recognition protein a protein that acts as a marker on membranes

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

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

rough endoplasmic reticulum endoplasmic reticulum with ribosomes attached

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

smooth endoplasmic reticulum endoplasmic reticulum with no ribosomes attached

sodium–potassium pump a membrane protein that uses energy to transport sodium ions out of, and potassium ions into, cells against their concentration gradients

solute a substance that can be dissolved in another substance

solution a mixture of solute and solvent

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

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

stroma the jelly-like semifluid interior of a chloroplast

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

thylakoid membrane the interconnected, folded membranes within chloroplasts

tonoplast the membrane surrounding the vacuole

transport protein a protein that carries molecules across membranes

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

unicellular an organism made up of a single cell

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

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

wilt to become limp and floppy

CHAPTER REVIEW QUESTIONS

Remembering

1 Match each structure with its function.

Organelle/structure		Function	
i	Nucleus	a	Collecting and packaging centre of the cell
ii	Endoplasmic reticulum	b	Photosynthesis and storage
iii	Lysosome	c	Transport of substances around the cell
iv	Mitochondria	d	Control centre of the cell
v	Golgi apparatus	e	Aerobic respiration, which releases energy to the cell
vi	Chloroplast	f	Breakdown of materials

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

3 Explain what would happen, in terms of the diffusion of water molecules, if an animal cell was placed in a hypotonic solution.

Understanding

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

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

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

7 Explain the importance of turgor to plants.

8 Explain why red blood cells become crenated in a hypertonic solution.

Applying

9 **a** Describe features that are common to all cells.

b Describe features that are unique to:

i prokaryotic cells.

ii eukaryotic cells.

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

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

a Using the following components of a factory, describe a structure or function of a cell that is similar. For example, a factory has outside walls; all cells have a membrane and some types of cells also have cell walls.

Factory: goods manufactured; business plans; photocopying room; manufacturing area; warehouse; management offices; assembly workers, warehouse packers; doors; hallways; power source

b Outline one difference in function between a factory and a cell.

c Suggest another analogy for a cell.

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

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

14 When a person's kidneys fail, the person can be connected to a dialysis machine. Arterial blood is pumped through dialysis tubing that is made of selectively permeable membranes. Surrounding the tubing is a solution similar to blood plasma. Waste materials diffuse from the tubing into the surrounding solution. Cleaner blood then travels back into the person's veins.

a What must be done to the surrounding solution in order for the wastes to continue diffusing out of the dialysis tube?

b Predict what would happen if this was not done to the surrounding solution.

c Find out more about how dialysis machines work.

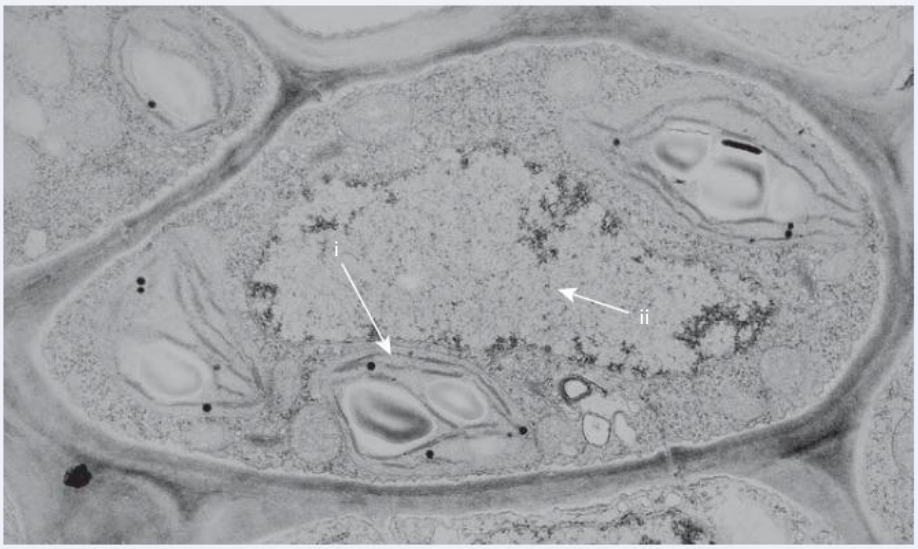
Analysing

15 a State whether the cell shown in Figure 1.47 is from a prokaryote or eukaryote. Give reasons for your answer.

b Identify whether the cell shown in this photograph was viewed with an electron or light microscope. Give your reasons.

c Some organelles may be present in this cell but are not shown in the photograph. Suggest why this might be the case.

d Name the organelles with arrows pointing to them.



Getty Images/Visuals Unlimited/Martha J. Powell

Figure 1.47 Photograph of an unidentified cell

16 One of the jobs of our white blood cells is to engulf potentially dangerous bacteria and destroy them. Explain why there are a large number of lysosomes present in white blood cells.

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

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

19 Three duck eggs with their shells removed all weigh 50 g. They are placed in different concentrations of salt solutions: 1.0, 1.5 and 2.0 M (molar) concentration, respectively. After two hours, the eggs are reweighed. The egg placed in the 1.0 M salt solution weighed 54 g, the egg placed in the 1.5 M salt solution weighed 50 g and the egg in the 2.0 M salt solution weighed 46 g.

a Construct a line graph showing probable change in egg mass over a two-hour period.

b Explain, for each concentration, why the eggs gained or lost mass or stayed the same.

Evaluating

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

21 A student examines a human cheek cell under a light microscope. As she cannot see any mitochondria, she says there are none present in these types of cells. Outline arguments you would use to convince her that she is incorrect.

22 Evaluate the advantages and disadvantages of using different types of microscopes. Include the following types of microscopes (you will need to conduct some additional research to answer this question):

- **a** light microscope
- **b** SEM
- **c** TEM
- **d** scanning probe microscope.

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

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

Reflecting

25 Explain why it is useful to identify the features that are characteristic of all living organisms.

26 Your friend says that a particle taken into a cell by phagocytosis is not truly inside the cell. Analyse this statement and use an argument to agree or disagree with it.

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

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

29 A person marooned on a desert island surrounded by sea water must look for fresh water to drink. There are plants on the island. Suggest how the person might find enough water to stay alive. Discuss what would happen to the person if he or she used the sea water for drinking.



CHAPTER 2
ENERGY TRANSFORMATIONS

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

KEY KNOWLEDGE

Energy transformations

- the distinction between photosynthetic autotrophs, chemosynthetic autotrophs and heterotrophs
- photosynthesis as a chemical process in which solar energy is captured and transformed to chemical energy by fixing carbon to produce a carbohydrate and releasing oxygen as a by-product
- aerobic and anaerobic cellular respiration as a chemical process that commonly uses glucose to produce energy for the cell in both autotrophs and heterotrophs.

Investigation of an issue

- characteristics of effective science communication: accuracy of scientific information; clarity of explanation of scientific concepts, ideas and models; appropriateness for purpose and audience
- the biological concepts specific to the investigation: definitions of key terms; use of appropriate biological terminology, conventions and representations
- the use of data representations, models and theories in organising and explaining observed phenomena and biological concepts, and their limitations

KEY SCIENCE SKILLS

Draw evidence-based conclusions

- identify the limitations of conclusions, including identification of further evidence required

Communicate and explain scientific ideas

- use appropriate biological terminology, representations and conventions, including standard abbreviations, graphing conventions and units of measurement
- identify and explain formal biological terminology about investigations and concepts
- use clear, coherent and concise expression

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Figure 2.1 ▲
Life depends on an energy source

Wherever life exists, in the deep sea trenches kilometres below the surface of the oceans, in the geothermal springs of New Zealand or in the Antarctic, it depends on a source of energy, a supply of water, exchange of gases and removal of wastes.

All living things need energy to function. They need matter to grow and to replace ageing or damaged parts. In general, each cell within an organism has the same needs. However, the manner in which each organism meets these needs offers us an insight into the diversity of all living things.

Energy sources for life

All complex systems on Earth require a supply of energy to drive them. Energy allows matter to be combined from simple structures into more complex ones. For example, the developing offspring of multicellular organisms usually begins with the fusion of two cells, one from each parent, which eventually form a complete and independent unit.

The energy that drives cellular processes is provided by the Sun. Plants and algae have evolved a way to utilise the Sun's energy, which now we call **photosynthesis** (essentially meaning 'building from light'). Photosynthetic **autotrophs** are organisms that transform the Sun's energy into chemical bonds during the synthesis of **organic** materials such as glucose. These organic molecules provide energy to the organism. The environment provides basic **inorganic** compounds such as carbon dioxide and water, which are the building blocks of organic compounds. Energy is stored in the chemical bonds of organic compounds and is released when the chemical bonds are broken during cellular metabolism.

Other sources of energy include geothermal energy, which is heat generated from Earth's core. Some of this extreme heat escapes to generate geothermal activity on Earth's surface and in the ocean. Hydrothermal vents are regions in the deep ocean where volcanic magma heats sea water to more than 300°C. On Earth's surface, volcanic activity creates extreme environments. For example, the Wai-o-tapu geothermal reserve, near Rotorua in New Zealand, has numerous hot springs and geysers (Figure 2.2). These environments are home to colonies of organisms that can tolerate the lack of sunlight, high temperatures, extreme pressures and acidity. It is here that large communities of a particular micro-organism (Archaebacteria) use simple inorganic chemical compounds including sulfur and iron as their source of energy and matter.

Figure 2.2 ▶
Hydrothermal vents and geothermal regions are home to chemosynthetic bacteria.



Getty Images/Christopher Chan

The process by which these bacteria harness the energy released from chemical reactions to synthesise organic compounds is called **chemosynthesis** (which means 'building from chemicals'). All chemosynthetic organisms use the energy released by chemical reactions to make a **carbohydrate**, but different species use different pathways. For example, around hydrothermal vents, chemosynthetic bacteria convert hydrogen sulfide and carbon dioxide into glucose for use as fuel, producing sulfur and water.

Together, photosynthesis and chemosynthesis fuel all life on Earth. It is these autotrophs, also known as **producers**, that make all of the organic matter, or food, on which all other organisms rely for nourishment.

Autotrophs transform the Sun's energy

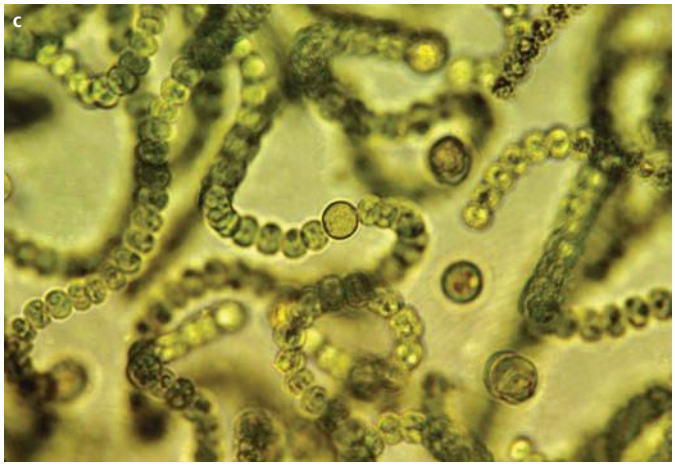
Photosynthetic autotrophs transform sunlight into chemical energy in the biochemical process of photosynthesis. Plant cells have specialised organelles called **chloroplasts** that contain the pigment **chlorophyll**. This pigment is able to absorb most of the wavelengths in sunlight. Green plants mainly use the red and blue wavelengths for photosynthesis, but this narrow range accounts for only about 2–10% of the total visible light that strikes the leaves. Of this, 10% is trapped in the high-energy bonds during the production of carbohydrates. While only 0.2–1% of light reaching a leaf is captured for the production of fuel, this is enough to power all the needs of the plant and the ecosystem it helps to support.



iStock.com/wweagle



Getty Images/Science Photo Library/Eye of Science



Corbis/Dr. Ron Dengler/Visuals Unlimited

◀ Figure 2.3 Photosynthetic autotrophs including (**a**) algae, (**b**) plants and (**c**) cyanobacteria transform energy from sunlight and store it as chemical energy in the bonds of glucose.

Heterotrophs obtain matter and energy from autotrophs

Organisms such as humans are **heterotrophs** – members of the community that cannot synthesise their own organic compounds from inorganic materials. So how do we manage? Heterotrophs depend on autotrophs directly or indirectly for their energy needs and their supply of matter. They do this by consuming other organisms, and therefore are known as **consumers**.

Heterotrophs cannot carry out photosynthesis and so they cannot derive their energy directly from the Sun. Animals of all sizes, from insects to elephants, must obtain their energy from the food they eat. Herbivores, including grazing animals, consume large amounts of plant material. They extract energy stored in chemical bonds by a process called **cellular respiration**.

Herbivores have enzymes that can digest **cellulose**, the major component of the plant cell wall. This enzyme breaks the chemical bond between individual glucose molecules making up the cellulose, which is the crucial first step in a herbivore's ability to extract the Sun's energy from plants. Cellular respiration involves a series of chemical reactions that extracts the energy in glucose bonds to form a small chemical called **adenosine triphosphate (ATP)**. This molecule has chemical bonds that are easily broken to release energy, and so it is a readily available source of energy that allows cells to perform their many functions.

RECALL

- Photosynthetic autotrophs use the Sun's energy to synthesise organic compounds.
- Chemosynthetic autotrophs use energy released from chemical reactions to synthesise organic compounds.
- Together, photosynthesis and chemosynthesis fuel all life on Earth. The organisms that carry out these processes are producers.
- Heterotrophs cannot make their own energy and must acquire it by eating other organisms. They are consumers.

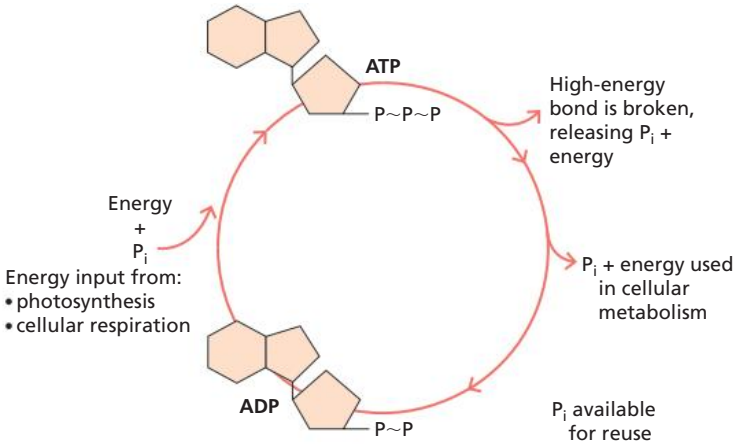
RECAP 2.1

1. Define 'autotroph'.
2. Distinguish between photosynthesis and chemosynthesis.
3. Name the group of organisms that use chemosynthesis to build organic compounds and their general location.
4. Distinguish between autotroph and heterotroph.

Energy is transferred between reactions

Cells use chemical energy released from some reactions to fuel other reactions. These reactions can happen simultaneously in cells. In this process, some energy is lost as heat, which escapes from cells into the surrounding environment. As these reactions do not always occur in the same place within the cell, energy has to be transferred between reactions. This transfer is achieved by ATP, which is readily available within the cell.

ATP is an energy-carrier in all living cells. It picks up energy from energy-releasing reactions and transfers it to energy-requiring ones. ATP is a molecule containing adenosine attached to a sugar group (ribose), which is bound to a chain of three phosphate groups (Figure 2.4).



◀ **Figure 2.4**
The ATP–ADP cycle is the cell's way of renewing its supply of immediate energy. P_i = inorganic phosphate group.

ATP is a well-suited, renewable energy source. When a cell requires energy to drive a reaction, the high-energy chemical bonds attaching the last phosphate group (abbreviated as P_i) to ATP are broken, thus releasing stored energy. This energy is now available to fuel a cellular reaction. The remaining molecule now has only two phosphate groups and is called **adenosine diphosphate (ADP)** (Figure 2.4).

Free energy can also be used to add a phosphate group to ADP, converting it to ATP. The ATP–ADP cycle is the cell's way of shuttling energy between reactions. It provides the cell with an efficient way of coupling energy-yielding processes to energy-requiring processes within the cell by conserving, transferring and releasing energy.

RECALL

- ATP is the main energy-carrier in a cell.
- Energy is released when one of the phosphates of ATP is removed.
- ATP is replenished when energy is used to add a phosphate to ADP.

RECAP 2.2

1 Describe the structure of an ATP molecule.

2 Explain the relationship between ATP and ADP.

Photosynthesis is a chemical process harnessing solar energy

If a pot plant growing in soil at a suitable temperature is put in light and watered, the plant's mass increases over time. The rate of photosynthesis (energy being captured) in the plant is greater than the rate of cellular respiration (energy being used for normal living) and so it can use some of the energy to build new structures such as branches and leaves. If the plant is enclosed in an airtight container, we can measure the amounts of oxygen and carbon dioxide in the contained air over time. If the photosynthetic rate is greater than the cellular respiration rate, the amount of oxygen would increase and the amount of carbon dioxide would decrease with time. If the plant was kept in the dark, the plant would undergo cellular respiration only and we would find the amount of carbon dioxide would increase and oxygen would decrease in the surrounding container. The plant would gradually lose mass.



Shutterstock.com/Andy Dean Photography

Figure 2.5 ▲
Plants exposed to light increase in mass. Pumpkin plants would not be able to grow large fruit in the dark.

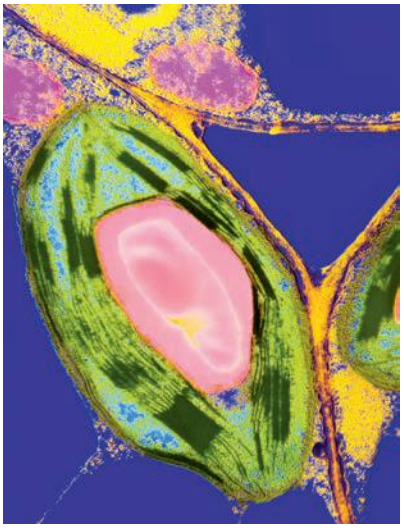
Photosynthesis is a series of steps

Photosynthesis is the process by which plants utilise light energy and use it to break down water and carbon dioxide molecules, and build them up into glucose, oxygen and water molecules. It can be summarised by the following equation.

Photosynthesis:

carbon dioxide + water → glucose + oxygen + water

$$6CO_2 + 12H_2O \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$$



Science Photo Library/Dr Jeremy Burgess

Figure 2.6 ▶
False-colour transmission electron micrograph of a green chloroplast from a leaf. The green, thread-like strands are thylakoid membranes. They pack together tightly to form grana. The large pink region is a starch grain, where the products of photosynthesis are temporarily stored after they have been produced in the light-independent reactions that take place in the stroma (magnification 5000x).

See Chapter 1, Figure 1.21a, for a generalised sketch of a chloroplast. Chloroplasts have their own genetic material and ribosomes.

However, this equation shows only the initial reactants and the final products. It does not tell the whole story. Photosynthesis actually occurs as a series of steps in a biochemical pathway, each **catalysed** by specific **enzymes**. It requires light as an energy source that is captured by the pigment chlorophyll.

Chloroplasts

Chloroplasts are the site of photosynthesis within an autotrophic cell. Chloroplasts have an outer and an inner membrane. The **stroma** is enclosed by the inner membrane. This is a gel-like matrix rich in enzymes. Suspended in the stroma is a membrane system, the **thylakoid** membranes. These are flat, sac-like structures that are called **grana** when grouped together into stacks.

The photosynthetic reaction is divided into two distinct stages: the **light-dependent stage** and the **light-independent stage**. Each stage is confined to specific sites within the chloroplast.

The light-dependent stage

Light energy is absorbed by different pigments within the thylakoid membranes. These pigments are chemicals that include chlorophylls (green), carotenoids (orange) and

xanthophylls (yellow). Chlorophylls absorb the wavelengths of blue and red light, and they reflect the green wavelengths, which is why plant parts having an abundance of chlorophyll molecules appear green to us. All green algae and plants have chlorophylls as their major photosynthetic pigments.

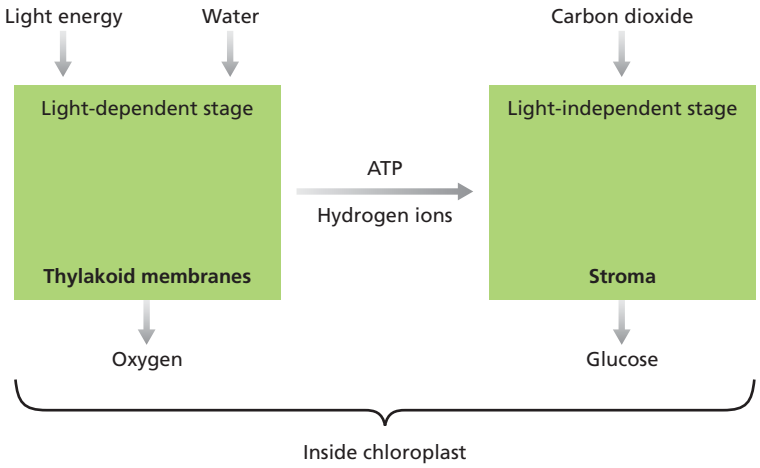
When a chlorophyll molecule in the thylakoid membrane absorbs light energy, electrons within the molecule become energised. The energy is used to split water molecules (H_2O) into hydrogen ions (H^+) and oxygen gas (O_2), a by-product of photosynthesis (Figure 2.7). ATP molecules are formed in this stage.

The light-independent stage

The light-independent reactions occur in the stroma of the chloroplast. In this reaction, glucose molecules are produced from carbon dioxide. This reaction requires a supply of carbon dioxide gas (CO_2), hydrogen ions (H^+) and chemical energy in the form of ATP. ATP molecules and H^+ ions formed in the light-dependent stage provide the chemical energy for the conversion of carbon dioxide to glucose molecules (Figure 2.7).

Many chemical reactions are involved in both the light-dependent and light-independent stages of photosynthesis.

Sucrose, starch and cellulose are **polymers** of glucose molecules produced in photosynthesis via other biochemical pathways. During daylight hours, chloroplasts convert the newly formed glucose molecule to sucrose or starch. Of all plant carbohydrates, sucrose is the most easily transported as it is small. Starch is the most common storage form and is made up of long branching chains of glucose. It is stored briefly in the stroma during the day. At night, cells convert starch to sucrose for export to other cells in leaves, stems and roots that lack chloroplasts.



◀ **Figure 2.7**
Photosynthesis is a series of reactions occurring in two stages: the light-dependent and the light-independent stages.

RECALL

- Photosynthesis is a series of chemical reactions in which cells use light energy to break down water and carbon dioxide molecules and build up glucose, oxygen and water molecules.
- Chloroplasts are organelles within autotrophic cells that are the site of photosynthesis.
- The light-dependent stage of photosynthesis occurs when light is absorbed by chlorophyll in thylakoid membranes of chloroplasts. In this stage, water molecules are split into hydrogen ions and oxygen gas.
- The light-independent stage of photosynthesis occurs in the stroma of a chloroplast; hydrogen ions and carbon dioxide are combined to produce glucose.

RECAP 2.3

1 Name the products or outputs of the light-dependent reaction that are used as inputs in the light-independent reaction of photosynthesis.
2 Write a balanced equation for photosynthesis.
3 Do all living plant cells carry out photosynthesis? Explain your answer.

Cellular respiration makes energy available for use in cells

All organisms, with the exception of the Archaea, use glucose as the primary source of energy to drive cellular metabolism. The chemical bonds in glucose are broken, resulting in more stable products and the release of free energy in the form of ATP. This reaction, known as **aerobic cellular respiration**, can be summarised by the following equation.

Aerobic cellular respiration:

$$\text{glucose} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water} \ (+\text{adenosine triphosphate})$$

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O \ (+36\ \text{ATP})$$

The word 'aerobic' is used when oxygen is present. The equation above simply shows the initial reactants and the final products. There are approximately 20 reactions that occur in this biochemical pathway, each catalysed by specific enzymes. Most animals, plants, protists, fungi and bacteria are **aerobes**: they all require oxygen for cellular respiration. However, oxygen is not always present and many micro-organisms use other molecules instead. These organisms are called **anaerobes** and live in environments without oxygen. For all organisms that use glucose as an energy source, the breakdown of glucose to supply the cell with available energy, regardless of whether oxygen is present or not, starts with a biochemical pathway called **glycolysis**.

Glycolysis

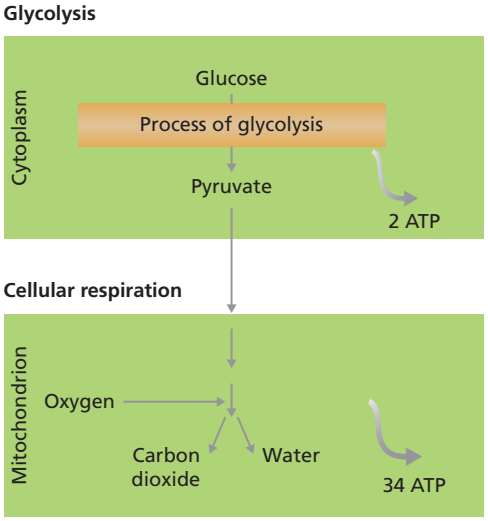
Glycolysis takes place in the **cytosol** of cells. The biochemical pathway of glycolysis is made up of 10 reactions, with each step controlled by a specific enzyme. The initial reactant is glucose and the final product is two molecules of a compound called **pyruvate**. The glycolysis pathway also produces a net of two ATP molecules that may be used by the cell as a source of energy. These ATP molecules, which can be used by the cell immediately, may be sufficient for the needs of certain micro-organisms but this is not sufficient for multicellular organisms. The fact that all organisms carry out glycolysis, either as their sole source of energy or as the first step in more elaborate pathways to gain sufficient ATP for their needs, points to glycolysis being one of the earliest reactions that evolved to produce energy for the cell. But what occurs after glycolysis to produce more ATP? This depends upon whether oxygen is present or absent.

Cellular respiration with oxygen

In eukaryotic cells that are supplied with oxygen, the two molecules of pyruvate formed in glycolysis enter the mitochondrion (Figure 2.8). Mitochondria are small, regularly shaped structures found scattered throughout the cell's cytosol. They are often described

as the 'energy powerhouse' of the cell because large numbers of ATP molecules are produced in them.

After a series of steps, facilitated by various compounds within the mitochondria, carbon dioxide molecules and water are produced. From all the reactions associated with aerobic cellular respiration, it is possible to produce a net of about 34 ATP molecules in one cycle. Therefore, glycolysis and aerobic respiration can together produce about 36 ATP molecules from one glucose molecule.



◀ **Figure 2.8**
Glycolysis, the first stage of cellular respiration, occurs in the cytoplasm. The second stage of aerobic cellular respiration occurs in the mitochondria.

Cellular respiration without oxygen

The first energy-releasing pathways evolved around 3.8 billion years ago when there was very little free oxygen in the atmosphere. The process was essentially anaerobic in that it was able to run to completion without requiring oxygen. Many bacteria and protists still live in places where oxygen is absent or not always available. Such organisms have evolved anaerobic biochemical pathways that follow on from glycolysis to produce additional ATP by utilising molecules other than oxygen. Prokaryotes have evolved many anaerobic pathways, but **eukaryotes** commonly use two forms, which are referred to as **alcohol fermentation** and **lactic acid fermentation**.

Alcohol fermentation

Many micro-organisms, including yeast, plants and some bacteria, carry out anaerobic cellular respiration. The products of alcohol fermentation are carbon dioxide and ethanol, an alcohol. The overall reaction for alcohol fermentation is summarised below.

Alcohol fermentation:

$$\text{glucose} \rightarrow \text{ethanol} + \text{carbon dioxide} \ (+\text{adenosine triphosphate})$$

$$C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2 \ (+2\ \text{ATP})$$

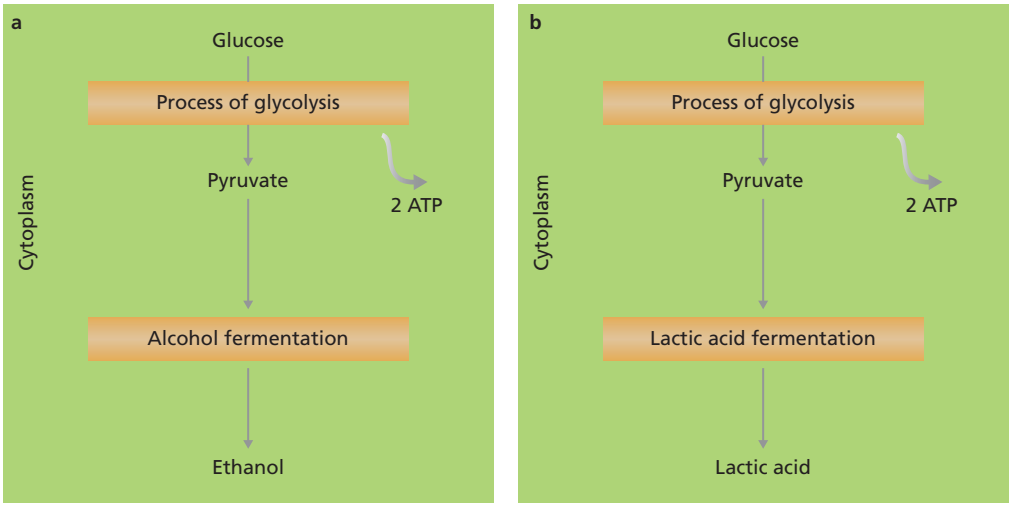


Figure 2.9 ▶
In anaerobic respiration, the second stage is either (**a**) alcohol fermentation in yeasts, bacteria and plants or (**b**) lactic acid fermentation in animals.

Humans make use of these metabolic waste products in the production of wine, beer and bread. Plants, however, cannot make use of ethanol. It cannot be reconverted into carbohydrate, nor can it be broken down in the presence of oxygen. Furthermore, alcohol is toxic to cells and cannot be allowed to accumulate. Many plants (or parts of plants) can respire anaerobically for a short time – examples are germinating seeds and roots living in water-logged soil, where there is little oxygen. However, before the concentration of ethanol reaches a certain level they must revert to aerobic respiration, otherwise they will be poisoned by the ethanol.

This is also true for yeast. Yeast is a classic example of an anaerobic organism that is used in the brewing and wine-making industries. Yet yeast grows much better in aerobic than in anaerobic conditions. If too little oxygen is present, the ethanol concentration rises so much that the yeast cells are killed. The secret to making beer and wine is not to let the conditions become too anaerobic. It is commercially beneficial to develop new strains of yeast that are tolerant to high concentrations of ethanol. This is a major occupation of microbiologists working for brewing companies.

Lactic acid fermentation

Lactic acid is the end product of anaerobic respiration in animals. Even though it is more efficient to generate most of our energy using aerobic methods, some circumstances, such as during strenuous exercise, require energy production faster than our bodies can adequately deliver oxygen. For example, our working muscles generate energy anaerobically, which results in a build-up of lactic acid. Once the strenuous exercise slows down, oxygen becomes available once again and lactic acid reverts back to pyruvate, allowing continued aerobic metabolism and energy for the body's recovery from the strenuous event.

Aerobic respiration produces a lot of energy. In anaerobic respiration, glucose is not broken down as completely as it is in aerobic respiration and so less energy is released as a consequence. A lot of energy still remains locked up in the ethanol or lactic acid molecules.

Lactic acid fermentation is an important pathway for energy production. This anaerobic respiration in animal cells is represented by the equation below.

Anaerobic respiration:

$$\text{glucose} \rightarrow \text{lactic acid} \quad (+\text{adenosine triphosphate})$$

$$C_6H_{12}O_6 \rightarrow 2CH_3CH(OH)COOH \quad (+2\ ATP)$$

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RECALL

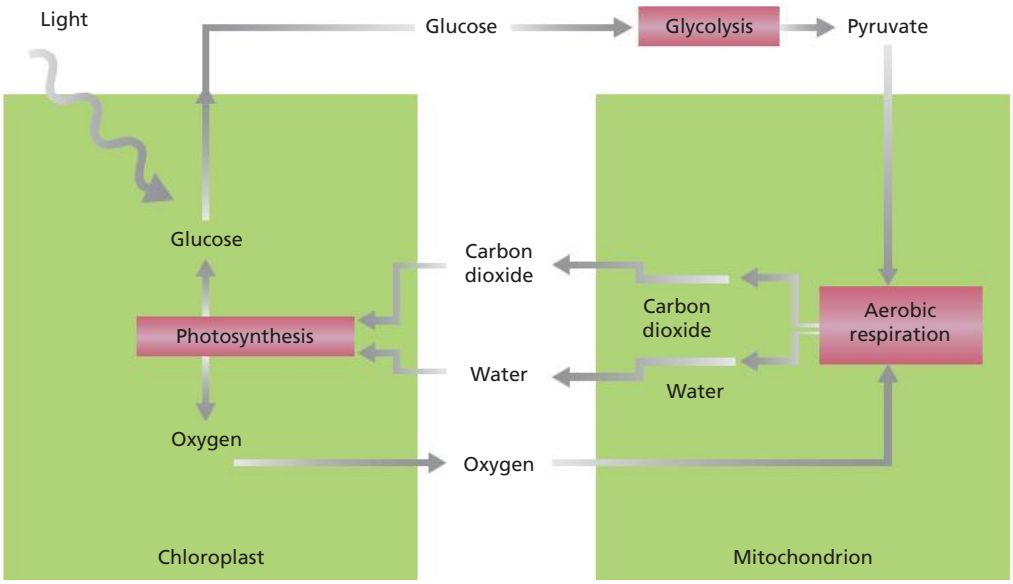
- Glycolysis is the first stage of cellular respiration and occurs in the cytoplasm. It produces two ATP molecules.
- In the presence of oxygen, pyruvate produced from glycolysis enters mitochondria where aerobic cellular respiration is completed. 34 ATP molecules are produced.
- Together glycolysis and aerobic respiration produce a net of about 36 molecules of ATP from each molecule of glucose. Carbon dioxide and water are also formed.
- In the absence of oxygen, pyruvate produced from glycolysis undergoes a series of steps in anaerobic cellular respiration to produce either ethanol and carbon dioxide (alcohol fermentation) or lactic acid (lactic acid fermentation) in the cytoplasm.

RECAP 2.4

1 Write a balanced equation for aerobic cellular respiration and show the number of ATP molecules produced.
2 Identify the initial substrate in the glycolysis pathway and the final product.
3 Compare the products of anaerobic respiration with those of aerobic respiration in animals and plants.

Photosynthesis and aerobic cellular respiration are closely related and interdependent

The outputs of photosynthesis are the inputs of aerobic cellular respiration. Similarly, the outputs of aerobic cellular respiration are the chemical inputs of photosynthesis. In plants and other autotrophs, the two processes can occur in the same individual cells when both chloroplasts and mitochondria are present. But many cells in green plants, such as root cells, do not have chloroplasts. These cells, and those of heterotrophs, depend on the products of photosynthesis in other cells to be transported to them (either by circulation within the organism or by consuming the organism) so they can carry out cellular respiration. Thus, there is a dependency between autotrophs and heterotrophs.



◀ Figure 2.10
Photosynthesis uses the products of cellular respiration, and cellular respiration uses the products of photosynthesis.

EXPERIMENT 2.1

THE EFFECT OF LIGHT ON PHOTOSYNTHESIS

Living plant cells carry out cellular respiration all the time. When light is present, green plant cells also undergo photosynthesis.

When studying water plants, the rate of photosynthesis and cellular respiration can be measured by the amount of carbon dioxide used or produced. This can be observed indirectly by recording the pH of the surrounding water. When carbon dioxide dissolves in water, it forms carbonic acid (H_2CO_3) in the following reaction:

$$CO_2 + H_2O \rightarrow H_2CO_3$$

If the amount of carbon dioxide increases, more carbonic acid forms and the acidity increases (pH decreases). If the amount of carbon dioxide decreases, carbonic acid levels also decrease, reducing the amount of acid so that the pH increases and the surrounding watery solution becomes more basic.

Aim

To test the effect of light on the rate of photosynthesis

Materials

- two healthy *Elodea* leaf shoots (or an alternative freshwater oxygenator available from the local aquarium or biological supplier)
- five test tubes (four of them with stoppers)
- aluminium foil
- phenol red indicator in a dropper bottle
- 0.1 M ammonia solution in a dropper bottle
- 0.1 M hydrochloric acid in a dropper bottle
- beaker
- grow-lux lamp or bright light

What are the risks in doing this experiment?	How can you manage these risks to stay safe?
Hydrochloric acid and ammonia can be corrosive.	Avoid contact with skin and eyes. If spilt or splashed, rinse affected area immediately with plenty of water and report any accidents to your teacher. Eye wash facilities and equipment should be readily available. Do not mix solutions.
Phenol red indicator can irritate skin and eyes.	Take care to avoid contact with skin and eyes.
Elodea is a noxious weed.	Dispose of *Elodea* safely, away from waterways.

Procedure

1. Half-fill a test tube with tap water and add two to three drops of phenol red indicator. Note the colour.
2. Add five drops of 0.1 M ammonia solution. Note any colour change.
3. Add five drops of 0.1 M hydrochloric acid. Note any colour change, and then add a further five drops of hydrochloric acid. Record your results. (Note that this part of the experiment is simply to produce some reference indicator colours.)
4. Collect enough aged tap water in a beaker (preferably the water the *Elodea* was in) to fill four test tubes in a beaker. Add five to six drops of phenol red to the water (in the beaker) to give it a good colour.
5. Place an *Elodea* shoot into each of two test tubes and fill with the water–phenol red mixture. Label the tubes 'A' and 'B'. Fill the other two test tubes with more of the same water and label these 'C' and 'D'.
6. Stopper the four tubes and record their colours.
7. Wrap tube A and tube C with aluminium foil.
8. Place all tubes under a grow-lux lamp or in bright light (but not direct).
9. Observe all four tubes the next day. Record any colour changes.
10. Remove the foil from the tubes and leave them in the light for another day. Observe and record their colours.

Results

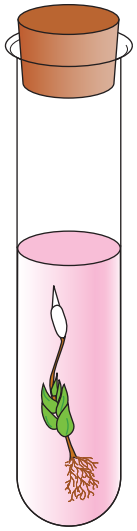
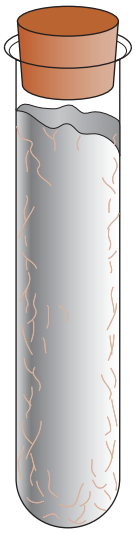
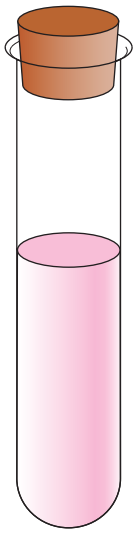
1 Copy Table 2.1 and record the indicator colours for:
   - **a** tap water and phenol red
   - **b** tap water, phenol red and 0.1 M ammonia
   - **c** tap water, phenol red, 0.1 M ammonia and 0.1 M hydrochloric acid.

2 Copy Table 2.2 and record the colour of tubes A to D.

Table 2.1 Reference indicator colours

Tap water and phenol red	Tap water, phenol red and 0.1 M ammonia	Tap water, phenol red, 0.1 M ammonia and 0.1 M hydrochloric acid

Table 2.2 Measuring the effect of light on photosynthesis

	Tube A	Tube B	Tube C	Tube D
	Plant with foil wrap 	Plant without foil wrap 	Foil wrap without plant 	No plant, no foil wrap 
Initial observations				
Colour pH				
Day 1 observations				
Colour pH				
Day 2 observations				
Colour pH				

Pool your data with other groups in the class to establish repetition of samples.

3 Explain the results seen in tube A after one day.

4 Explain the results seen in tube B after one day.

5 Describe the colour of the indicator in tubes A and C the day after the foil was removed. Explain why the indicator was this colour for each tube.

Discussion

1 Explain why aluminium foil was used to wrap around the test tubes instead of putting them in a dark place.
2 Name the tubes that were the control. List the variables being tested in this experiment.
3 Write balanced equations for:
   a photosynthesis
   b cellular respiration.
4 Describe the conditions under which plants carry out photosynthesis. Describe the conditions under which plants carry out cellular respiration.
5 Explain why it was necessary to stopper the test tubes.
6 Explain why tubes C and D were used.
7 Predict what gas, other than carbon dioxide, could be used as a measure of the rate of photosynthesis and respiration. Explain why the concentration of carbon dioxide is easier to measure in this experiment.
8 Discuss the advantages of using water plants for this experiment.
9 Identify some possible sources of error in your experiment.

Taking it further

Devise an experiment to investigate the effect of different light intensities on the rate of photosynthesis.

Conclusion

1 Propose conclusions about the rate of photosynthesis compared to the rate of respiration if:
   a there is a net production of carbon dioxide
   b there is a net use of carbon dioxide
   c the amount of carbon dioxide remains the same.
2 Discuss what effect light has on the rate of photosynthesis compared to the rate of cellular respiration.

RECALL

- The outputs of photosynthesis are the inputs of aerobic cellular respiration. The outputs of aerobic cellular respiration are the inputs of photosynthesis.
- When the rate of photosynthesis is equal to the rate of aerobic cellular respiration in photosynthetic tissue, there is no net increase or decrease of carbon dioxide or oxygen in the surroundings.
- When the rate of photosynthesis is greater than the rate of aerobic cellular respiration, there is a net increase of oxygen and a net decrease of carbon dioxide in the surroundings.
- When the rate of photosynthesis is less than the rate of aerobic cellular respiration, there is a net increase of carbon dioxide and a net decrease of oxygen in the surroundings.

RECAP 2.5

1 Describe how the net input and output of carbon dioxide is dependent on the rate of photosynthesis.
2 Predict at what time of the day you would expect the greatest output of oxygen from photosynthetic tissue.

Investigation of an issue: Bioethanol burns clean

Refer to Chapter 11 for more information on the investigation of an issue.

Burning *fossil fuels* to generate power is a global concern because of pollution. One fossil fuel is the petrol used to power our road transport. It consists of a blend of liquids refined from crude oil. *Combustion* of petrol produces a mixture of toxic chemicals and *greenhouse gases*. Owing to the class of greenhouse gases released, these emissions persist in the atmosphere for a long time and contribute to the risk of climate change. Furthermore, petrol is not a *renewable energy source*. It is a limited resource that becomes gradually depleted over time. One alternative to fossil fuels that has been proposed is *biofuels*. The advantage of biofuels is that they are considered to be renewable and to 'burn clean' (Sadeghinezhad et al., 2014).

The chief biofuel used in road vehicles today is ethanol derived by fermenting glucose found in food crops such as corn, sugar cane and soybean (Pimentel et al., 2009). This biofuel is renewable because glucose is generated continually by the natural process of *photosynthesis*, and the plants used as a glucose source are easily grown and replaced. Microbes are added to a broth of the plant material and generate ethanol by the process of *fermentation*. Burning ethanol in the presence of oxygen generates energy and releases water and carbon dioxide. During this process of *combustion*, each molecule of ethanol recombines with three oxygen molecules to release two molecules of carbon dioxide and two molecules of water.

Over to you: Developing and evaluating a model for 'clean-burning' bioethanol

Task 1: A number of key science terms in the above passage must be understood in order to discuss the issues it relates to. Identify and define these terms, using your knowledge of the concepts in this chapter or the information given in this passage.
Task 2: Biochemical processes can be represented by word equations with inputs written on the left, outputs on the right, and an arrow pointing from inputs to outputs. Write word equations for photosynthesis, fermentation, and combustion, including the number of molecules involved.
Task 3: Construct a diagram that links the processes (equations) of photosynthesis, fermentation and combustion in a cycle. In particular, consider the links between glucose, ethanol and carbon dioxide. Your diagram functions as a model for how ethanol serves as a 'clean-burning' fuel.
Task 4: Write a 150–200 word caption for your model that explains to a public (non-scientific) audience how ethanol represents a renewable energy source that 'burns clean'.
Task 5: Your model summarises the conversion of compounds (matter) from one form to another. Suggest at least two aspects of ethanol production and consumption that the model fails to address (that is, the model's limitations). For each aspect, propose what type of data you would like to see to be able to consider how effective ethanol is as a renewable energy source.

References

Pimentel D., Marklein A., Toth M. A., Karpoff M. N., Paul G. S., McCormack R., Kyriazis J. & Krueger T. (2009) Food versus biofuels: Environmental and economic costs. *Human Ecology,* 37: 1–12.
Sadeghinezhad E., Kazi S. N., Badarudin A., Togun H., Zubir M. N. M., Oon C. S. & Gharehkhani S. (2014) Sustainability and environmental impact of ethanol as a biofuel. *Reviews in Chemical Engineering,* 30: 51–72.

CONCEPT SUMMARY

Autotrophs

Organisms capable of making their own food from inorganic substances using light (through photosynthesis) or chemical energy (through chemosynthesis); includes green plants, algae and certain bacteria

Autotrophs are producers

Heterotrophs

Organisms that cannot synthesise their own organic compounds from simple inorganic material and thus depend on other organisms for nutrients and energy requirements

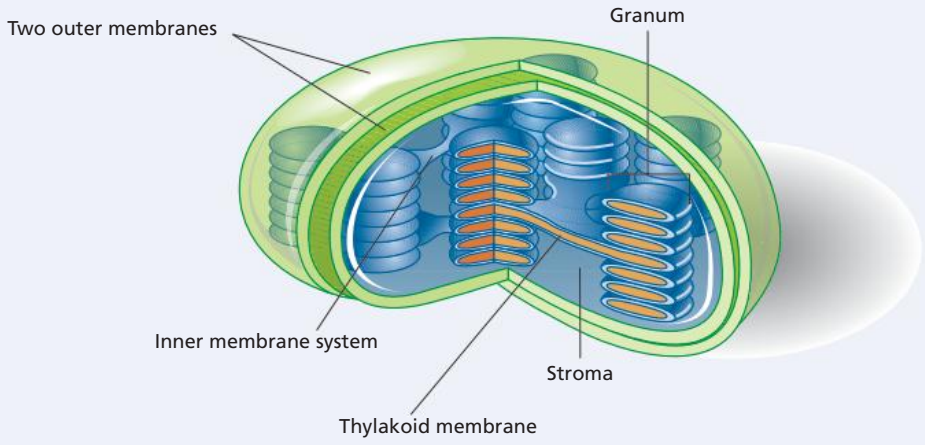
Heterotrophs are consumers

Photosynthesis

carbon dioxide + water → glucose + oxygen + water

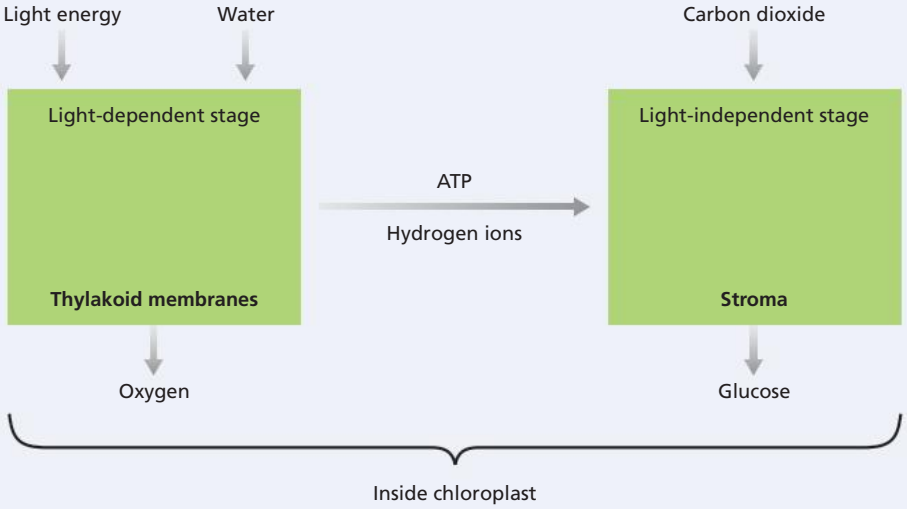
$6CO_2 + 12H_2O \rightarrow C_6H_{12}O_2 + 6O_2 + 6H_2O$

Occurs in chloroplasts



Thykaloid membranes

Stroma



Glucose

Oxygen

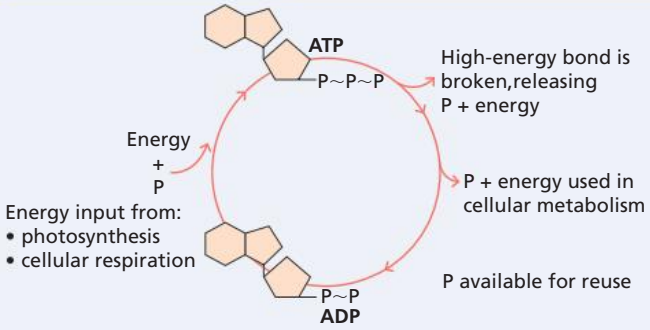
Carbon dioxide

Water

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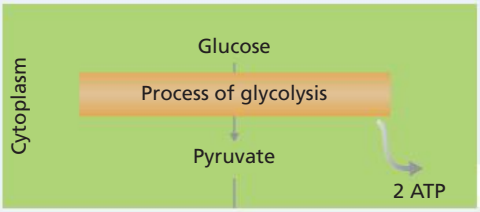
Photosynthesis and respiration are interdependent

ATP: cellular energy



Cellular respiration

Glycolysis



Occurs in cytoplasm

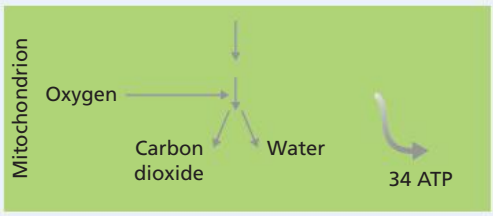
With oxygen

Without oxygen (yeast, some bacteria and plant cells)

Without oxygen (animal cells)

Aerobic respiration

glucose	+	oxygen	→	carbon dioxide	+	water	+	adenosine triphosphate
$C_6H_{12}O_6$	+	$6O_{2t}$	→	$6CO_2$	+	$6H_2O$	+	36ATP



Occurs in mitochondria



Alcohol fermentation

glucose	→	ethanol	+	carbon dioxide	(+	adenosine triphosphate)
$C_6h_{12}O_6$	→	$2CH_3CH_2OH$	+	$2CO_2$	(+	2 ATP)

Occurs in cytoplasm

Lactic acid fermentation

glucose	→	lactic acid	+	adenosine triphosphate
$C_6H_{12}O_6$	→	$2CH_3CH(OH)COOH$	+	2 ATP

Occurs in cytoplasm

CHAPTER GLOSSARY

adenosine diphosphate (ADP) a low-energy compound composed of adenine and ribose and two phosphate groups attached; it is converted to ATP for energy storage when it gains a phosphate group

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

aerobe an organism that requires oxygen

aerobic cellular respiration mitochondrial pathway of cellular respiration that occurs in the presence of oxygen and generates about 36 ATP

alcohol fermentation a form of anaerobic respiration (no oxygen present); glucose is converted to ethanol, a type of alcohol

anaerobe an organism that can live without oxygen

autotroph an organism capable of making its own food from inorganic substances using light (through photosynthesis) or chemical energy (through chemosynthesis); includes green plants, algae and certain bacteria

carbohydrate an organic compound that serves as a structural component and a major energy source in the diet of animals; includes glucose, starches and cellulose

catalysed when the rate of a chemical reaction is increased by a chemical (catalyst) that is unchanged chemically at the end of the reaction

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

cellulose a complex carbohydrate molecule found in cell walls

chemosynthesis the synthesis of organic substances using energy from chemical reactions

chlorophyll the green pigment found in chloroplasts; it is able to absorb light

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

consumer any organism that cannot manufacture its own food, but depends on others for its food

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

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

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

glycolysis an energy-yielding process occurring in the cell cytosol in which glucose is partially broken down to pyruvate in enzyme reactions that do not require oxygen; this first stage of cellular respiration produces two ATP molecules

grana the stack of thylakoid membranes in a chloroplast that contain chlorophyll

heterotroph an organism that cannot synthesise its own organic compounds from simple inorganic material; it depends on other organisms for nutrients and energy requirements

inorganic a compound that is not organic; includes simpler carbon compounds such as carbon dioxide

lactic acid fermentation a form of anaerobic respiration (no oxygen present) that occurs in animal cells and some anaerobic bacteria; glucose is converted to lactic acid

light-dependent stage the first stage of photosynthesis; it requires light energy that is absorbed by chlorophyll; water molecules split to produce oxygen and hydrogen ions and ATP

light-independent stage the second stage of photosynthesis; through a series of reactions carbon dioxide, hydrogen ions and ATP produce carbohydrate

organic describes complex, carbon-containing compounds

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

polymer a large molecule built up from linking smaller molecules together

producer an autotrophic organism that can synthesise organic matter from inorganic matter, using the energy of the Sun (if it is photosynthetic) or that from chemical reactions (if it is chemosynthetic)

pyruvate the end product of glycolysis

stroma the jelly-like, semifluid interior of a chloroplast

thylakoid membrane the interconnected, folded membranes within chloroplasts

CHAPTER REVIEW QUESTIONS

Remembering

1 List the conditions necessary for photosynthesis.
2 Name the product of photosynthesis that contributes to the growth of plants.
3 Describe where glycolysis takes place in all cells.
4 List two differences between aerobic respiration and fermentation.

Understanding

5 Distinguish between the light-dependent and the light-independent stages of photosynthesis in terms of location, requirements and products.
6 Describe two structural differences and two structural similarities between chloroplasts and mitochondria.
7 Compare alcoholic fermentation, lactic acid fermentation and aerobic respiration. In your comparison, you should consider starting materials, end products and energy produced.
8 Are photosynthesis and cellular respiration exact opposites? Explain.
9 Identify the inputs of photosynthesis from which oxygen gas is derived.
10 ATP is an energy-carrier molecule. Explain how its structure is related to its function.

Applying

11 Compare a battery to ATP. Describe how they are similar.
12 Describe the conditions under which aerobic cells carry out fermentation.
13 Figure 2.11 shows the results of an experiment in which the relationship between net carbon dioxide production and uptake by a green plant was investigated.
   a Determine at what time the rate of photosynthesis would be equal to the rate of respiration.
   b Decide if the plant was put in light or dark conditions for the first 10 minutes of the experiment. Explain why you think so.
   c Predict what happened at 10 minutes to cause the change.
   d Suggest a reason why the carbon dioxide uptake levelled off at 30 minutes. Predict some limiting factors.
   e Predict what would happen to cellular metabolism if the temperature surrounding the plant increased beyond the plant's limit.
   f Explain why the carbon dioxide concentration in the air surrounding the plant can be used as a measure of the rate of photosynthesis.

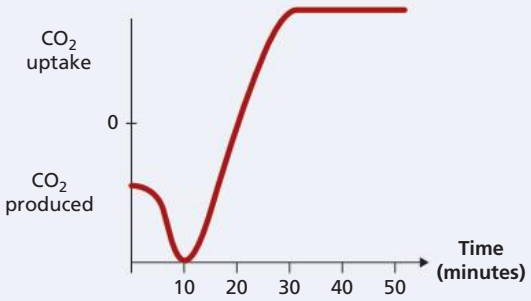


Figure 2.11 ▲ Inputs and outputs of carbon dioxide over time

14 ATP is like currency in an economy. Use the ATP–ADP cycle to explain how it can be likened to spending and earning money.
15 The compensation point is when the rate of photosynthesis exactly equals the rate of cellular respiration. Predict how plant growth is likely to be affected at compensation point.

Analysing

16 If plant cells make their own glucose, explain why they need mitochondria.
17 Predict what would happen to a cell if its mitochondria failed to work.
18 During a heart attack, blood flowing to the heart muscle is interrupted by a blockage of a coronary artery. Predict how you would expect the metabolism in the heart to change.
19 A jar of preserved fruit looks frothy and smells of alcohol. Explain what has happened. Suggest what could be done to prevent this happening.

Evaluating

20 Discuss why alcohol fermentation is used in cake and bread making rather than lactic acid fermentation.

21 'Muscle cells cannot contract when deprived of oxygen.' Evaluate this statement by using your knowledge of pathways for cellular respiration.

22 Chloroplasts were extracted from plants from two different habitats and observed. Plant A grows in open grassland and Plant B grows in a dense tropical rainforest. Predict which plant would have the most thylakoid membranes in their chloroplasts. Explain the reason for your choice.

Creating

23 You are given two test tubes containing two types of yeast cells that are the same in every way except that one can carry out only aerobic respiration and the other can carry out only anaerobic respiration. The tubes are stoppered and labelled A and B. Yeast in tube A grows rapidly, while the yeast in tube B grows slowly. Predict which tube contains the cells capable of performing only aerobic respiration. Justify your choice. Devise an experiment to explain the test result.

24 Your friend says she doesn't believe the air she breathes out contains carbon from the food she's eaten. Outline what you would say to convince her. Explain how what you have learned in this chapter has given you the confidence to answer her correctly.



CHAPTER 3
FUNCTIONING SYSTEMS

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

KEY KNOWLEDGE

Functioning systems

- a study of one selected vascular plant with reference to how its cells are specialised and organised (cells into tissues, and tissues into organs) for the intake, movement and loss of water from the plant
- a study of one selected mammalian system (circulatory, digestive, excretory or respiratory) with reference to how cells in the system are specialised and organised (cells into tissues, tissues into organs and organs into systems), how a specific malfunction can lead to biological consequences and how the system is interconnected to other systems for the survival of the organism.

Investigation of an issue

- the 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
- the nature of evidence and information: distinction between opinion, anecdote and evidence, weak and strong evidence, and scientific and non-scientific ideas; and validity, reliability and authority of data including sources of possible errors or bias

KEY SCIENCE SKILLS

Analyse and evaluate data, methods and scientific models

- take a qualitative approach when identifying and analysing experimental data with reference to accuracy, precision, reliability, validity, uncertainty and errors (random and systematic)
- explain the merit of replicating procedures and the effects of sample sizes in obtaining reliable data
- evaluate investigative procedures and possible sources of bias, and suggest improvements

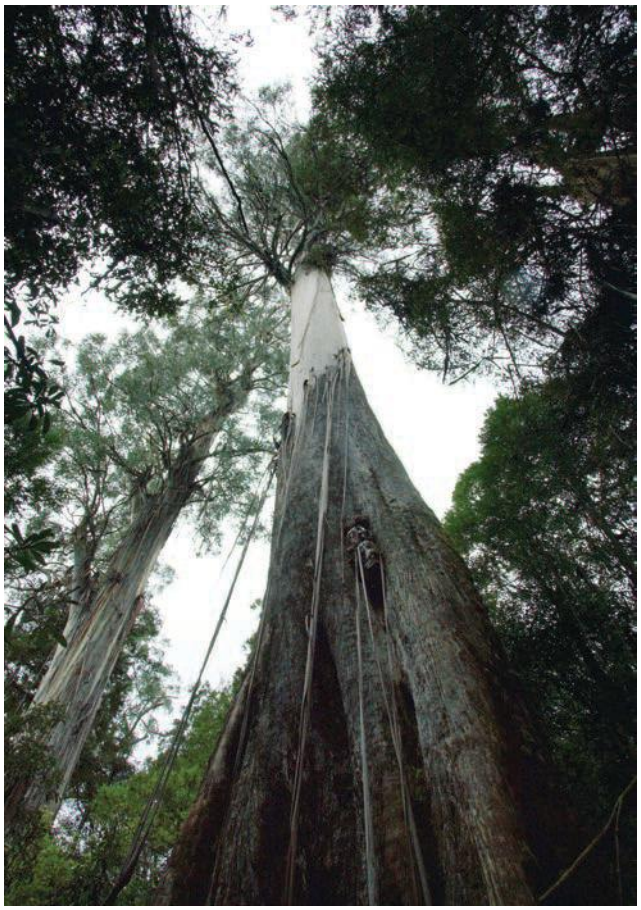
Draw evidence-based conclusions

- determine to what extent evidence from an investigation supports the purpose of the investigation, and make recommendations, as appropriate, for modifying or extending the investigation
- draw conclusions consistent with evidence and relevant to the question under investigation
- critically evaluate various types of information related to biology from journal articles, mass media and opinions presented in the public domain
- discuss the implications of research findings and proposals

Communicate and explain scientific ideas

- discuss relevant biological information, ideas, concepts, theories and models and the connections between them
- use clear, coherent and concise expression
- acknowledge sources of information and use standard scientific referencing conventions

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Forestry Tasmania, photo by Richard Bennett

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

The redwoods, or Sequoias, of California are famous for being among the tallest trees in the world. There is one redwood in California recorded at 115 m. The tallest flowering tree species in the world is *Eucalyptus regnans*. Known as mountain ash in Victoria and swamp gum in Tasmania, there is one specimen a few kilometres from Hobart that is 101 m tall. Aptly named 'Centurion', this particular swamp gum is estimated to be around 400 years old and is the tallest flowering plant and hardwood tree in the world. One of the greatest physiological challenges for tall trees is how to draw water and nutrients from the roots to the canopy. This requires many kilograms of water to be lifted through vertical distances of 50–100 m up the trunk of the tree against the force of gravity.

Water transport in vascular plants

While multicellular plants do not possess all of the same systems that animals do, they have specialised cells that make up tissues with specific functions to assist in their survival. The individual cells are organised into **tissues** (such as clusters of photosynthetic cells), which form the **organs** (such as the leaf) of the plant body. Each of these tissues is specialised to perform important functions that support the life of the organism. These include obtaining energy, producing organic compounds, distributing materials, removing wastes and exchanging gases. In a vascular plant, specialised cells and tissues distribute organic compounds, water, minerals and gases around the plant. **Vascular tissue** is involved in the transport of substances in plants. The structure of vascular tissue ensures that each organ – the leaves, stem, roots, flowers and seeds – receives what it needs. The organs are grouped as systems. In plants there are two systems: the shoot system and the root system.

1 The shoot system is comprised of all parts of the plant found above ground. It is responsible for the transportation of resources, the absorption of oxygen and carbon dioxide, reproduction and carrying out photosynthesis in leaves.
2 The root system is below ground and is responsible for absorbing water and nutrients from the soil.

Obtaining water can be a challenge to many organisms. Autotrophs such as plants are generally immobile. Unlike animals, which can move to find water, plants require a local water supply. With the exception of the algae and aquatic plants, plants obtain their water through the roots from soil. Life in a **terrestrial** environment necessitates a root system to obtain water and a specialised transport system of vascular tissue to move the water from the roots to the leaves.

Water is absorbed initially by the roots and moves against the pull of gravity up through the stem to the leaves. When we look at how that occurs, we find the plant is best serviced by a one-way water movement system – the **xylem**.

Vascular tissue is composed of two different types of tissues: xylem and **phloem**. Phloem is composed of thin-walled cells that transport sugars, in the form of sucrose, and other plant products from one part of a plant to another. Xylem is responsible for the transport of water, along with nutrients and minerals, absorbed from the soil through the root system. It is made up of two types of cells: **tracheids** and **vessel elements**

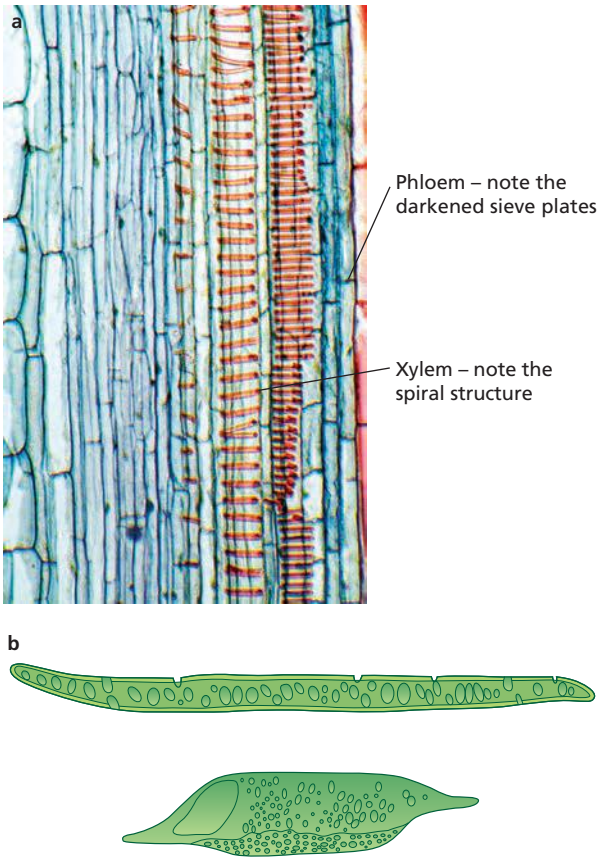
(Figure 3.2). These tissues consist of tubular, elongated cells that allow water to pass freely. As xylem cells mature, they die, leaving behind hollow cells supported by the remaining cell walls. The cell walls contain a strong substance called **lignin**, which is one of the most abundant organic polymers on Earth. The hollow cells of xylem are ideally suited to the transport of water. The dead xylem tissue forms the woody part of many plant stems. Wood is composed entirely of xylem tissue and provides the main support for most large plants such as trees.

The root system

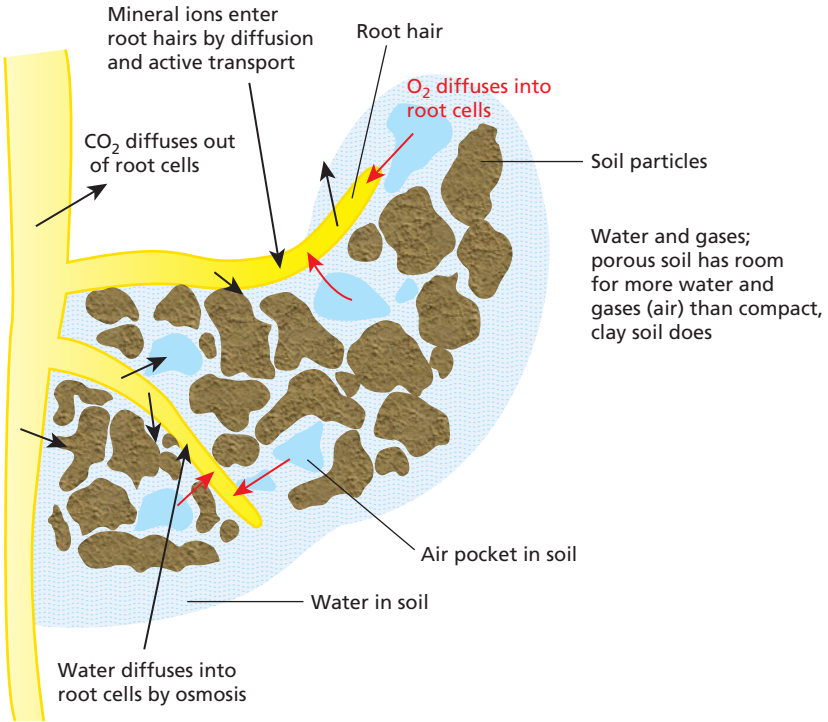
So how does the water in the ground reach the uppermost leaves of the plant? Some of these leaves can be more than 100 m above the ground. Part of the answer lies hidden below ground, in the plant's root system. Sometimes the root system is larger than the plant's entire shoot system.

The roots of a plant have several functions. They absorb water and minerals from the soil, support and anchor the plant and, in many plants, they are the main storage tissue.

As well as anchoring the plant, the roots provide the surface through which water is taken up. This surface area is greatly increased by the presence of thousands of root hairs along the tip of the root. A plant's root hairs provide an enormous surface area across which water is absorbed. This can be up to 130 times greater than the surface area of its shoot system.



▲ **Figure 3.2**
(**a**) A micrograph image of a longitudinal section of a stem, showing xylem and phloem tissue. (**b**) Diagram of xylem tracheid (long and thin) and vessel (open-ended) element



◀ **Figure 3.3**
Water and dissolved ion uptake and gas exchange across root hairs in soil.

Each root hair is a slender extension of each root epidermal cell that makes up the **epidermis**. These extensions increase the surface area for water absorption. The root hairs penetrate between the soil particles and are immersed in the soil water. The water can easily move from the soil into the epidermal cell through its cell wall and plasma membrane. The root hairs are generally found just behind the root tip. Here they take up water six times faster than regions that are further back along the root.

Beneath the epidermis, large, thin-walled **parenchyma** cells make up the main root body. In the centre, there is a core of vascular tissue that consists of several groups of xylem cells (made of lignin) between which are distinct groups of phloem cells. The vascular tissues are arranged in such a way that, as the root grows into the soil, the vascular tissue also extends down the centre of the root, enabling the transportation of materials. These two tissues have distinctive parts to play in transporting materials and in many plants they also strengthen the root system.

Water and dissolved minerals enter the root from the soil by the process of **osmosis** in the case of water molecules, and by **diffusion** and **active transport** in the case of dissolved ions. Once inside the root hair, the water moves to the parenchyma cells and into the xylem vessel via pits in the cell walls. The force of the water entering the root and 'pushing' its way into the cells creates pressure (Figure 3.4).

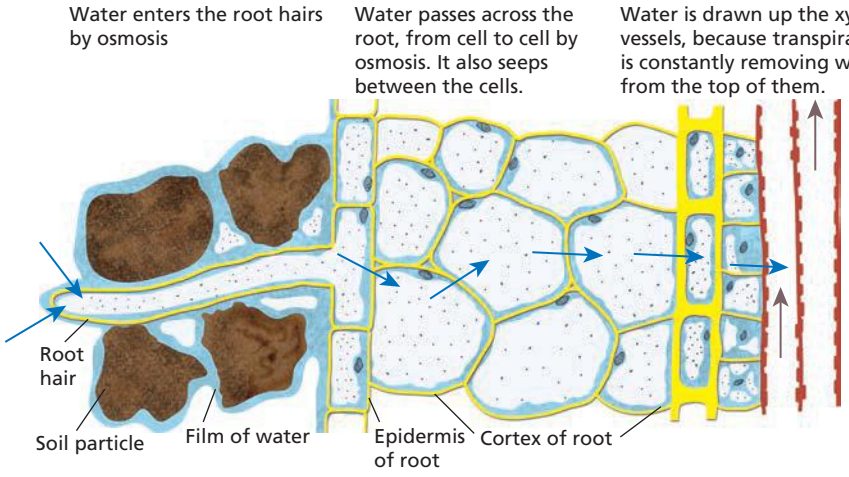


Figure 3.4 ▶ Movement of water through root epidermal cells, through the root cortex and into the xylem tissue where it is drawn upwards via transpiration (see page 71)

Chapter 1 explained processes by which substances move into and out of cells.

If the stem of a plant is severed, the cut end will exude copious amounts of water for some time. This suggests that there is a force pushing water up the stem from the roots. This force is known as **root pressure**, as discovered by Stephen Hales in 1727. Hales found that root pressure could be responsible for raising water to a height of over 6.4 m in a vine. This forces water into the plant and works to ensure that the water and minerals reach the vascular tissue of the stem. There are, in fact, more processes involved in moving water from roots to leaves than just root pressure.

RECALL

- In plants there are two systems: the shoot system and the root system.
- Vascular tissue is involved in the transport of substances in plants. Xylem is a water-conducting tissue composed of tracheids and vessels. Phloem tissue transports sugars and other plant products around the plant.
- Root hairs increase the surface area for water absorption.
- Water and dissolved minerals enter the root from the soil by the process of osmosis in the case of water molecules, and diffusion and active transport in the case of dissolved ions.

RECAP 3.1

1 Describe the function of vascular tissue in plants.
2 Name the two types of vascular tissues in plants.
3 List three functions of roots.
4 Explain how a plant increases its surface area for water absorption.

The shoot system

Water and dissolved minerals continue their journey to the leaves via the stem of the plant. To understand how this happens, we must first look at the internal structure of the stem, in particular, the vascular tissues.

The structure of the specialised tissues and their arrangement in the stem makes it possible for water and mineral ions to move upwards, sometimes to great heights. These tissues, along with phloem tissue, are grouped into a series of **vascular bundles**, each rather like an electric cable in the stem (Figure 3.5). The veins visible on a leaf are vascular bundles.



Getty Images/Science Photo Library/Steve Gschmeissner

▲ **Figure 3.5** Cross-section of vascular bundles in the stem of a geranium. The xylem and phloem transport different resources.

The way water moves through a plant, specifically through the roots and stem to the leaves, involves many connected processes. We have looked at root pressure created when water enters the plant cells, but what aids the movement of water up the stem as root pressure is reduced?

If you examine a glass of water, you can observe how water is curved up against the sides of the glass. It is easy to see this effect in a narrow measuring cylinder. It can be explained by **adhesion**, the forces of attraction between water molecules and the molecules that make up the sides of the container. The narrower the tube the water is in, the further the molecules reach up the side. Xylem vessels are very narrow, so water is able to climb some distance up these tubes by adhesion forces alone. However, the problem is not only how to hold up the column of water, but also how to prevent it from breaking in the middle. What is responsible for this? Forces of attraction between the water molecules themselves help to pull the molecules up the narrow xylem vessel. This is **cohesion**. But there is another problem. If you suck water up a straw too hard, the walls of the straw will collapse and the column of water breaks. In the xylem, the thickened, lignified walls normally prevent this from happening. The tension in the xylem of a eucalypt is extreme, but the strength of the water columns must be sufficient or tall trees would not be able to exist. Therefore, the combined forces of root pressure, adhesion and cohesion ensure the continuous column of water movement through the xylem tissue in the stem of the plant.

This constant upwards movement is driven by the evaporation of water from the leaves: **transpiration**. The continuous column of water through the plant is known as the **transpiration stream**. Continuous columns of water therefore extend from the top

of the plant, from the leaves, down through the xylem to the roots. The force that holds them there is generated by the Sun evaporating water from the leaves to the atmosphere, and by the forces that act on the water in the stem. This process, where the water is pulled up vertically through the xylem, is called **transpirational pull**.

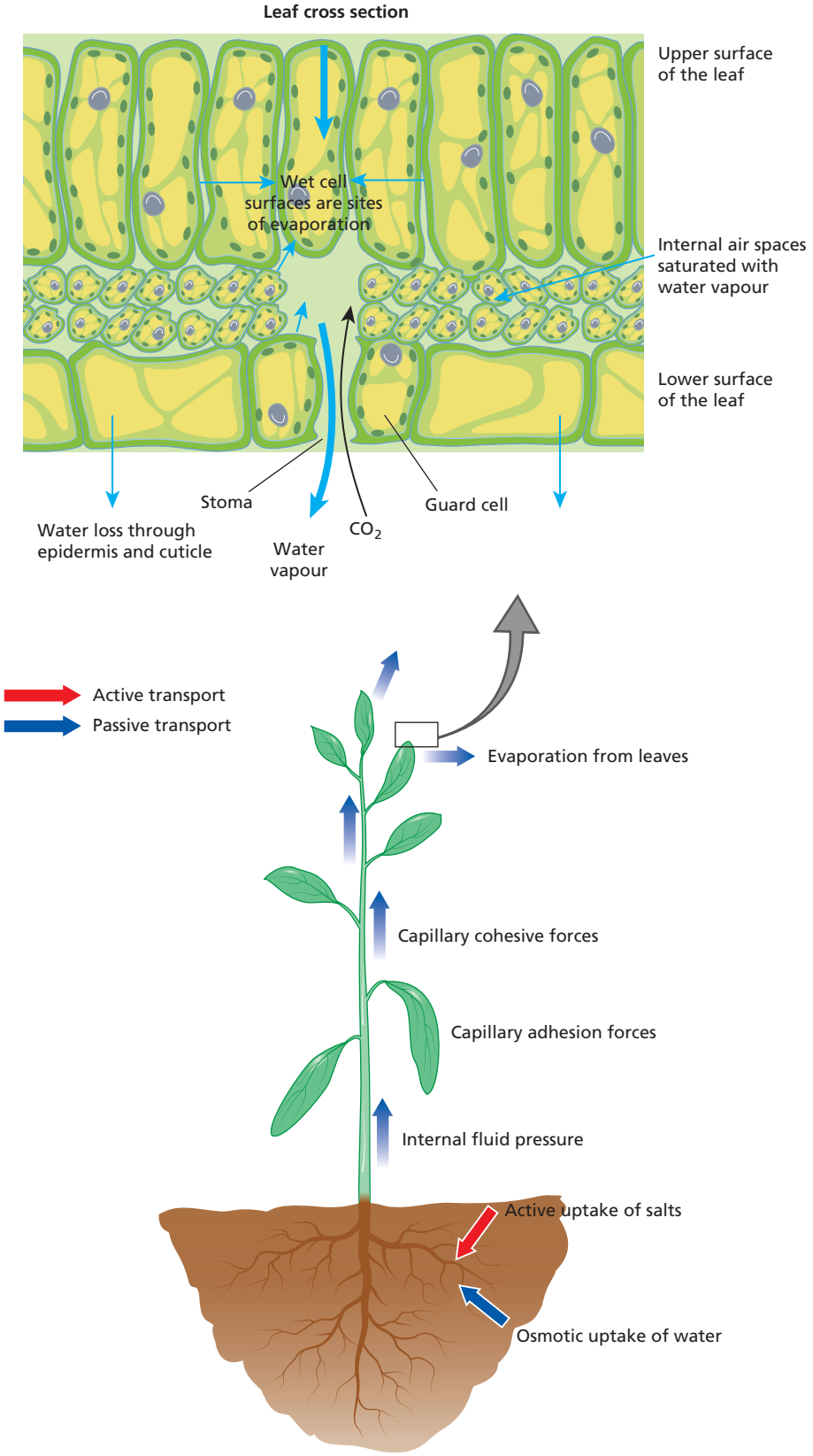


Figure 3.6 ▶
The process of transpiration in plants. The process is solar powered.

When a plant loses more water through transpiration than it takes up through its roots, it wilts and is said to suffer from water stress. When there is a lot of water in a solution, we say that the solution has a high water potential, and it is a dilute solution. A more concentrated solution has less water and so has low water potential. Pure water has the highest water potential. The loss of water from the leaves raises the tension of the water columns in the xylem, and the **water potential** gradient from the soil (high water potential) to the xylem (lower water potential) increases. As a result, the roots remove increasing amounts of water from the soil. Once the flow of the water to the roots slows down, pores in the leaves called **stomata** (singular stoma, see Figure 3.6) close rapidly, thereby keeping water loss to a minimum.

RECALL

- The combined forces of adhesion and cohesion ensure a continuous column of water movement through the xylem tissue in the stem of a plant.
- Water and minerals enter at the roots, and water exits via stomata in the leaves.
- Movement through xylem is due to a combination of root pressure and transpirational pull.

RECAP 3.2

1 List the features of xylem that make it effective in transporting water around the plant.
2 Explain the forces that enable water in a xylem vessel to reach the top of a tree.
3 Explain where the energy for transpiration originates.

EXPERIMENT 3.1

PLANT TRANSPORT SYSTEMS

Water is an essential requirement for photosynthesis to occur. As photosynthesis mostly occurs in the leaves of plants, water and the substances dissolved within it move through vascular plants in the xylem, from the roots to the leaves. Xylem consists of hollow cells of tracheids and vessels.

Aim

To examine how water is transported through a celery stalk and leaves

Materials

Each group will require:

- stick of celery that has been standing in red food dye or eosin for several hours, cut 2 cm from its base
- single-edged razor blade
- microscope, stereo microscope or hand lens
- microscope slides and coverslips
- mounted needles (optional)
- millimetre ruler
- transverse and longitudinal stem sections of *Helianthus* (for Taking it further)

What are the risks in doing this experiment?	How can you manage these risks to stay safe?
Razor blades are sharp and can easily cut skin.	Handle razor blades carefully and report any injuries to your teacher immediately.
Food in the lab can be contaminated.	Do not eat the celery.

Procedure

1. Remove the celery from the coloured solution.
2. Examine the stalk and leaves for spread of the dye; holding them up to the light may help. Observe the areas where the dye is concentrated. Draw the distribution of dye in the leaf.
3. Cut thin transverse sections (1 mm) across the stem and branch (and leaf if possible). Arrange the sections onto a microscope slide.
4. Examine the sections under low power and make diagrams showing the distribution of the dye.
5. Cut another 1–2 mm piece of stem.
6. Use the razor blade to cut out a small piece of the area coloured by the dye and put this on a microscope slide.
7. Use a couple of razor blades or mounted needles to tease the piece of tissue apart.
8. Add a coverslip, using a drop of water if the tissue is becoming dry.
9. Use low power, then high power to find 'spirals' or 'coils'. Draw these structures.

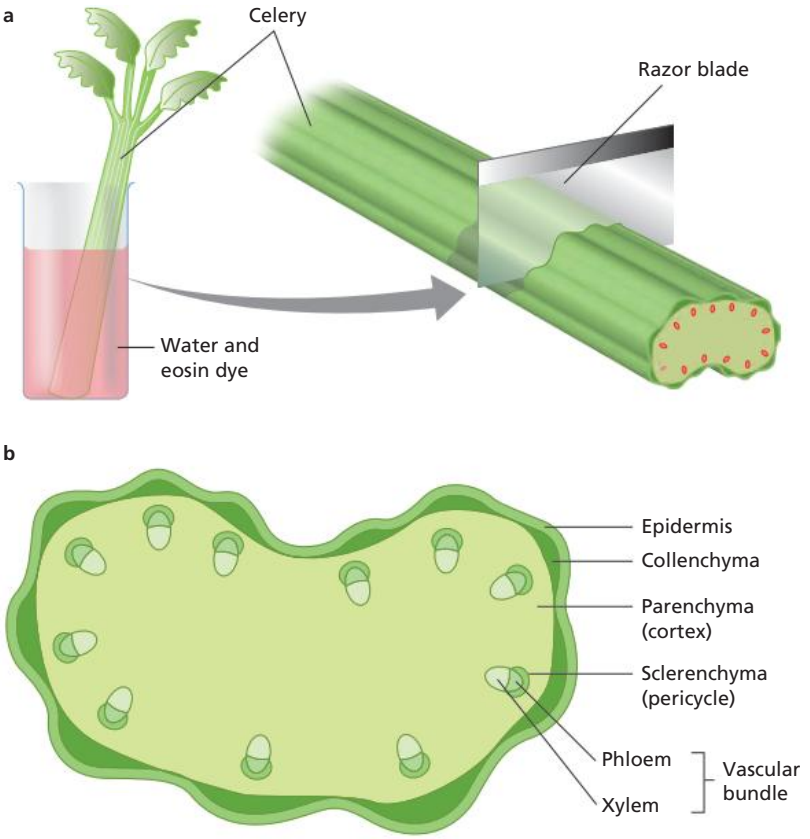


Figure 3.7 ▲
Movements of materials in xylem: (**a**) experiment using celery to show the movement of materials in xylem; (**b**) transverse section through celery stem, showing tissue distribution (light microscope view)

Discussion

1. Describe how the dye is distributed in the plant. Has the whole stem turned a little pink or is the dye found in particular places? Explain your answer.
2. Discuss the assumption that the dye shows us where the xylem is.
3. Suggest what causes the dye to travel to the leaves.
4. If a stem is placed in Indian ink, which is a mixture of small particles rather than a solution (which the red dye is), the colour does not reach the leaves. Explain why this would be the case.

5 **a** Name the types of cells that the coils and spirals you should have seen are found around.
b Identify what the spirals are made of.
c The spirals have functions equivalent to those of the spirals of cartilage around the trachea. Suggest their functions.

Taking it further

1 Examine prepared slides of transverse and longitudinal stem sections of *Helianthus* (sunflower) or another suitable plant. If the slide has been prepared with toluidine blue, lignin will be stained a greenish-blue colour; unlignified cell walls tend to stain a reddish-purple. Alternative stains may make the lignin a reddish colour.
a Draw some diagrams from the longitudinal and cross-sections, showing where the regions of xylem (lignified areas) and phloem are. You should also be able to draw other types of spirals and coils.
b In the phloem you may be able to find some sieve plates, sieve tubes (same diameter as the sieve plates) and companion cells (smaller). Draw and label all these.

Mammalian systems: The digestive system

All organisms require access to nutrients that must eventually reach cells. We have examined the movement of nutrients through a multicellular autotroph, but how exactly do nutrients reach all the cells of a multicellular **heterotroph**?

In order to answer this question we will first investigate the nutritional needs of heterotrophs, specifically humans. **Digestion** in humans involves the unwrapping and breakdown of large 'packages' of energy and nutrients. The largest packages are in the form of the food taken in, such as bread, meat, butter, fruit and vegetables. The nutrients within these packages, however, are mainly the complex forms of substances such as carbohydrates (starch and cellulose), proteins and lipids (oils and fats). These complex forms are too large to pass across the plasma membrane and into the cells where they are required. Digestion is the process whereby the large complex molecules that make up our food are broken down into simple substances that are small enough to be able to move across the plasma membrane and into the **internal environment**. Digestion takes two forms.

1 **Mechanical digestion** (physical digestion) is when large pieces of food are broken down into smaller pieces through chewing or muscular movement in the stomach. The aim of this is to increase the surface area of the food so it can be acted on by enzymes in chemical digestion.
2 **Chemical digestion** is when enzymes break down complex substances into their simplest forms, such as carbohydrates to glucose, proteins to amino acids, and lipids to glycerol units and fatty acid chains. These are chemically different substances.

Digestion takes place in the **digestive system** (also called the **gastrointestinal tract**). The digestive system has four main roles that involve the functioning of specialised structures.

1 **Ingestion**: the taking in of nutrients
2 **Digestion**: the breakdown of complex molecules into smaller components by chemical means
3 **Absorption**: the taking up of digested molecules into the internal environment of the cells of the digestive tract
4 **Egestion**: the removal of waste food materials from the body

In humans, the digestive system can be considered to be one long tube made up of many different types of tissues, open at both ends.

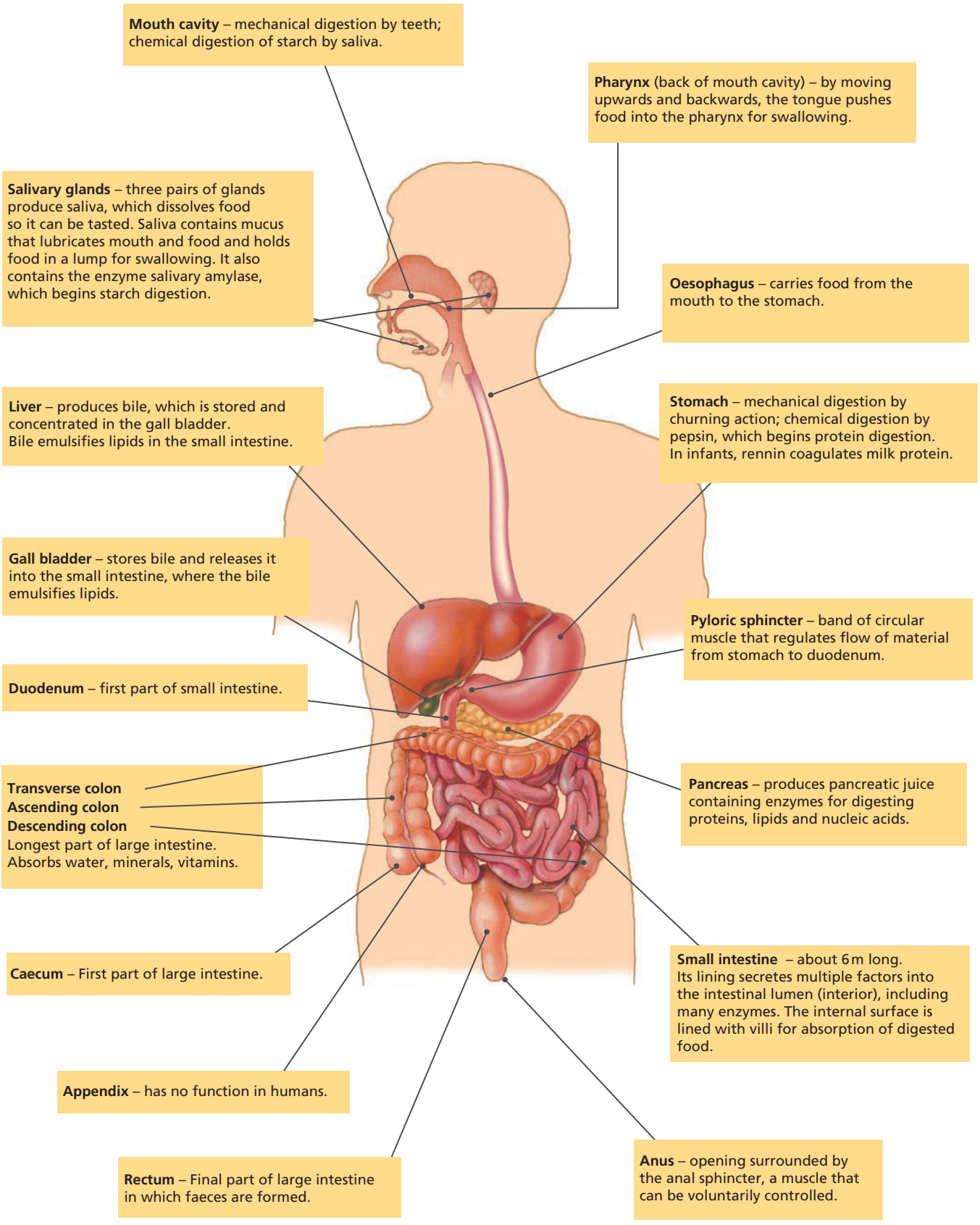


Figure 3.8 ▲
The structure and functions of parts of the digestive system

Ingestion

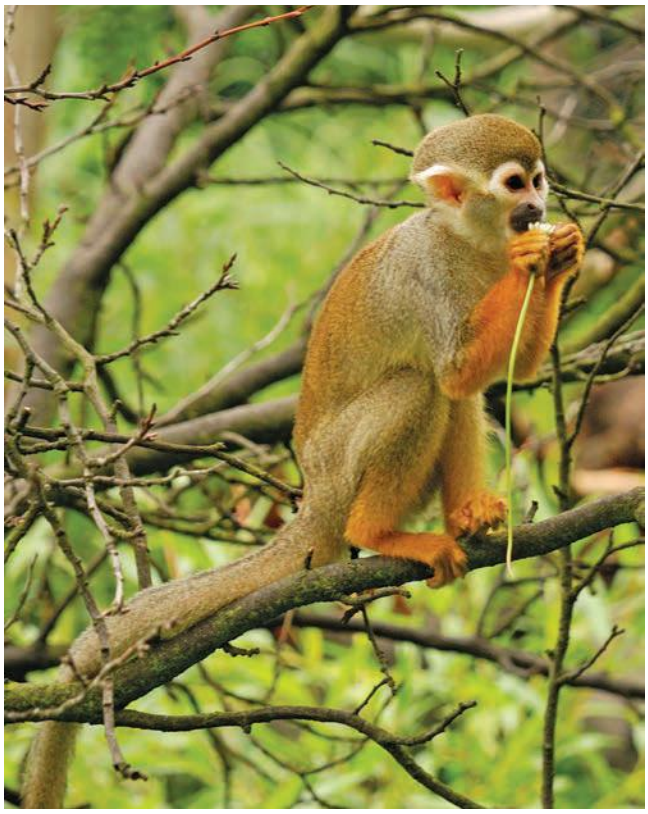
Most animals ingest food through the mouth. Once food has entered the mouth, mechanical and chemical digestion commences – the first stage of breaking food down. The molar teeth at the rear of the mouth help to grind the food into smaller pieces. The tongue, a strong muscle, helps to move the food around the mouth, thereby increasing the food's contact with the teeth. As this is happening, the enzyme **amylase** is secreted from salivary glands situated near the base of the tongue. This enzyme is present in saliva and is specifically suited to the chemical breakdown of complex carbohydrates, such as starch, into simpler carbohydrates, such as maltose. The action of the teeth increases the surface area of the food for greater action by the enzyme.



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▲ Figure 3.9
Different animals have different methods of getting food into their mouths.

Digestion and secretion

Once the food is ready for swallowing, it moves to the back of the mouth and, with the assistance of the tongue, is pushed into the **oesophagus**. The oesophageal opening is extremely close to the opening of the trachea (windpipe). A small flap of tissue, the epiglottis, closes off the trachea, preventing food from entering the respiratory tract. The food moves down the oesophagus with the aid of unidirectional muscular contractions known as **peristalsis**. Some chemical digestion of starch will continue here until the food reaches the stomach.

In the stomach

The stomach is a muscular part of the gut with the potential to stretch significantly. In animals with specialised diets, this is a very useful ability. The vegetarian koala and wombat eat vast amounts of low-energy food and require a space where the digestion of hard material can take place. Circular muscles called **sphincters** regulate the movement of food into and out of the stomach. Sphincters act like the drawstrings on a bag: when the sphincter muscles contract, the opening closes.

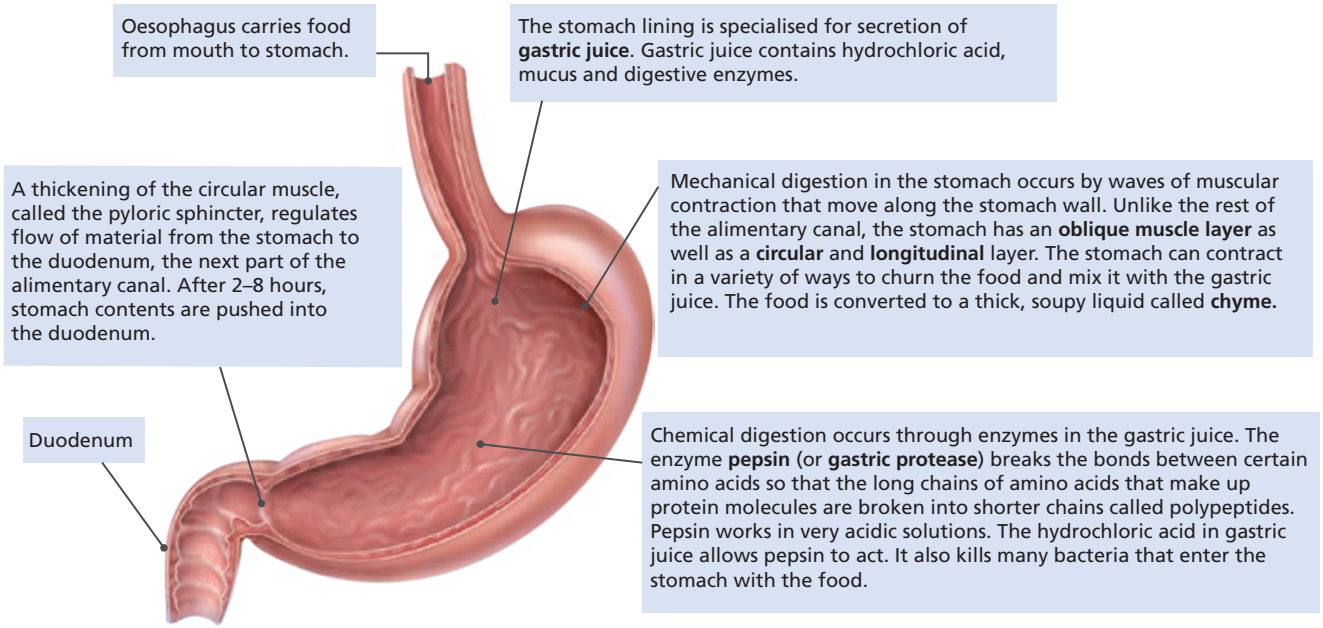
Mechanical digestion occurs in the stomach as the muscles of the stomach wall relax and contract. The food is still in very large pieces and the aim is to allow the enzymes easy access to most of the surface of the food. The main focus of digestion in the stomach is the chemical digestion of proteins.

The presence of food in the stomach stimulates the production of **gastric juice** from cells lining the stomach wall. This contains mucus, water, hydrochloric acid and the protein-digesting enzymes pepsin and protease. The presence of hydrochloric acid makes the pH of the stomach around 2.0–3.0; the perfect environment for the action of specialised gastric enzymes. These enzymes break down the long-chain **polypeptides** of proteins into smaller-chain polypeptides.

Mucus is also secreted by cells lining the stomach wall. It acts to protect the epithelial lining of the stomach from being digested by the enzymes because the cells that line the stomach also contain protein.

Food will remain in the stomach for up to six hours until it resembles a 'soupy' substance known as **chyme**. However, further digestion along the length of the gastrointestinal tube is required before the molecules that make up food are in a small enough form to be absorbed into the cells of the body.

Figure 3.10 ▼
The stomach and its functions



In the small intestine

From the stomach, digested food then moves into the **small intestine** by the actions of peristalsis. A small muscular opening, known as the **pyloric sphincter**, found at the base of the stomach, controls the amount of food leaving the stomach and entering the small intestine. This prevents too much food entering the small intestine too quickly. In adult humans, the small intestine is approximately 7 m long, having a surface area of 4500 m^2. There are three defined regions in the small intestine:

1 the duodenum (about 26 cm long)
2 the jejunum (about 2.5 m long)
3 the ileum (about 3.5 m long).

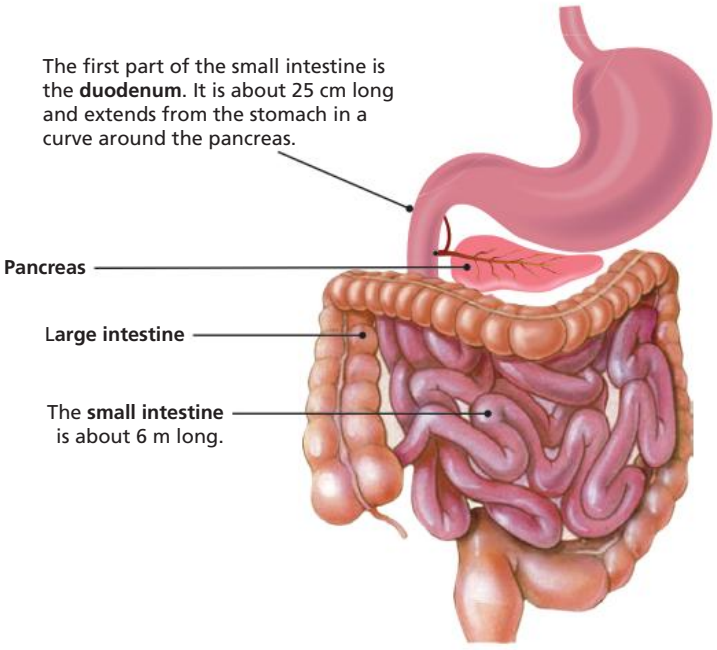
Secretions from the pancreas enter the duodenum at the top of the small intestine. These secretions, known as **pancreatic juice**, contain a mixture of amylase, trypsin, lipase and bicarbonate. The chyme entering the duodenum is combined with the hydrochloric acid from the stomach. The stomach produces great quantities of mucus to protect its walls against the acidic environment. The duodenum does not produce mucus but the acid must still be neutralised. Bicarbonate secreted from the pancreas neutralises

the acidity of the digested food coming from the stomach. This also stops the action of pepsin and protease.

Bile, a substance produced by the liver, passes down the bile duct and into the duodenum. If there is no food to digest in the small intestine, the bile is stored in the **gall bladder**. Bile is involved in the mechanical breakdown of fats. Bile is not an enzyme but instead has a detergent-like action on the fats. It acts mechanically to emulsify fats down into smaller pieces, increasing the surface area for the action of the enzyme lipase. Lipases are enzymes that are produced by the pancreas and act on the fat droplets. They chemically break down fat into fatty acids and glycerol.

Proteins consist of amino acids joined together chemically to form small peptide chains. These join together to form polypeptides, which in turn join to form a protein. Peptides, polypeptides and proteins are terms used to describe amino acid strings of various lengths. There are two different groups of enzymes that break down proteins. The pancreas produces the enzyme trypsin. This enzyme acts on the long-chain polypeptides and breaks them down to shorter-chain peptides. A second group of pancreatic enzymes, erepsins, completes the digestion of the short-chain peptides by breaking them down into individual amino acids.

From the duodenum, food enters the jejunum. The jejunum is largely responsible for absorbing the majority of nutrients. The last section of the small intestine, the ileum, is specialised to absorb vitamin B_{12} and bile salts. Digestion of proteins continues and eventually the amino acids are available for absorption into the blood, and from there travel to the body cells. Carbohydrates continue to be broken down into simple sugars such as glucose, which can also be absorbed.



▲ **Figure 3.11** The location of the small and large intestines

RECALL

- Digestion is the process that breaks down large complex molecules into simple substances.
- Mechanical digestion increases the surface area of food particles on which digestive enzymes may act. Chemical digestion involves acid and the actions of digestive enzymes on the nutrients, ensuring they are of a molecular form and size that can be absorbed by cells in the body.
- The role of the digestive system includes ingestion, digestion, absorption and egestion.
- Starch digestion starts in the mouth, and protein digestion starts in the stomach. Digestion is completed and most nutrients are absorbed in the small intestine. The pancreas secretes the main digestive enzymes. Bile from the liver assists in fat digestion.

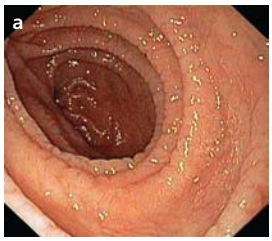
RECAP 3.3

1 Describe the main functions of the digestive system.
2 Name the process and describe the way food is moved from the mouth to the stomach.
3 Explain how gastric juice aids in digestion.
4 List the three regions of the small intestine and what occurs in each.

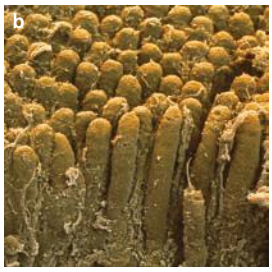
Absorption

The digestive tract discussed so far is considered to be part of the **external environment** of the animal. The products of digestion are now ready to be removed from the digestive tract and transported across a plasma membrane and into the internal environment of the animal, into the bloodstream. Absorption of nutrients can occur along the length of the gut. Substances such as alcohol and some drugs can be absorbed through the stomach wall into the bloodstream. Because of this, the effects of such substances are felt very quickly. However, most nutrients are absorbed along the length of the small intestine.

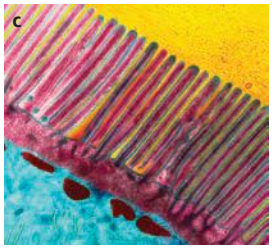
In the small intestine, nutrients such as glucose, amino acids, fatty acids and glycerol move from the gut into the blood by means of diffusion and active transport. The structure of the small intestine is perfect for the uptake of nutrients. The lining is moist and thin with a rich supply of blood vessels and is highly folded, providing extra surface over which nutrients can be absorbed. Special structures, known as **villi**, project from the surface of the small intestine tissue, greatly increasing the surface area of the gut lining. Villi are covered with microscopic **microvilli**, which further increase the surface area (Figure 3.12). Each villus is supplied with a network of capillaries that intertwine with **lymph** vessels called **lacteals** that transport materials. Glucose and amino acids are absorbed into the capillary network; fatty acids and glycerol are absorbed by the lacteals and enter the **lymphatic system**. Along with the digested nutrients, water absorption also occurs in the small and large intestines.



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Science Photo Library/Steve Gschmeissner

Figure 3.12 ▲
(**a**) Folds of the mucosa on the inside of the small intestine. (**b**) Villi cover the internal surface of the small intestine as seen in this scanning electron micrograph. (**c**) Electron micrograph showing microvilli that cover the surface of each villus.

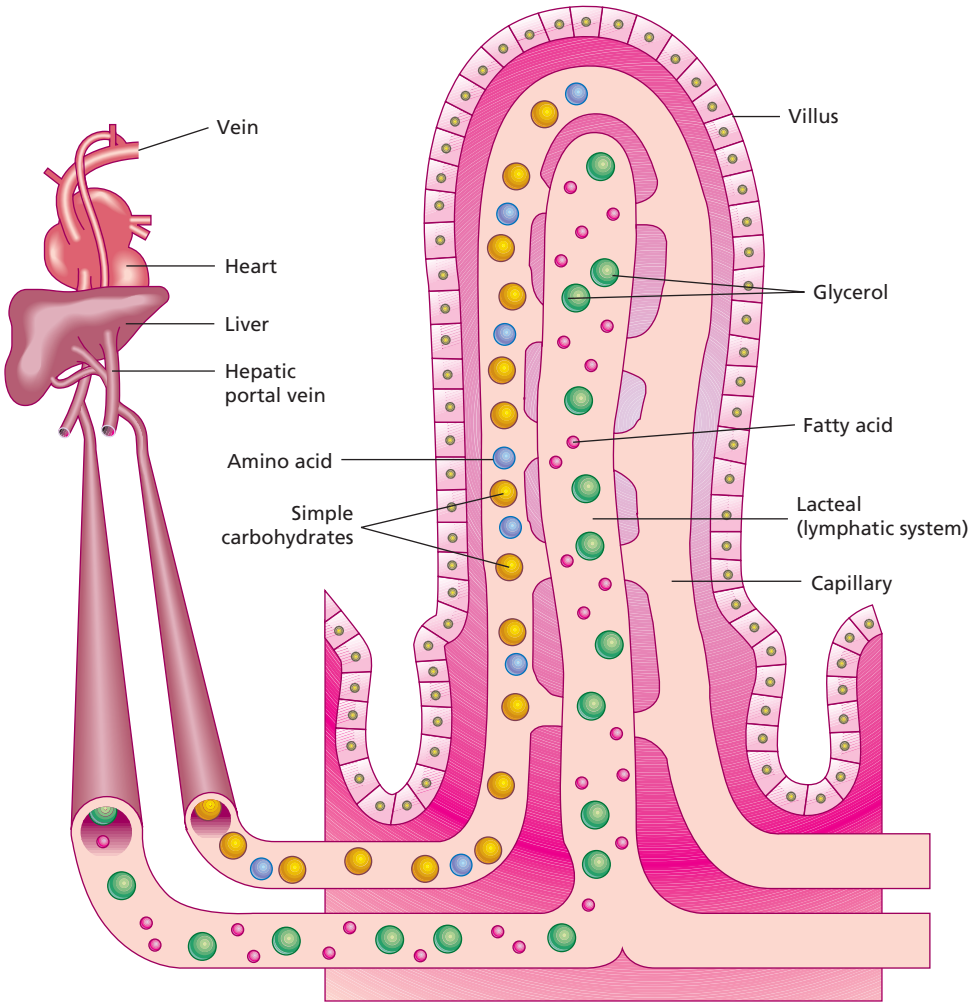


Figure 3.13 ▶
Cross-section of a villus. Amino acids and simple carbohydrates are absorbed into the villi lining of the small intestine.

Egestion

The **large intestine** is the final length of the gut. This section consists of two main parts, the **colon** and the **rectum** (Figure 3.14). The main functions of the large intestine are to compact undigested food material, such as dietary fibre, and to absorb water and some salts back into the body. Bacteria present in the colon act on the undigested matter, producing vitamins A and K. These vitamins are absorbed through the lining of the large intestine. Peristalsis continues through the large intestine, pushing the waste material into the rectum. This waste material, **faeces**, is eliminated from the body through the **anus**.

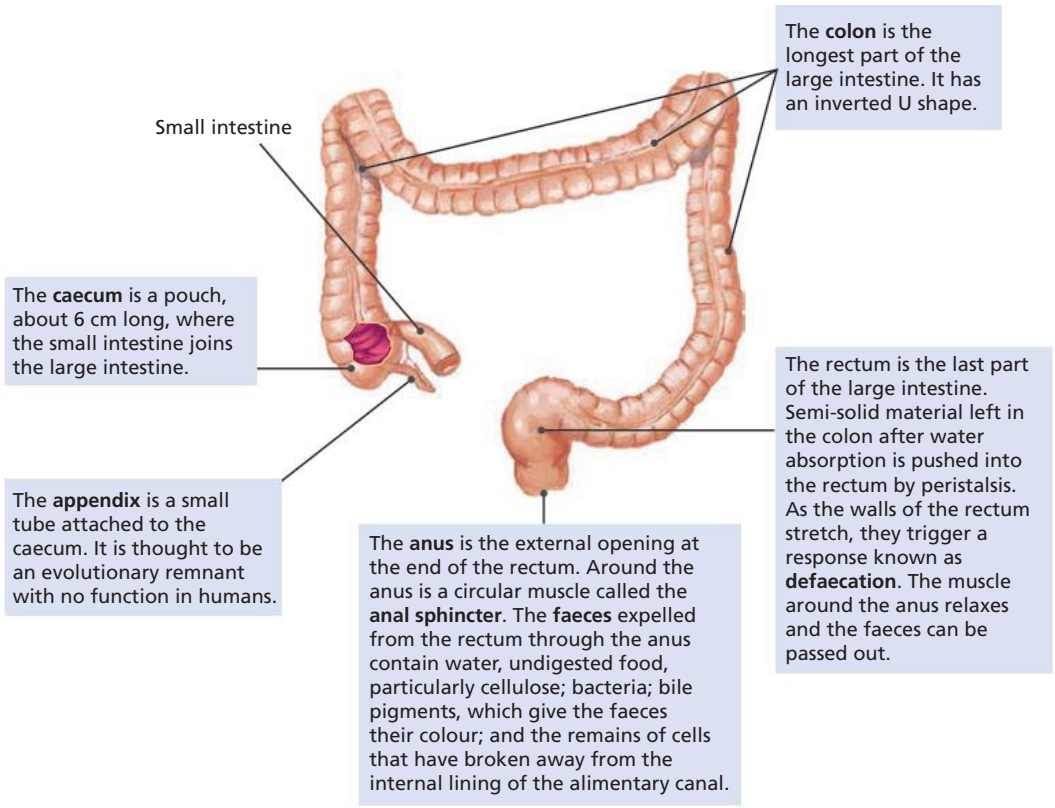


Figure 3.14
The parts of the large intestine and their functions

RECALL

- The products of digestion are moved from the external environment of the digestive tract to the internal environment of the bloodstream in the small intestine.
- Villi and microvilli increase the surface area of the gut lining, facilitating efficient absorption.
- In the large intestine, water and some salts are absorbed back into the body and undigested food material is compacted for excretion through the anus.

RECAP 3.4

1. List, in order, the structures that food must pass through in a typical mammalian digestive system.
2. Describe the two ways that absorbed nutrients leave the intestine and get into body cells.
3. Name structures that assist in increasing the surface area of the digestive system. Explain how their features facilitate absorption.
4. Draw an outline of a human and their digestive tract. Shade all areas that are considered to be the external environment.

Mammalian systems: The circulatory system

The body's main internal transport system is the **circulatory system**. It is the link between the cells inside the body, which have certain requirements, and the environment outside the body, which supplies those requirements. Special organs are needed to extract these requirements from the environment. We have seen that the digestive system absorbs nutrients. The respiratory system absorbs oxygen. The blood is the transport link between all body systems. The circulatory system of the human body has four principal functions:

The role of hormones is discussed in further detail in Unit 3 Biology.

1 transportation of water, oxygen and carbon dioxide
2 distribution of nutrients and removal of wastes
3 maintenance of body temperature
4 circulation of hormones.

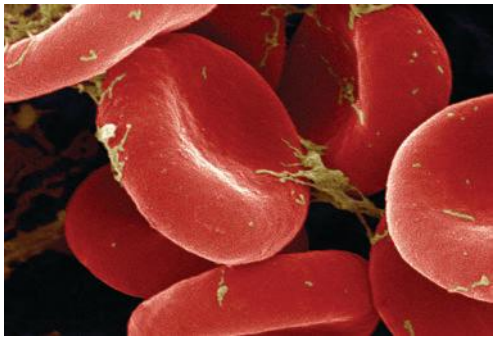
The essential features of a transport system must include the ability to reach every cell in the body, distributing the necessary requirements in a usable form and not disrupting the functioning of other systems in the body. The circulatory system consists of three general components that incorporate each of these essential features.

1 A fluid in which materials are transported, such as blood
2 A system of blood vessels or spaces throughout the body in which the fluid moves
3 A pump, such as the heart, that pushes the fluid through the blood vessels or spaces.

The heart, blood and blood vessels make up the **cardiovascular system**.

Circulatory fluid: The blood

The average 70 kg adult human is nourished and protected by about 5 L of blood. Approximately 55% of the blood is liquid, called the **plasma**; the remaining 45% is composed of blood cells, including erythrocytes, leukocytes and platelets. The blood cells are considered to be a tissue because they are cells that work together for a common purpose. Table 3.1 summarises the components of blood.



Getty Images/UIG/BSIP

Figure 3.15 ▲
A scanning electron micrograph of red blood cells (and fibrin, the protein formed during the clotting of blood)

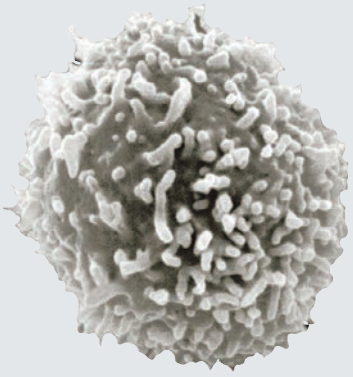
Red blood cells and oxygen transport

There are about 5 million red blood cells (or erythrocytes) per cubic millimetre of blood in a healthy human adult. Each cell is shaped like a disc with both flat sides pressed in, and measures about 8 μm in diameter and about 2 μm thick.

Nucleated red blood cells are produced in the bone marrow. Just before they are released from the bone marrow and move into the circulatory system, their nucleus breaks down. This makes them pliable and elastic so that they can twist and flex as they move through blood vessels that are sometimes narrower than their unbent size. The lack of nuclei also allows more space to carry oxygen. Red blood cells have a life span of about four months. The spleen and the liver break down and remove old and damaged red blood cells.

The main function of red blood cells is to carry oxygen and, to a lesser extent, carbon dioxide. Normally only about 0.3 mL of oxygen can dissolve in 100 mL of blood. However, red blood cells contain an iron-containing pigment called haem and a special protein called globin, which gives them their red colour. **Haemoglobin** enables blood

Table 3.1 Structure and function of the components of the blood tissue

Blood component	Structure and function
Plasma  Getty Images/Science Photo Library	Pale yellow fluid component of the blood through which the solid blood components, along with body heat, dissolved gases, nutrients, wastes and hormones, are transported around the body. Contains a number of dissolved proteins that have different functions. These plasma proteins carry other molecules, such as calcium, drugs, hormones, lipids, vitamins and cholesterol. They also help keep the acidity of the blood at the optimum level (between pH 7.35 and 7.45). One protein is essential in blood clotting. Another group contains antibodies that provide immunity against diseases such as measles. Others regulate the balance of fluids in the plasma.
Erythrocytes (red blood cells)  Corbis/Visuals Unlimited/Dr. Stanley Flegler	Contain haemoglobin, a molecule that enables the cell to bind oxygen molecules. Without haemoglobin, red blood cells would supply enough oxygen to support life for about 4.5 seconds. With haemoglobin, life can continue for about 5 minutes. (This seems like a short time, but blood is continuously transported back to the heart and then to the lungs, where the oxygen supply is renewed.) Do not have a nucleus in their mature stage, allowing the cell to carry more haemoglobin.
Leukocytes (white blood cells)  Corbis/Visuals Unlimited/Dr. Stanley Flegler	Function mainly to protect the body against invading micro-organisms and toxins. Are much fewer in number than red blood cells. Are of several types and, unlike red blood cells, contain a nucleus. Some types destroy micro-organisms by engulfing them and then using enzymes to digest the micro-organism and the leukocyte itself; others are specialised in producing antibodies that are an important part of the body's immune system. Fragments of white blood cells and invading micro-organisms are called pus.
Platelets  Corbis/Visuals Unlimited/Dr. Stanley Flegler	Small fragments of larger cells in bone marrow. Function primarily to initiate blood clotting. Are irregularly shaped and move easily through smooth blood vessels when resting. Become active and rupture if they encounter a sharp edge, such as a cut, as they move through a blood vessel. When the platelet membrane breaks, the platelet releases a substance that reacts with proteins in the plasma to create a mesh of fibres. This mesh prevents further blood flow. After a few days, fibres contract and begin to close the wound to the blood vessel.

to carry about 20 mL of oxygen per 100 mL of blood. This is about the same as the proportion for oxygen in air.

When there is a high concentration of oxygen, as in the capillaries exiting the lungs, the oxygen combines with the haemoglobin to form **oxyhaemoglobin**. Where there is a low concentration of oxygen, as in the tissues, the oxygen molecules dissociate from the haemoglobin. The oxygen diffuses through the red blood cell plasma membrane, travels through the plasma and out through the plasma membranes of the capillary wall to cells with a low concentration of oxygen.

When the body is at rest, the cells use only about one-quarter of the total oxygen carried in the blood. However, with heavy exercise, more than three-quarters of the available oxygen is used. Thus, the body has a large capacity to provide extra oxygen to cells in case of emergencies.

Blood and carbon dioxide transport

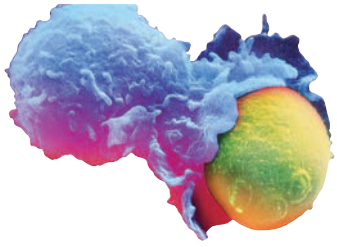
Cellular respiration in each cell produces carbon dioxide as a waste product. Its removal ensures the cell pH level is maintained for optimal function. Just as the bloodstream is able to deliver oxygen to every cell in the body, it is the bloodstream that removes the carbon dioxide from every cell in the body.

Carbon dioxide is quite soluble and reacts with water to form **carbonic acid**. This is normally a slow reaction. In the red blood cell, however, where the initial reaction occurs, the enzyme carbonic anhydrase speeds up the reaction. Approximately 70% of the carbon dioxide produced by cells is carried as carbonic acid in the plasma back to the lungs. The rest is either carried in the plasma as carbon dioxide (7%) or attaches to haemoglobin in red blood cells (23%).

As the blood passes through the lungs, the lowered concentration gradient for carbon dioxide causes all the previous reactions to reverse. The carbonic acid reverts back to carbon dioxide and water. The carbon dioxide leaves the internal environment of the blood, passing into the external environment of the lungs where it and the water are exhaled as vapour.

Chapter 2 discussed the process and products of cellular respiration.

White blood cells



Getty Images/Photo Researchers

Figure 3.16 ▲
A scanning electron micrograph of a white blood cell (on the left) engulfing a yeast cell

Apart from ensuring oxygen and carbon dioxide are transported effectively around the body, the bloodstream also ensures the body is protected against any sort of invasion by foreign bodies. The cells that carry out this function are the white blood cells, also called leukocytes. White blood cells are much larger than red blood cells and do not contain the coloured pigment haemoglobin. In order to be seen clearly under the microscope they need to be stained. They all have a nucleus, with nuclei of varying shapes, which helps in classifying them into different groups. When an infection is being fought there are about 10 000 white blood cells per cubic millimetre of blood.

White blood cells include different cell types that function collectively to fight foreign substances that enter the body. Some white blood cells live from only a few minutes to days, and others can live for years. They are found in the tissues as well as the blood because they are highly mobile, moving around somewhat like an amoeba. They can pass through capillaries by squeezing between the cells that make up the wall of the capillary and so get to regions of infection or damaged cells.

Unit 3 Biology goes into more detail about the role of leukocytes in immunity.

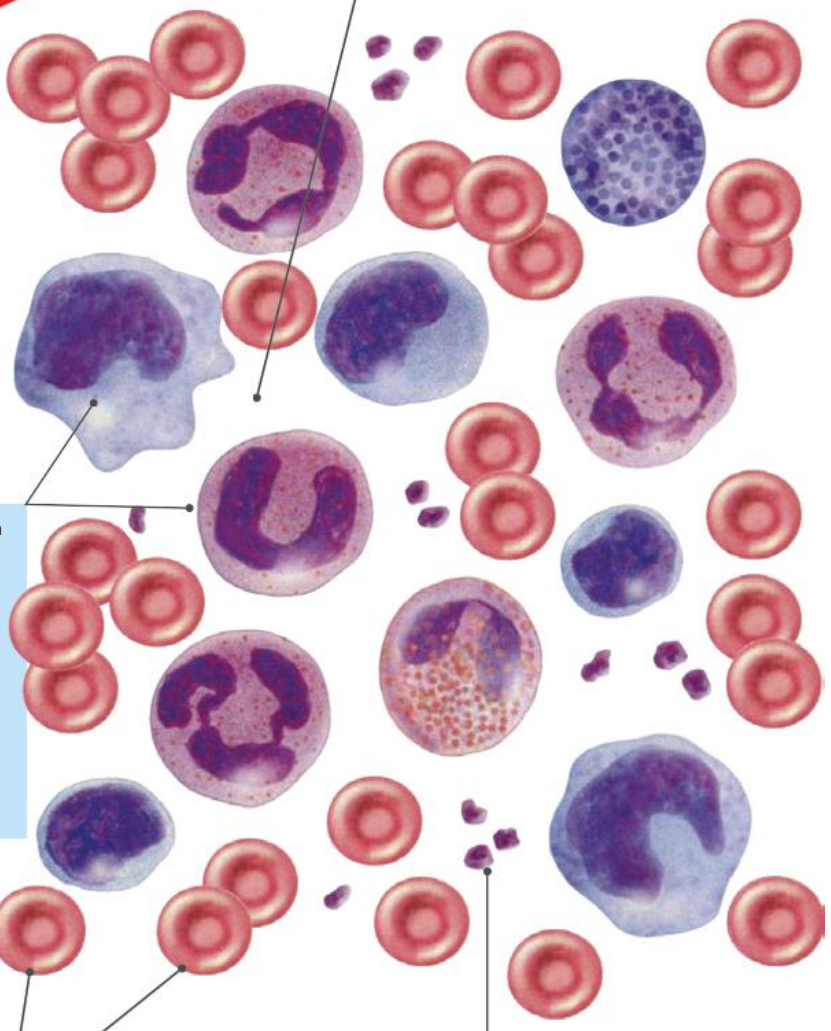
Platelets

In the case of an injury where bleeding is involved, platelets clump together to form a clot, which is a plug that stems the flow of blood. Platelets are smaller than red blood cells. They are fragments of cells, shaped like flattened discs, which arise in the bone marrow. They release chemicals at the site of injury in a blood vessel, causing it to contract to reduce blood loss. They have a life span of one or two weeks.

Blood is made up of a liquid part called **plasma**, and cells or cell fragments known as the **formed elements**.

Plasma makes up 55% of the blood volume; 91% of plasma is water, with the rest made up of dissolved substances, including nutrients (glucose, amino acids, lipids), ions (Na^+, K^+, Ca^{2+}, Cl^-, HCO_3^-), gases (oxygen, carbon dioxide), hormones, plasma proteins and wastes (e.g. urea).

Formed elements make up 45% of the blood volume. They include red blood cells or **erythrocytes**, white blood cells or **leukocytes**, and cell fragments known as platelets or **thrombocytes**.



White blood cells, or **leukocytes**, are larger but much fewer in number than erythrocytes. There are different types of leukocytes:
1 **granulocytes**, which have a granular cytoplasm with a lobed nucleus
2 **monocytes** and **lymphocytes**, which have a spherical nucleus and agranular cytoplasm.
Leukocytes can remove dead or injured cells and invading micro-organisms. They can live from a few minutes during an infection to years when infection is not present. They are the basis of immunological memory, which is stimulated by infection or vaccination.

Red blood cells, or **erythrocytes**, are biconcave discs – thinner in the middle than at the edges. They have no nucleus, which allows more room for **haemoglobin**, a substance that can combine with oxygen. When combined with oxygen, haemoglobin is red. This gives the erythrocytes and hence the blood, their colour. Erythrocytes live for about 120 days. They are produced in the bone marrow and destroyed in the liver and spleen.

Platelets, or **thrombocytes**, are very small cell fragments with no nucleus. They are about one-third the size of an erythrocyte. They are formed in the red bone marrow and last for about 7 days. Thrombocytes are important for normal blood clotting.

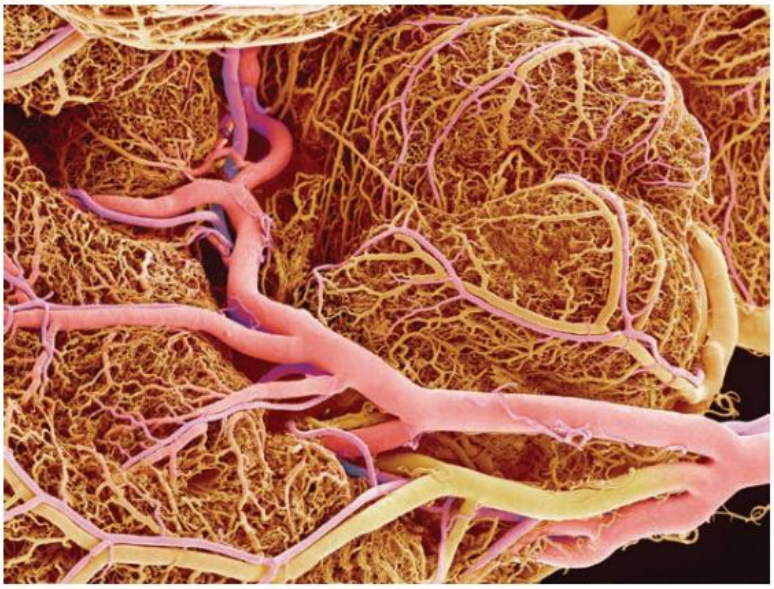
▲ **Figure 3.17**
The structure of blood

RECALL

- Blood tissue consists of plasma, red and white blood cells, and platelets.
- Red blood cells (erythrocytes) transport oxygen from the lungs to all body regions. They are packed with haemoglobin. They also transport some carbon dioxide from body tissues to the lungs.
- White blood cells (leukocytes) protect against foreign substances that enter the body.
- Platelets are fragments of cells that work to reduce blood loss by forming clots in the case of injury.

RECAP 3.5

1 State what plasma is and list the substances carried in plasma.
2 List the functions performed by white blood cells.
3 Outline the features of platelets and describe their functions.
4 Explain the benefits of having haemoglobin in red blood cells.



Getty Images/Science Photo Library/Susumu Nishinaga

Figure 3.18 ▲
Coloured scanning electron micrograph (SEM) of blood vessels in the lung. Substances are taken to and removed from cells via the blood, which circulates through arteries, capillaries and veins.

Circulatory system: The blood vessels

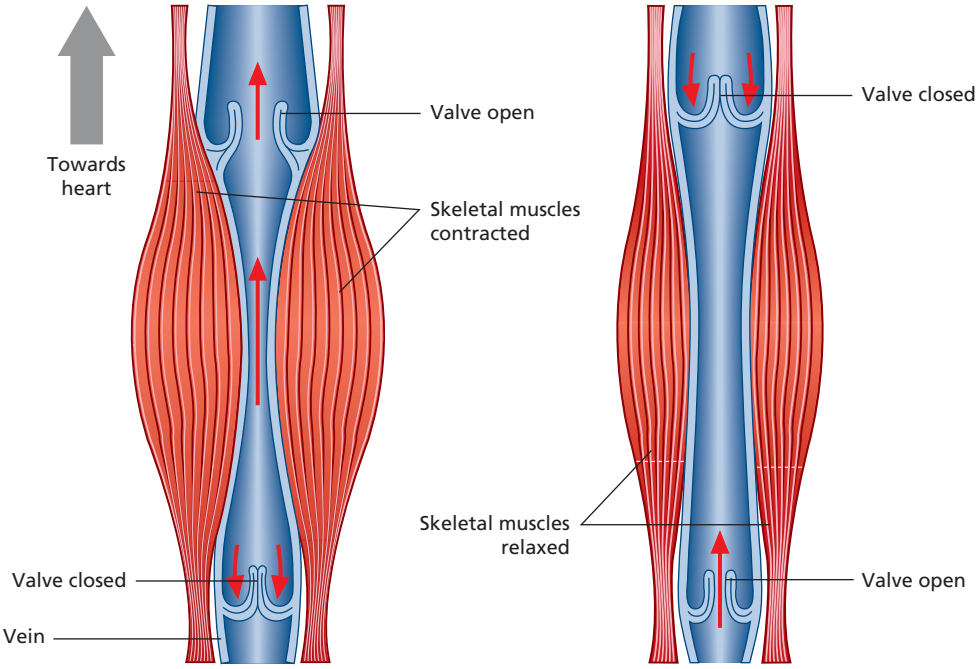
The bloodstream in mammals is said to be a **closed circulatory system**. This is because the blood is confined to a series of paths or vessels. The driving force behind the blood flow around the body is the pumping motion of the heart, and all vessels are connected to this organ. There are three main types of blood vessels. **Arteries** take blood away from the heart, **veins** carry blood to the heart and **capillaries** are found between these two blood vessels. Therefore, the major organs of the circulatory system are the heart, arteries, veins and capillaries.

The walls of the artery are thicker than those of the vein. This is because arteries have a lot more muscle and elastic fibres than veins. The muscle and fibre tissues of the arteries lead to the production of blood pressure as the heart beats, and forces the blood through the narrow central cavity, the **lumen**. Arteries swell as each wave of blood is ejected from the heart. They then recoil elastically to propel the blood further on. Arteries and **arterioles** (small arteries) can also narrow when nerves in the vessel walls or chemicals carried in the blood cause the circular muscles in the walls to contract.

The lumen of the vein is larger than that of the artery. More than 60% of the blood is distributed in the veins, which could be seen to act as a reservoir or as extra volume to be pumped around with increased exercise.

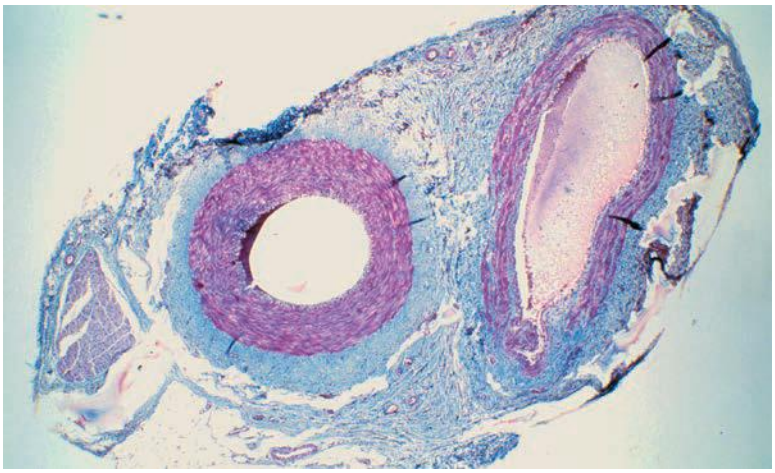
Veins have valves in them to help keep the blood flowing in one direction towards the heart. This is especially important in the legs. While the legs are not moving, the blood is squashed in the veins that travel between the muscles. The blood can only move up as the valves prevent it dropping back.

It is useful to know this as people who have to stand still for a long time in hot weather (such as soldiers on parade) sometimes feel faint, as too much blood is staying in the veins in their legs and not enough is returning to the heart in a timely manner, thus depriving the brain of enough oxygenated blood. By continually contracting and relaxing the muscles in their legs (e.g. by wiggling their toes), they can move the blood up to their heart and avoid fainting.



◀ **Figure 3.19**
Contraction of skeletal muscles, in conjunction with the presence of valves in the veins, helps blood return to the heart.

Unlike arteries or veins, capillaries have very thin walls and are very narrow. In fact, their walls are only one cell thick. This makes it possible for diffusion of all the nutrients that cells need, such as glucose and oxygen, to occur. Wastes, such as carbon dioxide and **urea**, the carrier molecule for excretion of nitrogen waste, are also able to pass from the cells to the blood. The diameter of capillaries is about the same as or smaller than a red blood cell, which further increases the diffusion rate of gases. Capillaries are so numerous and so small that every cell in the body is only a few millimetres away from a capillary.



Getty Images/CNRI

▲ **Figure 3.20**
A transverse section of an artery (left) and a vein (right) showing the difference between the walls. The vein has a thinner wall and is being flattened by the surrounding tissue.

Circulatory pump: The heart

Blood is pumped around the body by the heart. The heart is made of muscle and, in humans, can contract continuously about 70 times a minute, day and night, for as long as we are alive. **Cardiac** tissue, comprising cardiac muscle cells, is found only in the heart. It is the coordinated contractions of cardiac muscle, or **myocyte cells**, that provide the pumping action of the heart.

The heart has four chambers. Two are thin-walled **atria** (singular, atrium) and the other two are the more muscular **ventricles**.

Deoxygenated (oxygen-depleted) blood returns from the general body system of blood vessels, the **systemic circulation**, enters the right atrium, via the **vena cava**, and passes into the right ventricle. When the right ventricle contracts, blood is forced into the pulmonary artery, which leads to the lungs. This is called **pulmonary circulation**. Here, oxygen diffuses from the air into the blood and carbon dioxide passes out into the air in the lungs. The now oxygen-rich or oxygenated blood passes back into the heart through the left atrium and then into the left ventricle. When this ventricle contracts, the blood is forced into the **aorta**, the largest artery. Through its many branches, the aorta takes blood to all parts of the body. The **septum** prevents the deoxygenated blood on the right side of the heart from mixing with the oxygenated blood on the left side.

The blood is kept flowing in one direction in the heart by the presence of four valves: one between each atrium and ventricle (the two atrioventricular valves) and one between each ventricle and the artery it leads to (the pulmonary valve and aortic valve). The two ventricles contract at the same time and the atria contract at the same time, but the ventricles and atria contract at different times. This leads to the two atrioventricular valves snapping shut at the same time as the ventricles contract. The pulmonary and aortic valves close when the ventricle finishes contracting, so that blood under pressure from the enlarged elastic arteries does not flow back into the heart.

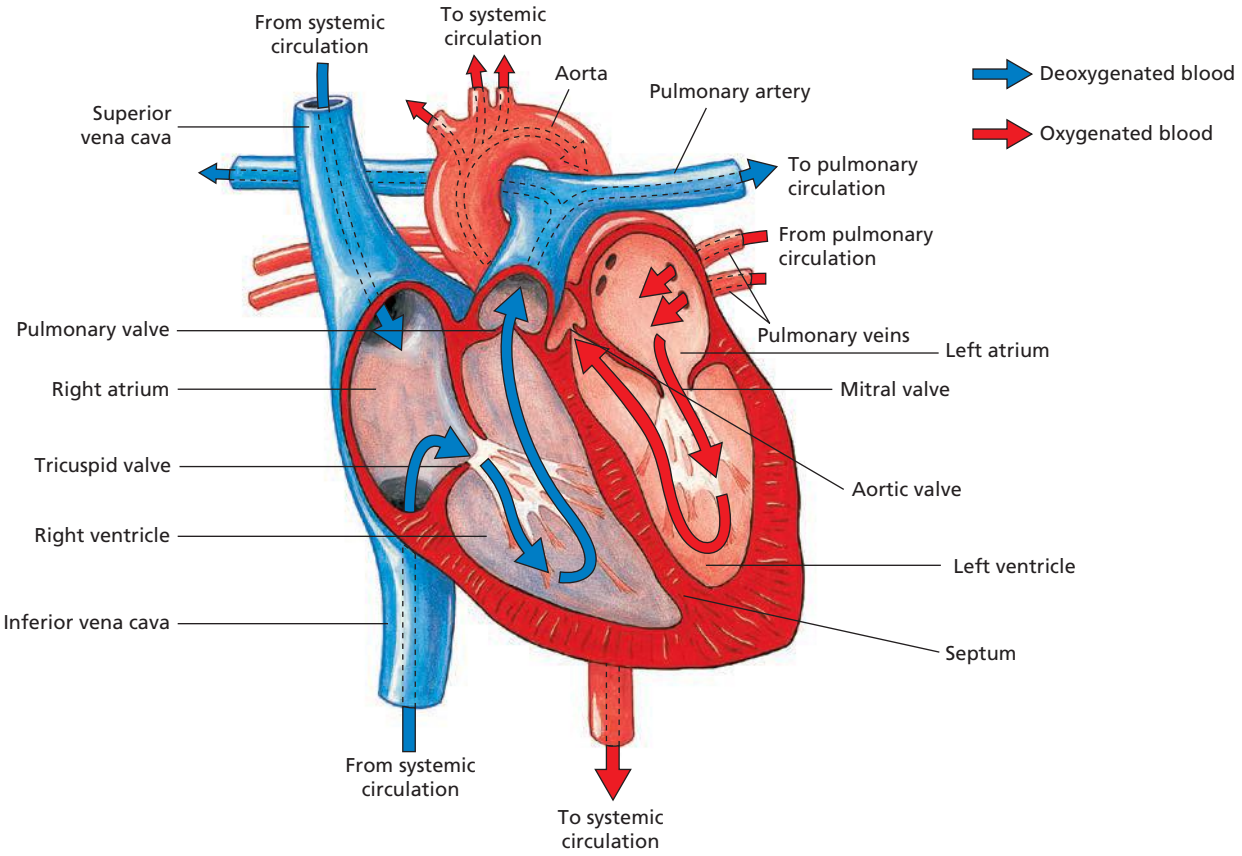


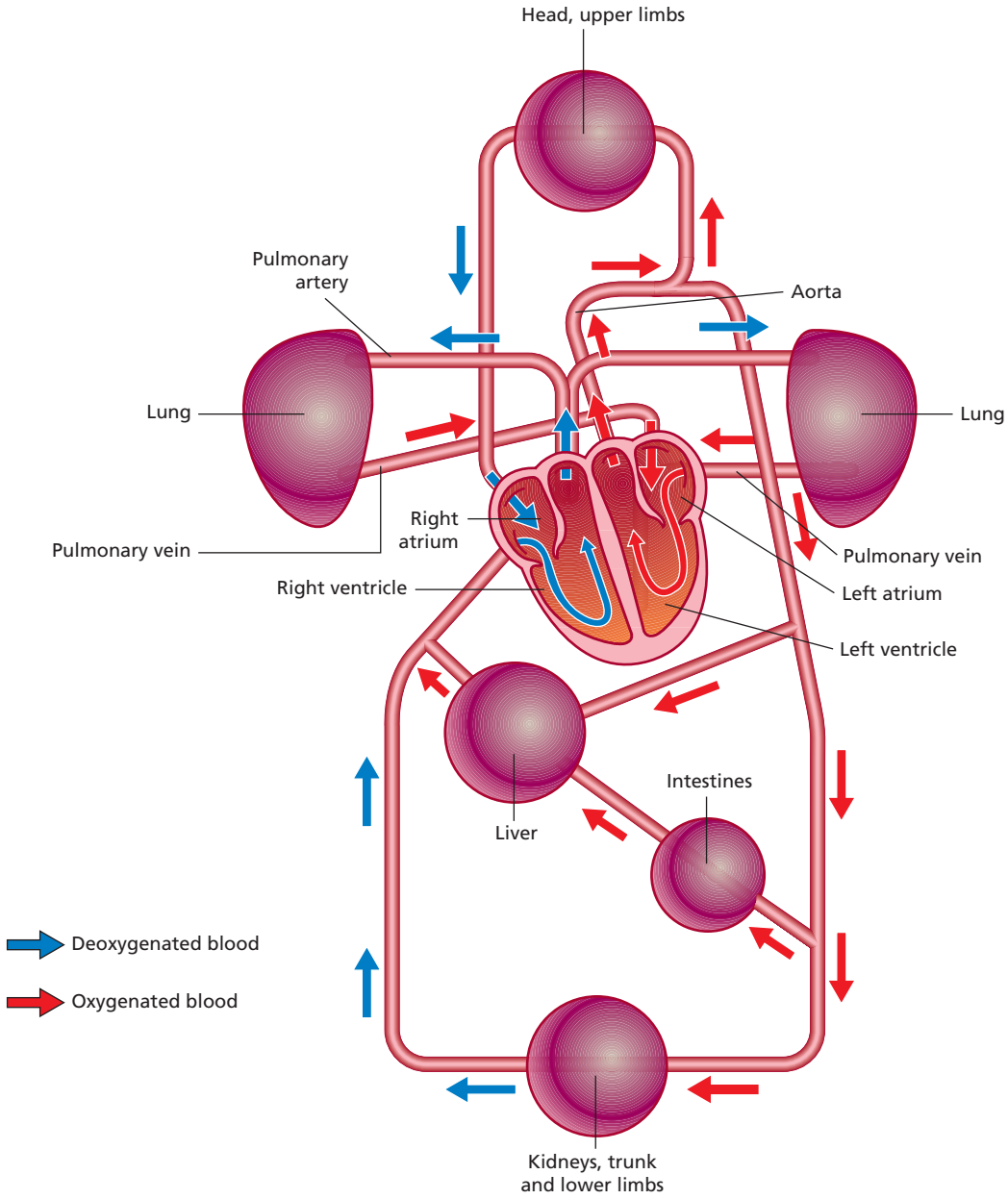
Figure 3.21 ▲
The human heart

When you use a stethoscope to listen to the heart, it is the sound of the valves closing and the sudden stop of blood flow that you hear. The trained listener can determine if particular valves are not shutting completely and if the timing of valve closure is abnormal.

The amount of blood pumped through the heart in a resting 70 kg adult is about 5 L per minute, which is equal to the entire blood volume of the person. During heavy exercise this can increase up to seven times that amount. This is possible partly due to the heart beating faster, from a resting pulse of about 70 beats per minute to about 210 beats per minute in young people. The ventricles also force out more blood for each contraction and do it under greater pressure (Table 3.2).

Table 3.2 Changes in heart rate and blood volume pumped at rest and during heavy exercise

	Heart rate (beats per minute)	Volume of blood pumped out for each ventricular contraction (mL)	L per minute
At rest	70	70	4.9
Heavy exercise	180	160	28.8



◀ **Figure 3.22** Blood circulation in mammals

RECALL

- The major organs of the mammalian circulatory system are the heart, arteries, veins and capillaries. Arteries have thick, muscular walls; veins are thinner but have a bigger central cavity and contain valves. Capillaries are very thin and narrow.
- The muscular heart has four chambers: two atria and two ventricles. Structures including valves in the heart ensure blood flows in one direction around the body.

RECAP 3.6

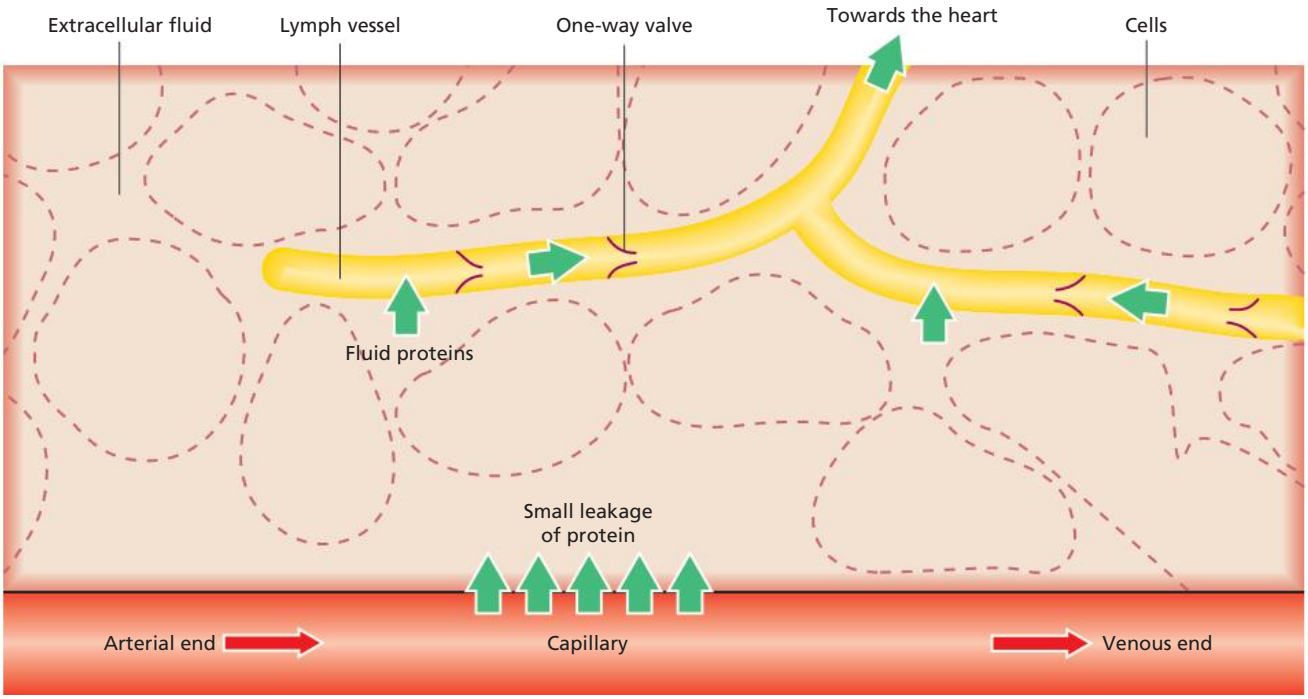
1. Outline the main differences between the three main types of blood vessels.
2. Explain what happens in the heart to ensure that oxygenated blood is pumped around the body.
3. Describe the differences between systemic and pulmonary circulation, and outline the significance of each system.

The lymphatic system

Gases and small molecules entering the internal environment are not the only substances to pass through capillary walls. Blood pressure forces some blood plasma out of the capillaries at the arterial end. Once the plasma, containing water, molecules and small proteins, has left the capillaries and entered the tissues, it is called **extracellular fluid**. Most of the extracellular fluid passes back into the capillaries at the venous end, as the blood pressure has dropped off. The fluid moves back into the capillaries by osmosis, caused mainly by the high concentration of proteins including **albumin** in the plasma.

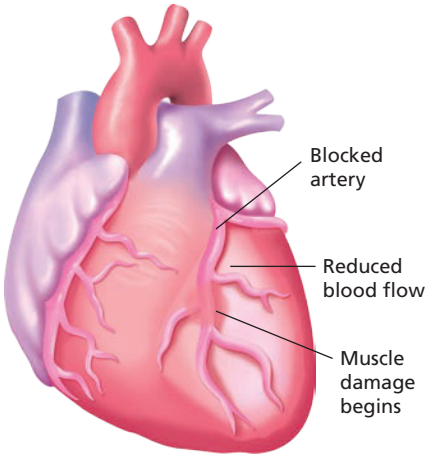
The extracellular fluid bathes cells of the tissues and provides nutrients to the cells. It continues to move from the capillaries, through the tissues and draining eventually into the circulation via **lymph vessels** in the **lymphatic system**. Lymphatic capillaries are small, blind-ending tubes, into which the extracellular fluid drains, entering through tiny flaps that act as one-way valves between the cells in their walls. The fluid flows through the lymph vessels to the heart to rejoin the normal blood circulation. It is pushed along by contracting muscles, and valves in the lymph vessel walls maintain a unidirectional flow to the heart.

Figure 3.23 ▼
Fluid and proteins are removed by the lymph vessels, which, with one-way valves, transport the fluid between cells away from them.



People who do not get enough protein can suffer from a condition known as 'kwashiorkor', typically evident from severe **oedema** and swelling of tissues. This swelling up from water occurs because people suffering from kwashiorkor do not have sufficient plasma proteins for the water to be drawn osmotically back into the capillaries.

When organs and systems malfunction: Heart attack



▲ Figure 3.24
A heart attack occurs when one of the heart's coronary arteries is suddenly blocked.

Considering the workload of the heart it is not surprising that heart muscle needs a continuous supply of oxygen. The oxygen comes from the blood via arteries on the heart's surface. These arteries are called **coronary arteries**. If one of these arteries becomes blocked, blood is not supplied to the area of the heart connected to that artery. A heart attack happens when there is a sudden complete blockage of the artery. As a result, the affected heart muscle begins to die. Without early medical treatment, this damage can be permanent. If there is a large area of heart muscle starved of oxygen, the attack can be fatal. A heart attack is sometimes referred to as a **myocardial infarction** (MI).

Heart attacks can result from **coronary heart disease**. This occurs when fatty deposits slowly build up on the inner wall of the coronary arteries. These fatty deposits, called **plaque**, gradually clog and narrow the inside channel of the arteries. If the plaque cracks, clots sometimes form over the damaged area. The clot can suddenly and completely block the blood flow to the heart muscle.

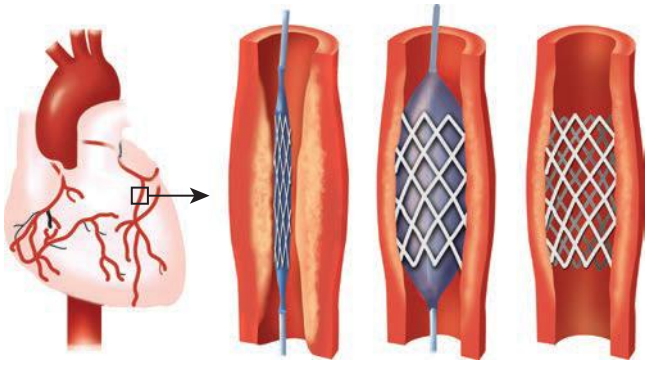
The severity and extent of coronary artery disease will determine the type of treatment offered.

There are many types and combinations of drugs used to treat coronary artery disease. If a heart attack has occurred, early treatment involves the use of special clot-dissolving medications that are administered directly into the bloodstream. Ongoing treatment with **anticoagulants**, such as warfarin, is common after a heart attack. These decrease the clotting ability of the blood. Medications to reduce high blood pressure and **cholesterol** are commonly prescribed to prevent coronary heart disease as well as medications to treat abnormal heart rhythms (**arrhythmia**), to decrease the heart's pumping strength and to relax blood vessels.

Surgery is often successful in treating patients. After recovering from a heart attack, some people may develop, or be at high risk of developing, arrhythmias that could be life-threatening. In this case a cardiac **defibrillator** can be put into the person's chest and connected to their heart to treat an arrhythmia if it occurs.

Coronary angioplasty is a procedure that aims to restore blood flow to the heart by using a special balloon to open a blocked artery from the inside. A tiny balloon is inserted and expanded at the site of the blockage to widen the narrowed artery. Once the blocked coronary artery is opened, a small metal coil called a **stent** is usually put into the site. It is expanded and is left in the artery to keep it open and reduce the risk of it narrowing again.

▼ Figure 3.25
During angioplasty, a short wire-mesh tube, called a 'stent', is inserted into an artery to allow blood to flow more freely through it. A balloon is used to expand the stent and set it in place.



If coronary arteries are narrowed or blocked in multiple areas, coronary bypass surgery may be necessary. A section of healthy blood vessel, often taken from inside the chest wall or the lower leg, is attached above and below the blocked artery. This allows blood to be redirected around the blocked area and flow to the heart muscle.

According to the National Heart Foundation of Australia, there are a number of healthy lifestyle choices that can help recovery from heart attack and greatly reduce the risk of further heart problems. These include being smoke-free, eating healthily, being physically active, controlling blood pressure and cholesterol, maintaining a healthy body weight and maintaining psychological and social health.

RECALL

- Lymph vessels carry extracellular fluid from tissues to the heart for return to circulating blood.
- Heart attacks can result from coronary disease.
- Prevention and intervention treatments for heart attack include medication, surgery and lifestyle changes.

RECAP 3.7

1. Distinguish between the lymphatic system and the circulatory system.
2. Explain the role of albumin in keeping fluid in circulation.
3. Describe how a heart attack happens.
4. Detail three ways to avoid or treat a heart attack.

Mammalian systems: The respiratory system

All animals exchange gases with their surroundings. However, unlike water and food, gases cannot be stored easily within living tissues, and so most animals must exchange gases with the atmosphere on a continual basis.

The mechanism of gas exchange from the external environment to the internal environment, and vice versa, is similar for all living organisms. In microscopic organisms, gas exchange occurs by diffusion across their plasma membrane. In larger terrestrial animals, the gas exchange system is inside the body to prevent dehydration of the gas exchange surfaces.

The surface across which the gas exchange occurs needs to:

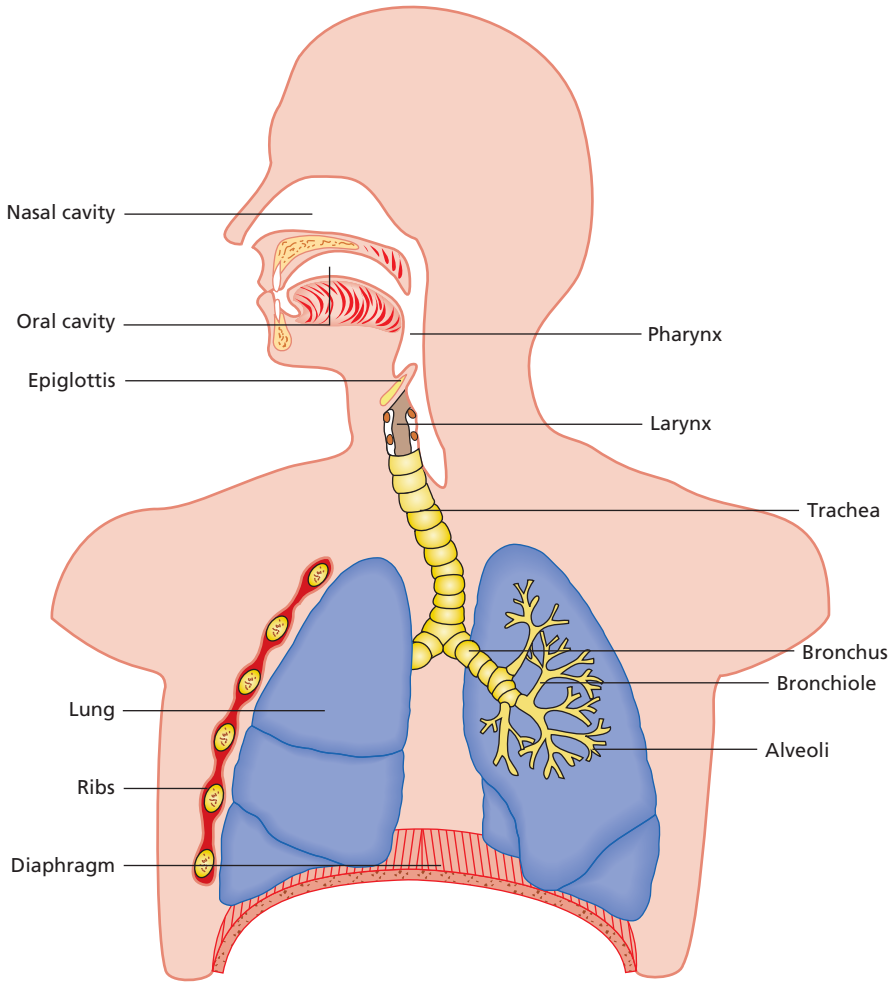
- be moist, as the gases dissolve in the water and diffuse from one side of the membrane to the other
- be thin and permeable, so the gas molecules can move across it easily and quickly
- have a large surface area in relation to the volume of the organism, so as to adequately provide the gaseous requirements
- have a greater concentration of required gas on one side of the membrane than the other, so that a concentration gradient is maintained.

Gas exchange in mammals

See Unit 3 Biology for more on factors affecting the functioning of enzymes.

Most mammals are terrestrial and obtain all their oxygen requirements from the air. They are **endothermic**, generating their own energy from cellular respiration. Aerobic cellular respiration taking place in their cells generates heat as a by-product, so in order to maintain a constant body temperature, their demand for oxygen to fuel cellular respiration is high. The heat generated ensures that the conditions are ideal for the normal functioning of the cell's other metabolic processes. These processes rely on the functioning of enzymes, among other things, that have an optimum temperature at which they operate. The mammalian lung has evolved to meet all gaseous demands.

Air passes into the lungs through the nose and mouth. It travels past the throat and **larynx** (voice box) into the **trachea**, which is strengthened with rings of cartilage to stop it collapsing. The trachea branches into two **bronchi** (singular, **bronchus**), which lead to



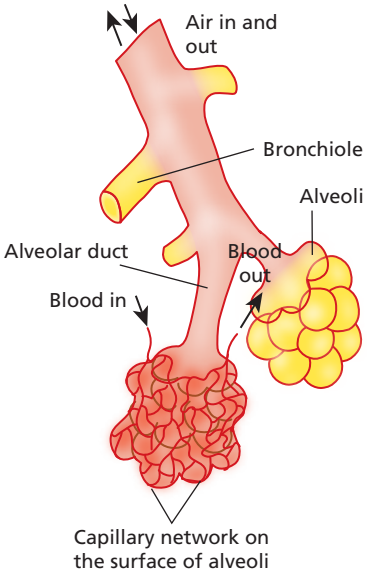
◀ **Figure 3.26**
The gas exchange system in humans

the lungs. On entering the lung tissue, each bronchus continually divides into smaller tubes called **bronchioles**. Eventually, each bronchiole ends in a cluster of tiny air sacs called **alveoli** (singular, **alveolus**).

The alveolar endothelial tissues not only provide a moist surface across which gas exchange occurs, but also increase the surface area of the lung tissue enormously. There are about 700 million alveoli in the human lung and they provide a surface area that is approximately the size of a tennis court.

A network of capillaries is wrapped around each alveolus. The thin wall of the alveolus, and the thin wall of the capillary, form the boundary between the external environment in the alveolus and the internal environment of the blood in the capillaries. Gas exchange between the two environments occurs by diffusion. The capillaries are so narrow that, as the red blood cells are pushed through them, they are partially squashed into a conical shape. This not only increases the amount of surface area in contact with the capillary wall, but ensures there is little fluid between the blood cell and the alveolar wall, so the distance the oxygen and carbon dioxide molecules have to travel is very short, less than 1 µm.

Each alveolus is covered, internally, with a thin layer of fluid in which the oxygen dissolves before it diffuses into the cells. This fluid contains a **surfactant**, a detergent-like **lipoprotein** complex, which reduces its **surface tension**. This prevents the alveolar walls from being pulled inwards so that the alveoli don't collapse and the lungs can stay properly inflated.



▲ **Figure 3.27**
Each alveolar sac is surrounded by a network of capillaries

Ventilation and breathing rate

In order to extract oxygen from the air by the alveolus, air must enter the gas exchange area of the body and diffuse into cells. Air is moved in and out of the lungs by movements of the ribs and the **diaphragm**. The rate of breathing is controlled mainly by the level of carbon dioxide in the blood. Most of the carbon dioxide produced by cells in respiration is converted into carbonic acid in the plasma. The bicarbonate ions pass into the blood plasma, where they are transported to the lungs for removal as carbon dioxide. This lowers the carbon dioxide concentration of the blood.

Ventilation maintains the concentration gradient of carbon dioxide and oxygen between the alveoli and the blood in the capillaries. The action of breathing lowers the carbon dioxide concentration in the alveoli and increases the local concentration of oxygen in the alveoli. The dense network of blood capillaries and fast blood flow in the alveoli also help to maintain the concentration gradients by supplying more carbonic acid for exchange and removing oxygen.

Maintenance of the concentration gradient is necessary in order for diffusion of oxygen into the blood and diffusion of carbon dioxide out of the blood into the alveoli to occur at a fast rate.

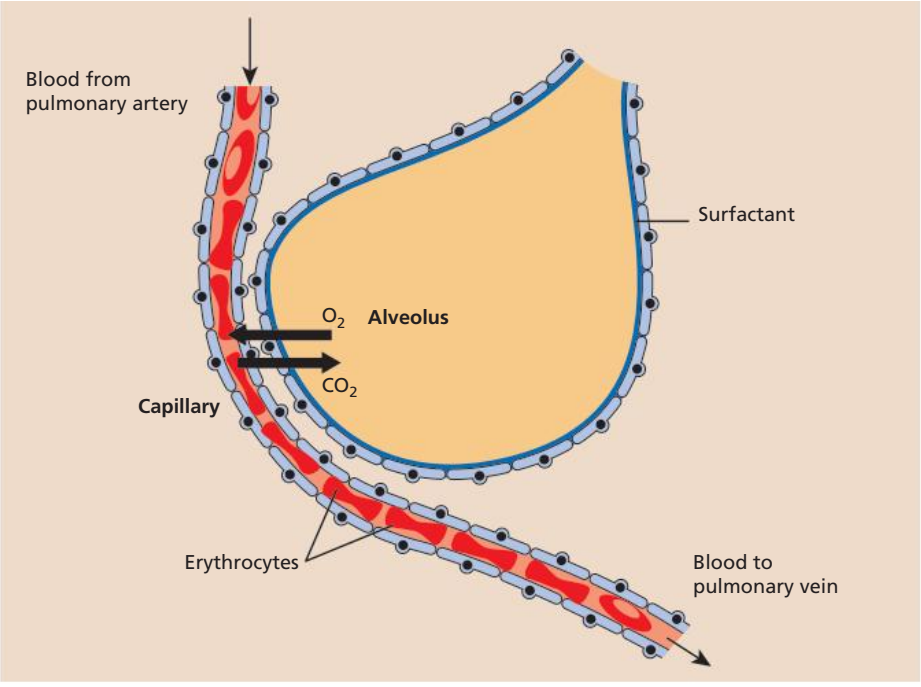


Figure 3.28 ▶
Diffusion distance for oxygen travelling from the alveolus to red blood cells is very short.

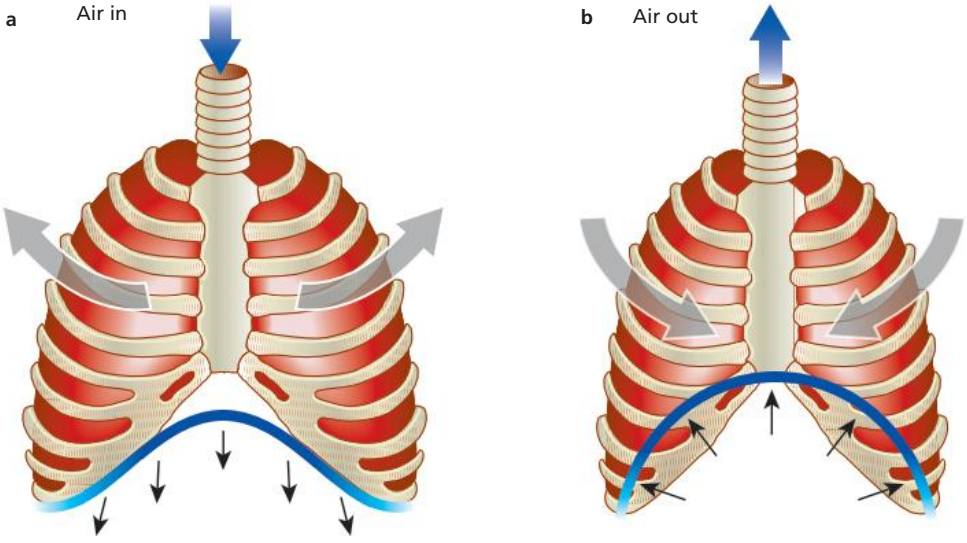


Figure 3.29 ▶
Changes in the size of the chest cavity during breathing. The blue line under the rib cage indicates the diaphragm position when you (**a**) inhale and (**b**) exhale.

RECALL

- For gas exchange to occur by diffusion, surfaces need to be moist, thin and permeable and have a large surface area, and a concentration gradient of the gas must exist.
- In mammals, air passes into the mouth and nose and travels through to the alveoli in the lungs.
- Gaseous exchange takes place between the alveoli and the capillaries that surround them.
- Breathing ventilates the lungs.

RECAP 3.8

1 List the characteristics of an efficient gas exchange surface.
2 Describe the function of the surfactant in mammalian lungs.
3 Explain what happens to the ribs and diaphragm during inhalation and exhalation.

When organs and systems malfunction: Respiratory disease

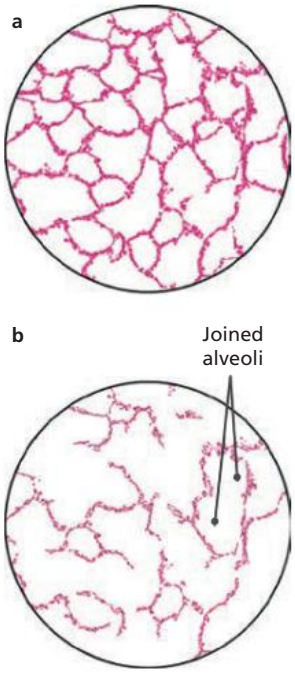
The environments in which we live, work and spend our leisure time affect the efficiency of our respiratory surfaces. For example, smoking and living in a polluted environment can damage the alveoli and reduce their ability to carry out gas exchange. Inherited conditions and infections can also have a profound effect on respiratory organs. Respiratory conditions can be long lasting (chronic) or short term (acute) and can cause ill health, disability and death.

Lung disease affecting airways includes asthma, allergies, bronchitis, emphysema and cystic fibrosis. Pneumonia and tuberculosis are examples of infectious diseases affecting the respiratory system. Lung cancer has many forms, and may develop in any part of the lungs.

Emphysema

Emphysema is a disease usually caused by long-term exposure to irritating particles in the air taken into the lungs. No one can avoid inhaling particles, as there are particles of matter in the air at all times. Some people, however, are exposed to excessively high levels. Smokers constantly inhale irritants in tobacco smoke; those who work in situations where a lot of dust is produced are also at risk. In cities with continually high air pollution, there is a greater risk of emphysema in the population.

The irritating particles cause damage to the alveoli. They lose their elasticity, are often replaced with fibrous tissue, and may break down, reducing the internal surface area of the lung (Figure 3.30). Because of the loss of elasticity of the lung tissue, the lungs are constantly inflated, and breathing out no longer occurs passively but requires voluntary effort. Thus, the emphysema sufferer has two problems – inadequate surface area for gas exchange, and difficulty in ventilating the lungs. Although emphysema has no cure, quitting smoking or removing the airborne irritants reduces the speed at which the disease worsens.



▲ Figure 3.30
(**a**) Photomicrograph of a section of lung tissue showing normal alveoli. (**b**) Photomicrograph of a section of lung tissue from a patient with emphysema showing how alveolar walls have broken down, forming larger, fewer alveoli with reduced total surface area

Lung cancer

Lung cancer is similar to most other cancers in that it involves the development of a tumour, a mass of cells that divides in an uncontrolled way. Evidence shows clear links between lung cancer and environmental factors, particularly tobacco smoking and exposure to asbestos fibres and other pollutants.

Surgery is the preferred treatment for patients with early stage lung cancer. A portion of a lobe, a full lobe, or an entire lung may be removed. The extent of removal depends on the size of the tumour, its location and how far it has spread. Unfortunately, most patients who have advanced disease are not able to be treated by surgery.

Chemotherapy (drug treatment) can be used to treat lung cancer. It can help control the growth and spread of the cancer, but it cures lung cancer in only a small number of people. Radiation treatment using high-energy X-rays can be used to kill cancer cells and shrink tumours. Radiation is often used in combination with surgery or chemotherapy or both.

Lung infections

Pneumonia is an infection of the lungs caused by bacteria, viruses, fungi or other organisms. The inflammation resulting from the infection causes secretion of fluid and mucus into the alveoli, thus reducing the amount of air that they can contain. The surface area available for exchange of gases is also reduced, and breathing difficulty is a symptom of many types of pneumonia. Tuberculosis is an infection, usually of the lung, by the bacterium *Mycobacterium tuberculosis*.

Most lung infections are spread by droplets. When infected people cough, sneeze or spit, tiny droplets of moisture containing the bacteria, viruses or fungi may be inhaled by others, so spreading the infection. Good hygiene practices, such as coughing and sneezing into a handkerchief and not spitting, help to reduce the spread of lung infections.

Antibiotics and antiviral medications are used to treat lung infections such as pneumonia and tuberculosis.

Asthma

Asthma is an allergic response to foreign substances that enter the body through the airways. During an asthma attack, the muscles that surround the bronchioles go into spasm – sudden involuntary contractions. This causes narrowing of the air passages and difficulty in breathing.

There are two basic types of drugs used in asthma treatment: anti-inflammatory drugs and bronchodilators. Anti-inflammatory drugs, particularly inhaled steroids, prevent asthma attacks and work by reducing swelling and mucus production in the airways. As a result, the airways are less sensitive and less likely to react to the environmental triggers of asthma. Bronchodilators relieve the symptoms of asthma by relaxing the muscles that can tighten around the airways. This helps to open up the airways.

RECALL

- Respiratory disease can be caused by the environments we live in, inherited conditions and infections.
- Respiratory conditions can be long lasting (chronic) or short term (acute) and can cause ill health, disability and death.

RECAP 3.9

1 Describe a respiratory disease caused by the following.
   a The environment
   b An allergic response
   c An infection

Mammalian systems: The excretory system

Mammals, including humans, must include protein in their diet as a source of amino acids. However, amino acids cannot be stored in the body; those not used are oxidised. The main waste produced by amino acid oxidation is nitrogen, which is excreted as urea.

The process that separates the nitrogen-containing amine group from the rest of the amino acid is **deamination**. Part of the amino acid is broken down and used for energy. However, the amine group is converted to ammonia, which is toxic to cells. A build-up of 0.005 mg of ammonia is enough to kill a human. So the human body must either eliminate it very quickly or convert it to a less toxic substance that can be stored temporarily prior to elimination.

In humans, cells in the liver convert the ammonia to less toxic urea. Urea is dissolved in the blood and carried to the organs that excrete it from the body; this is the role of the **kidneys**. In most animals, the urea is diluted by water. In many terrestrial animals, including humans, kidneys need to maintain the delicate balance between preserving an adequate amount of water in the blood and using water in the blood to excrete nitrogenous waste.

Human kidneys

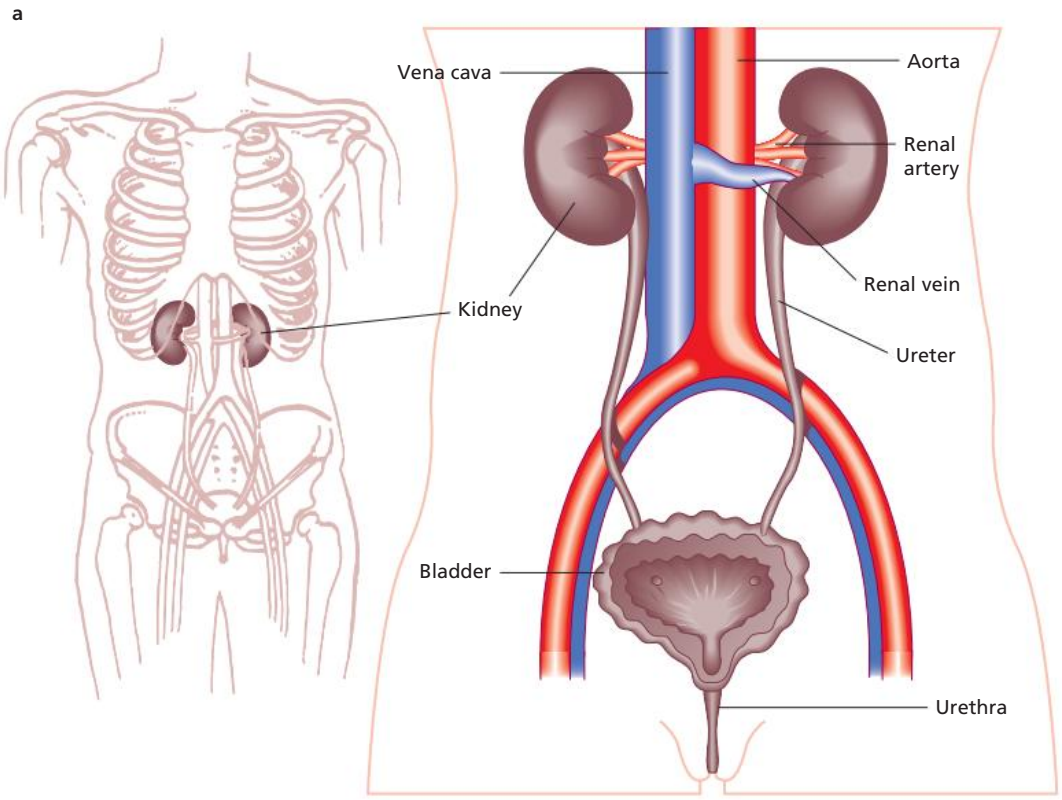
The main organs of the human excretory system are the kidneys. The kidneys are two bean-shaped organs, each about as big as a fist, located in the back of the upper abdomen at either side of the spinal column (Figure 3.31 on page 98). A branch of the aorta, the **renal artery**, brings blood containing nitrogenous waste and water, blood proteins, red blood cells and minerals dissolved in the blood plasma to the kidneys. Because the kidneys are the filters that remove wastes from the blood, they may hold as much as 25% of the body's blood at any given time.

The renal artery branches into smaller and smaller vessels until millions of capillaries are formed. Each capillary enters a **nephron** where filtration of the blood occurs.

Nephron structure and function

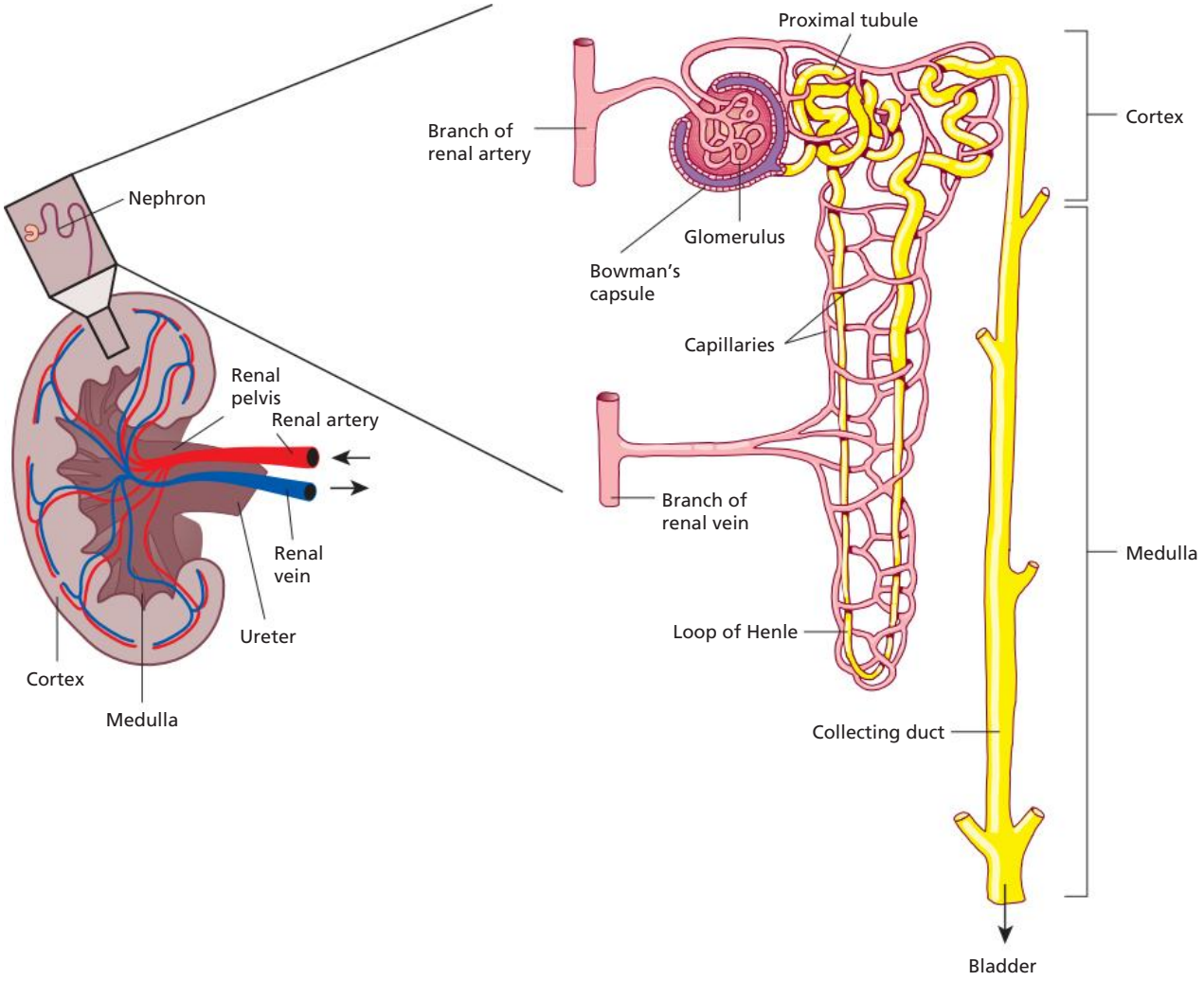
Each kidney consists of approximately one million slender tubules called nephrons, extending from the cortex of the kidney down into the medulla (Figure 3.32 on page 99). It is at the nephrons that water and solutes are filtered from the blood and amounts to be reclaimed are adjusted. Each nephron contains a ball of capillaries called a **glomerulus**. The glomerulus is situated inside the **Bowman's capsule**, which looks like a hollow rubber ball that has been pressed in on one side. As the capillaries that form the glomerulus are tightly bound into the smaller Bowman's capsule and pumped by the renal artery, blood in the glomerulus is under very high pressure. This pressure forces out some of the water and all solutes except protein from the blood through tiny pores into the Bowman's capsule. This **filtrate** has just moved into the external environment as it has passed through a membrane that separates it from the internal environment.

Figure 3.31 ▶
The human excretory system. (**a**) Diagram of the excretory system (**b**) Using a dye, this X-ray shows the tubes leading from the kidneys (top) to the bladder (bottom).





Getty Images/Biophoto Collection/Photo Researchers



▲ Figure 3.32
Structure of the kidney and the functional unit, the nephron

The filtrate moves to the **proximal tubule**, then to a hairpin-shaped **loop of Henle** and finally to the **distal tubule**. A collecting duct, the nephron's last region, is part of a duct system leading to the kidney's central cavity (**renal pelvis**), then into a ureter.

Blood does not give up all of its water and solutes. The unfiltered part flows into capillaries threading around the nephron's tubular parts. In these capillaries, the blood reclaims water and solutes from the tubules. Then it flows into veins and back to the general circulation. The longer the loop of Henle, over which much of the water reabsorption occurs, the greater is the ability of an organism to reclaim water from the glomerular filtrate and concentrate its urine.

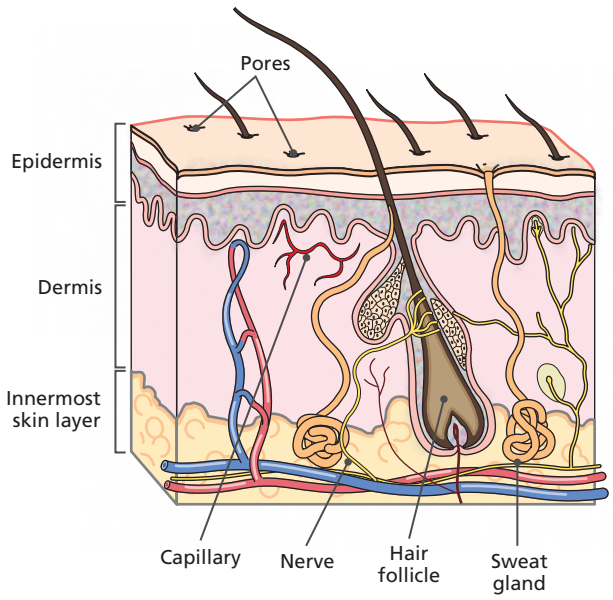
On average, about 600 mL of fluid flows through each kidney every minute. Approximately 20% of the fluid, 120 mL, is filtered into the nephron. If all this fluid were excreted, you would have to drink at least 1 L of fluid every 10 minutes just to maintain water balance. Fortunately, reabsorption ensures that 119 mL of the 120 mL of filtrate, along with some essential materials, is put back into the body. The remaining 1 mL becomes urine. Urine is approximately 95% water, with the remaining 5% consisting of dissolved salts, urea and a few other substances. A typical adult excretes approximately 25 g of urea per day. Secretion is the transfer of additional nitrogenous wastes, excess minerals and some other chemicals from the blood into the nephron. Even drugs such as penicillin are secreted.

Table 3.3 Summary of the roles of each part of the nephron

Name and structure	Function
Glomerulus: a cluster of capillaries that carry blood from the renal artery	Filtration: pressure of blood forces about one-fifth of its plasma out through the capillary walls, along with everything small enough to pass through: urea, glucose, amino acids and salt, but no red blood cells, platelets or large proteins. Filtered substances enter the Bowman's capsule.
Bowman's capsule: a hollow, cup-shaped end of the nephron with double walls one cell thick	Filtration: plasma with dissolved materials diffuses into the hollow space of the Bowman's capsule and is passed on to the tubule.
Proximal tubule: a hollow, winding, large-diameter tube	Reabsorption: glucose, sodium ions, calcium ions, phosphate ions and amino acids are actively pumped back into the capillaries. Most of the urea stays inside the tubule.
Loop of Henle (descending): straight part of loop moving away from the proximal tubule	Reabsorption: the concentration of water inside the tubule is greater than that of the surrounding blood vessels; water flows out of the tubule and into the blood by osmosis. Urea stays inside the tubule.
Loop of Henle (ascending): straight part of loop leading to the distal tubule	Reabsorption: sodium is actively pumped out of the tubule and into the blood. Walls of the loop of Henle are impermeable to water, so it remains inside.
Distal tubule: a hollow, winding, large-diameter tube	Reabsorption: a final adjustment of water and dissolved materials. If the body is dehydrated, the permeability of the distal tubule is increased to allow water to return to the capillaries by osmosis. If the body is not dehydrated permeability decreases, so water remains within the tubule and dilutes the urine that leaves the body.
Collecting ducts: a system of urine-collecting ducts that widen as they near the renal pelvis	Secretion: other wastes are transferred from the capillary network into the duct. Reabsorption: water moves by osmosis from the duct into the surrounding blood.

The body adjusts for excess water intake by increasing urine output. Conversely, it adjusts for increased exercise or decreased water intake by reducing urine volume but increasing the concentration of urea in the urine, so as to reduce water loss in the urine. The kidneys not only prevent the build-up of wastes but also help maintain water balance by controlling the volume, composition and pressure of body fluids.

Figure 3.33 ▼
A section of skin showing sweat glands



Sweating out waste material

Nitrogenous wastes can also be removed by sweat. The composition of sweat is similar to that of plasma except that sweat does not contain proteins. As the sweat moves along the sweat duct to the skin surface, some sodium and chloride ions are reabsorbed into the bloodstream. Thus, a little urea is lost as sweat.

The salt content of sweat is less than that of blood. Sweat loss, therefore, causes an increase in the salt concentration of the blood. On days of increased sweating, fluid intake must be increased. It is important to remember that sweating is mainly a temperature control mechanism rather than a way of removing nitrogenous wastes.

RECALL

- The excretory system removes nitrogenous wastes from the internal environment. Kidneys are the organs where filtration of blood occurs.
- Kidneys have many nephrons that collect and concentrate the filtrate that leaks out of the capillaries of the glomerulus.
- The start of a nephron is cup-shaped (Bowman's capsule). It continues as three tubular regions (proximal tubule, loop of Henle, and distal tubule that empties into a collecting duct).
- Urine forms in the nephron by filtration, reabsorption (a small volume of water and solutes remain in the tubule) and secretion (disposal of urea).

RECAP 3.10

1 List, in order, the pathway that nitrogenous waste takes, starting from blood and ending with the collecting duct.
2 Name the structure where the final amount of water is reabsorbed.
3 Draw a labelled diagram showing the structure of a nephron. On your diagram, indicate where filtration, reabsorption and secretion occur.
4 Explain what happens in filtration.

When organs and systems malfunction: Kidney failure

One in three adult Australians is at risk of developing kidney disease. A person can lose up to 90% of kidney function without realising it. At that stage it is almost impossible to prevent serious problems occurring.

Most kidney diseases affect the glomeruli, reducing their ability to filter the blood. Protein and sometimes red blood cells may leave the blood at the glomerulus and will then be present in the urine. If excessive proteins are lost in the urine, blood protein levels fall and fluid accumulates in the tissues, as it is not drawn back into the bloodstream by osmosis. This fluid retention in tissues causes swelling of the hands, feet, face and other areas.

Kidney failure occurs when the kidneys lose their ability to excrete waste and control the level of fluid in the body. Factors such as diabetes, high blood pressure or kidney diseases slowly destroy the nephrons in the kidneys, resulting in kidney failure. The fine capillaries of the glomeruli are also very susceptible to damage caused by harmful factors in the blood, such as proteins involved in immune responses. Depending on its cause, kidney failure may happen suddenly but is more likely to develop over a period of years. Eventually, the only way to maintain life is by filtering blood by dialysis or obtaining a kidney transplant.

Dialysis

During **haemodialysis** a person's blood is pumped through tubing made of a differentially permeable membrane, which is immersed in a bath containing a solution of certain salts. Blood cells and other large proteins cannot pass through the membrane, but urea, potassium and other substances in excess in the body can diffuse through and out of the blood into the bath. Patients usually undergo haemodialysis three times a week, for about four to five hours each time, attached to the machine.

In **peritoneal dialysis**, about 2–3 L of dialysis fluid is put into the abdominal cavity by a tube fastened in the body wall. The fluid is left in the cavity for a few hours, then

siphoned out and replaced by a fresh lot. The cavity is lined naturally by a membrane that has its own extensive blood supply. Thus urea and other substances can diffuse out of the blood into the fluid in the cavity and be removed. This method enables people to move around a lot more than with the normal dialysis.



Science Photo Library/HOP Americain/AJ Photo

Figure 3.34 ▶
Dialysis uses an artificial kidney machine (dialysis machine) to replace the excretory function of the failed kidneys.

Kidney transplants

People with advanced kidney disease often opt for a kidney transplant to avoid a lifetime of repeated dialysis and to improve their quality of life. A donated kidney may come from a family member or unrelated person, or be donated by the family of a recently deceased person. Anti-rejection drugs must be taken after the transplant to prevent the immune system of the recipient from recognising the new kidney as foreign and attacking it. Research over the years has indicated, in the area of kidney transplantation specifically, that organ donation from live donors offers prolonged normal organ functioning. It has been found that an organ from a perfectly matched sibling donor can function successfully for up to 35 years. From a less perfectly matched donor, which is more likely to trigger an immune response against the donated kidney, the life span of the organ can be 20 years. However, deceased donor transplants see the kidney maintaining function for a maximum of 10 years. Research indicates that the most long lasting and successful transplants are from living relatives.

Medication and diet

Medications can sometimes help slow the progress of chronic kidney disease. Drugs that control diabetes and high blood pressure are often used. Other medications may also be prescribed to compensate for the lack of kidney function. These include phosphate binders, vitamin D, erythropoietin, and vitamin and mineral supplements.

Kidney damage reduces the ability of the body to get rid of sodium, potassium, phosphorus and other waste by-products. Depending on the stage of kidney disease, a special diet to decrease the workload on the kidneys may be advised. These diets may include reducing the intake of protein, potassium, sodium and phosphorus.

RECALL

- Kidney failure occurs when the kidneys lose their ability to excrete waste and control the level of fluid in the body.
- Filtering blood by dialysis or obtaining a kidney transplant are two ways to treat kidney disease.

RECAP 3.11

1 Describe two types of dialysis.

2 List the different sources of kidneys for transplantation and describe the source that has the most success.

Investigation of an issue: Weighing up the evidence for a weight loss supplement

Refer to Chapter 11 for more information on the investigation of an issue.

Many health companies are now using social media to advertise their products. They use marketing strategies to make you want their product. One product advertised frequently on social media is a weight loss supplement called 'Garcinia cambogia'. It is named after the fruit from which the active ingredient is extracted, a chemical called 'hydroxycitric acid' (HCA). But how do we know if this product works and if it is safe? These questions should be investigated before using health supplements.

Advertisements tell us it is safe

According to advertisements, this health supplement is safe to use. However, the advertisements do not include valid and reliable evidence, so a consumer cannot easily check this claim. The advertiser tells us the product is 100% natural plant extract to support the claim that the product is safe. This is not a good argument for safety. Plants produce their own defensive chemicals as natural pesticides. Many of the chemicals we extract from plants, including caffeine, are actually used by plants to kill or deter predators. Natural does not always correlate with safe.

Most advertisements advise that you consult with a doctor prior to using Garcinia cambogia. It can have adverse effects when taken with other medications and is not recommended for people with diabetes or if you are pregnant. One advertisement mentions that people who have exceeded the recommended dose have experienced side effects including nausea, diarrhoea, digestive tract discomfort and headaches.

Therapeutic Goods Australia (TGA) is the regulatory body that oversees which products can be sold legally as drugs in Australia. It has determined that Garcinia cambogia is safe and of appropriate quality to be used as an ingredient in lower-risk medicines. TGA warns consumers to always check that a supplement and the company making it are listed on their website. TGA only lists products that contain approved low-risk ingredients. They also check to make sure the product is *manufactured* safely. However, the products themselves are not tested for their safety. Also, TGA does not test supplements to see if they work. They only do this for medical drugs. It is up to the consumer to look for evidence that the health supplement works.

Advertisements tell us it works

Companies selling Garcinia cambogia-derived HCA as a weight loss supplement claim that it works in two ways: by reducing production of fat cells, and by suppressing the appetite. Advertisements may tell us that 'studies show' or 'it is known' to suppress fat synthesis without providing any evidence. Some companies provide links to studies (Ishihara et al., 2000; Saito et al., 2005) where HCA was found to block the action of an enzyme called citrate lyase in rats and mice. This enzyme is involved in fat synthesis and blocking its action inhibits the production of fat. The rats and mice treated with HCA lost weight. Other referenced studies, such as that by Ohia et al. (2002), report that HCA raises levels of serotonin. This chemical acts on nerve pathways to enhance the mood and suppress emotional eating. However, what works in rats and mice does not always work in humans.

Over to you: Critically assessing the science to determine if this product works

Task 1: Adverts about Garcinia cambogia tell us it works and is safe. However, adverts are not always **scientifically accurate**. They often fail to provide all information and this distorts the science. Many fail to provide evidence, so consumers can't assess whether the claims are accurate.

Refer to Chapter 12 for a discussion on statistical measurements including means.

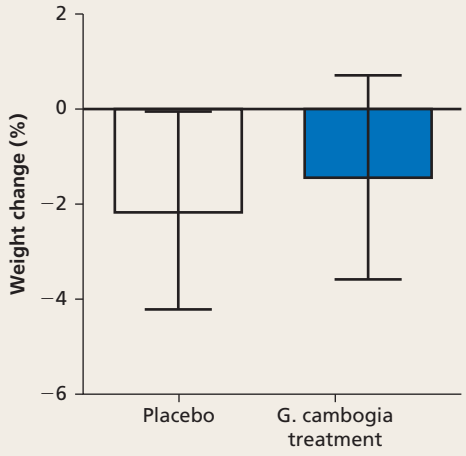


Figure 3.35 ▲
Weight change after 12 weeks of G. cambogia or placebo treatment. Results shown are means and standard deviations for 69 individuals in the placebo group and 66 individuals in the treatment group.

Examine the following evidence from a trial conducted on 135 obese human subjects. In this trial, half were given Garcinia cambogia and the other half a **placebo**. This was a **blind study**. The participants did not know if they were taking the supplement or the placebo. All participants were on low-calorie diets and took mild exercise. Overall, the placebo group and the Garcinia cambogia group contained subjects that were fairly well matched for age and gender. Examine the results provided (Figure 3.35) and answer the following questions.

1. Summarise the change in weights over the 12-week study period in the two groups.
2. Is there a clear difference between the **means** of the two groups? What do the overlapping **standard deviation** lines tell us about how different the two groups are?
3. Can you draw any conclusions about how the attitude of study participants affected weight loss in this study?
4. Do these results support the use of Garcinia cambogia as a weight loss supplement? Have the advertisements been giving their consumers the full story?

Task 2: The evidence from this trial indicated that Garcinia cambogia may not be effective in humans. A number of human trials have been conducted, with conflicting results. Table 3.4 provides a review of 7 independent studies. What is your decision? Would you recommend Garcinia cambogia as a weight loss supplement in humans?

Table 3.4 Results of 7 randomised clinical trials of HCA as a weight loss treatment (adapted from a review by Onakpoya, Hung, Perry, Wider & Ernst (2011))

Study year	Randomised participants completing trial	Treatment duration (weeks)	Mean weight treatment group (kg)	Mean change in weight treatment group (kg)	Mean weight of placebo group (kg)	Mean change in weight of placebo group (kg)
2000	89	12	75.5 (+/−10.2)	−3.7 (+/−3.1)	75.8 (+/−12.6)	−2.4 (+/−2.9)
2001	40	8	75.6 (+/−5.0)	0 (+/−11.5)	73.3 (+/−10.7)	0.5 (+/−11.7)
2001	21	2	79.3 (+/−9)	−0.4 (+/−0.9)	79.3 (+/−9)	−0.5 (+/−1.4)
2001	11	2	85.4 (+/−25.8)	−1.5 (+/−1.7)	85.4 (+/−25.8)	−1.0 (+/−1.34)
2004	53	8	91.7 (+/−15.7)	−4.5 (+/−16.6)	80.4 (+/−36.9)	−1.6 (+/− 34.1)
2004	29	8	88.5 (+/−21.8)	−5.5 (+/−23.7)	87.4 (+/−15.9)	−1.4 (+/−17.3)
2007	42	8	69.0 (+/−5.0)	−2.8 (+/−0.5)	65.0 (+/−5.0)	−1.4 (+/−0.5)

Task 3: Write a problem statement targeted at doctors with obese patients that clearly describes the issue surrounding dietary supplements such as Garcinia cambogia. Begin with an introductory paragraph. What is the real issue? Why is it a problem and why is it important to resolve the issue? What is at stake? Finally, propose a method to solve the problem. Remember to reference your information sources.
Tips:

- Think about addressing the issues of *safety* and *efficacy* (whether the product works). When considering whether to recommend a new treatment, doctors will often consider the cost versus benefit of the drug, bearing in mind the **placebo effect**.
- To ensure your review is concise, re-read it after you have written it and remove any unnecessary sentences or repeated concepts.
- Make sure you use sentences that are clear, direct, accurate, and use scientific terminology where appropriate.

Task 4: Write a short half-page letter to the editor of a popular newspaper describing the issue of Garcinia cambogia marketing to a general, non-scientific audience. The purpose of this letter is to make the audience aware of the problem using persuasive but scientifically accurate information.
Tips:

- Think about the expertise of the audience. This will influence how you accurately communicate the science to them.
- Think about why your audience would want to hear about this issue. How will you engage your audience in this subject?
- Will your audience have **confirmation bias** that might arise from having seen advertisements, or **cognitive bias** such as hoping that this product will work? How will you help your audience recognise this bias so they are more likely to engage with your arguments?
- Finally, think of ways to keep the work concise. Can information be presented graphically to explain ideas or demonstrate correlation between ideas?

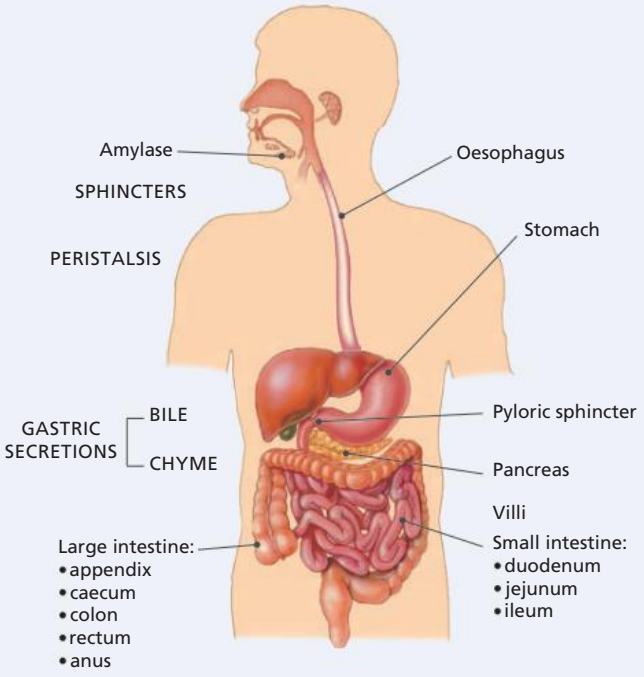
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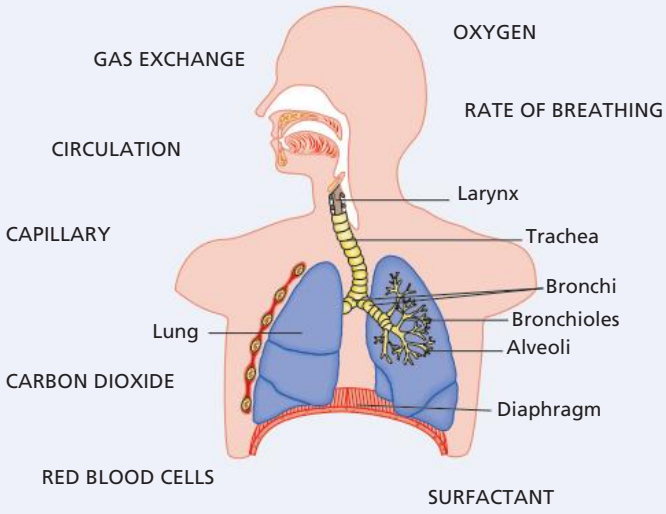
CONCEPT SUMMARY

Animal systems

Digestive system



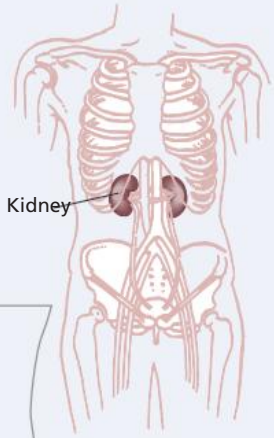
Respiratory system

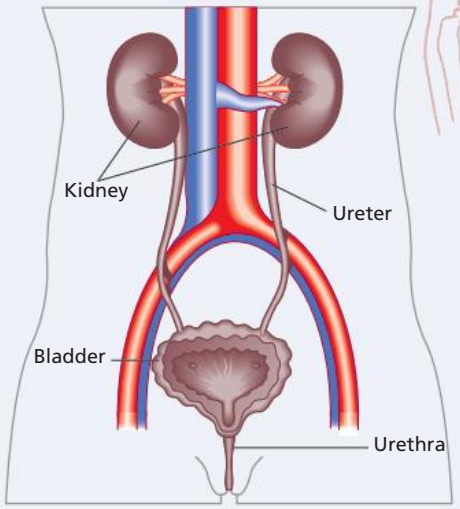




Excretory system

Amino acid deamination
Nitrogenous waste
Blood filtration



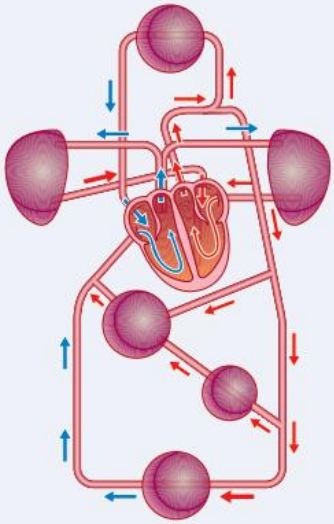


Circulatory system

Cardiac tissue
Myocytes
Atria

Ventricles
Vena cava
Systemic circulation

Pulmonary circulation
Aorta
Septum



Haemoglobin
Oxyhaemoglobin
Carbon dioxide
Carbonic acid
Red blood cells
White blood cells
Platelets

Plasma
Arteries
Capillaries
Veins
Arterioles
Skeletal muscles
Lymphatic system

Deoxygenated blood
Oxygenated blood

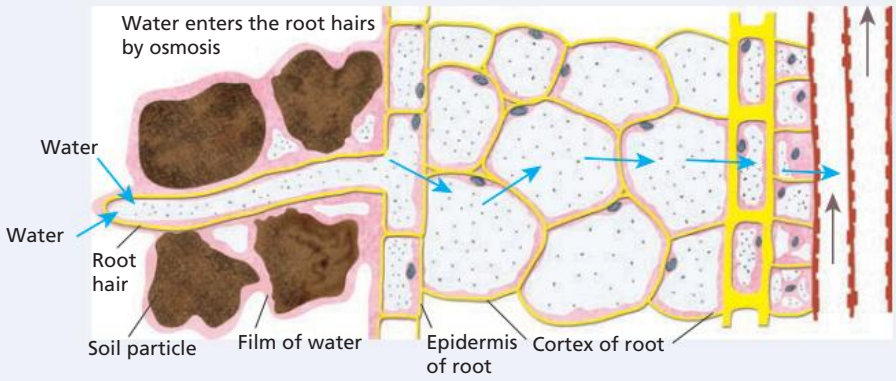
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Plant systems

Root system

Water passes across the root, from cell to cell by osmosis. It also seeps between the cells.

Water is drawn up the xylem vessels, because transpiration is constantly removing water from the top of them.

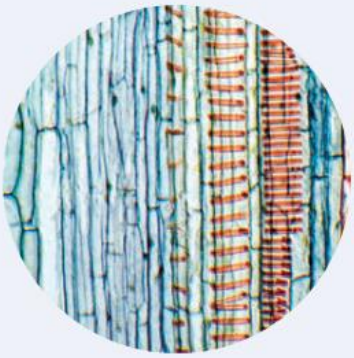


Water uptake

Occurs by osmosis

Dissolved mineral uptake

Occurs by diffusion and active transport



Shoot system

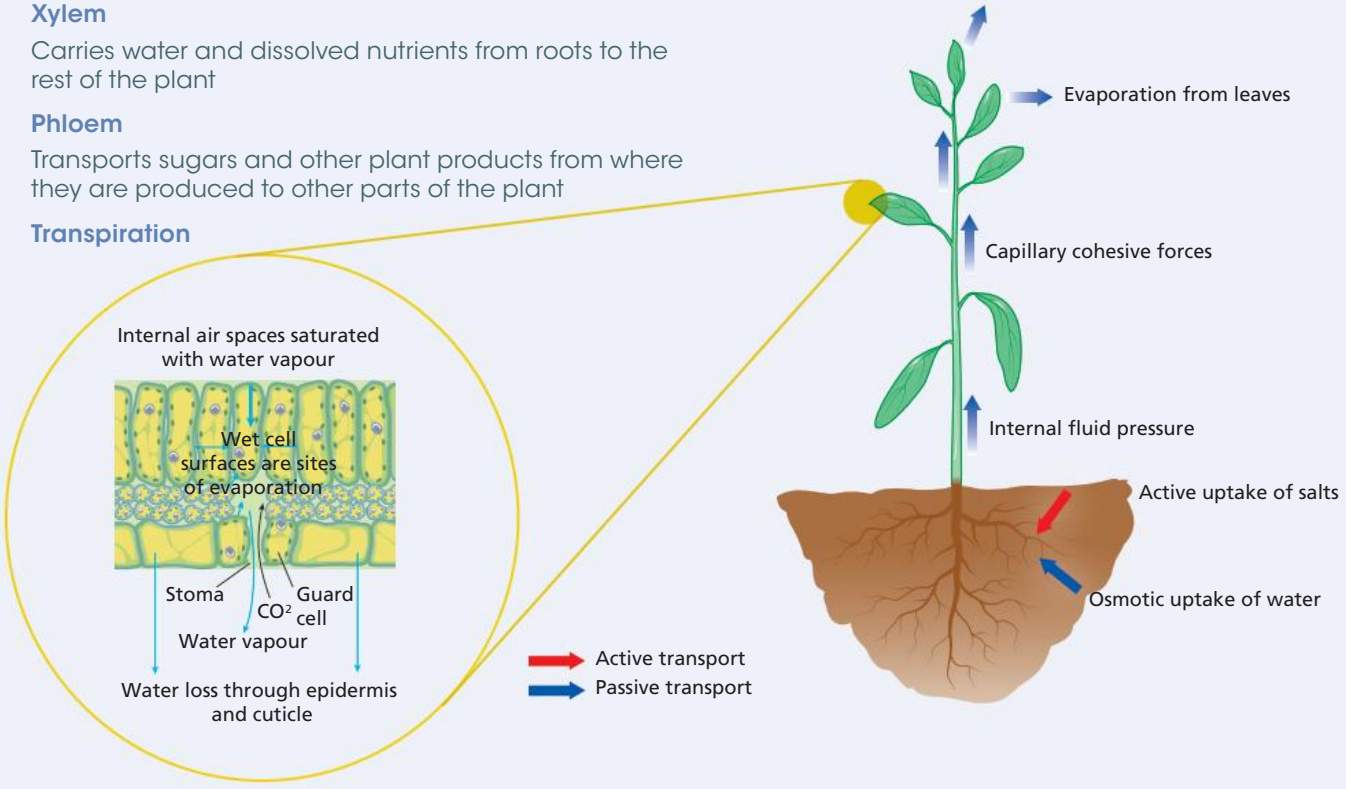
Xylem

Carries water and dissolved nutrients from roots to the rest of the plant

Phloem

Transports sugars and other plant products from where they are produced to other parts of the plant

Transpiration



CHAPTER GLOSSARY

absorption the main role of digestive system; the taking up of digested molecules

active transport the process whereby cells actively transport substances across a membrane from a low concentration to higher concentration of the substance; characterised by the fact that the process consumes energy

adhesion the strong forces that exist between water molecules and other substances, due to the polar nature of the water molecules

albumin a protein abundant in blood plasma

alveoli (alveolus) tiny air sacs located on the end of the bronchioles

amylase a substance present in saliva and secreted from salivary glands near the base of the tongue

anticoagulant a substance in the blood that inhibits normal blood clotting

anus the exit point of waste products and the end point of the gastrointestinal tract

aorta the largest artery; takes blood to all parts of the body (i.e. the systemic circulation)

arrhythmia an alteration in rhythm of the heartbeat

arteriole a small artery

artery a blood vessel that takes blood away from the heart

atria two thin-walled chambers of the heart

bile a substance produced by the liver and transported into the duodenum; it is not an enzyme and is involved in mechanical digestion of fats due to its detergent-like action

Bowman's capsule the structure in which the glomerulus is found, at the beginning of the nephron

bronchi (bronchus) two branches of the trachea that lead to the lungs

bronchiole the smaller tube of the bronchus

carbonic acid most of the carbon dioxide produced in respiration is converted into carbonic acid in the plasma

cardiac relating to the heart

cardiovascular system the heart, blood and blood vessels

capillary a small blood vessel that links arteries and veins; also, any very thin tube

chemical digestion a process whereby complex substances are broken down into their simplest forms via enzyme action

cholesterol a type of steroid associated with heart disease

chyme 'soupy' contents of the stomach (partially digested food)

circulatory system the body's main internal transport system

closed circulatory system a type of circulatory system in which blood is confined to a set of vessels

cohesion the strong forces that exist between water molecules

colon the first section of the large intestine, where water, minerals and vitamins are absorbed into the body

coronary angioplasty a procedure to open narrowed or blocked blood vessels that supply blood to the heart

coronary arteries arteries supplying blood to the heart

coronary heart disease disease of the heart and heart blood vessels

deamination a process that separates the nitrogen-containing amine group from the rest of the amino acid

defibrillator an apparatus used to attempt to restore the heart to a normal effective rhythm by application of an electric current to the chest wall or directly to the heart

diaphragm a sheet of muscle that, along with the ribs, moves air into and out of the lungs

diffusion the movement of a dissolved substance from an area of high concentration to an area of low concentration; the process does not require an input of energy

digestion the main role of the digestive system; the breaking down of complex organic molecules mechanically and chemically

digestive system where digestion takes place, also known as the gastrointestinal tract

distal tubule the portion of the nephron between the loop of Henle and the collecting duct

egestion the removal of wastes from the digestive system

endothermic describes animals that are able to generate their body heat through biochemical processes within their bodies

epidermis the surface layer of plant or animal cells, generally responsible for separating and protecting the organism from its environment

erythrocyte a red blood cell that is non-nucleated when mature; contains haemoglobin pigment that transports oxygen from the lungs to the tissues

excretion removal of wastes from the internal environment of the body

external environment the environment surrounding a cell outside the plasma membrane

extracellular fluid the fluid that bathes the outside of cells in multicellular organisms

faeces the waste material eliminated from the body through the anus

filtrate the fluid remaining after filtration takes place

gall bladder the organ that stores bile if there is no food to digest in the small intestine

gastric juice substances produced due to the presence of food in the stomach; gastric juice contains mucus, water, hydrochloric acid, and pepsin and protease enzymes

gastrointestinal tract see *digestive system*

glomerulus a network of capillaries that are located in the Bowman's capsule and are the first step in filtering the blood through the nephron

haemodialysis the process of dialysis whereby blood is passed through an artificial kidney or dialysis machine

haemoglobin the respiratory pigment of most vertebrates and some invertebrates; contains iron; blood appears red when oxygenated

heterotroph an organism that consumes other organisms as food

ingestion the taking in of nutrients

internal environment all material contained within the plasma membrane

kidney an organ that removes wastes and controls the body's fluid balance

lacteal a vessel that transports materials to and from the villi of the small intestine

large intestine the final length of the gut; consists of the colon and the rectum; functions to compact undigested food material, and absorb water and some salts back into the body

larynx the voice box

leukocyte a type of white blood cell that defends the human body against infectious diseases and foreign particles; the number circulating increases when injury or infection occurs

lignin found in xylem cells; provides strength and structure to the cell wall and plant

lipoprotein a biochemical structure that contains both lipids and proteins

loop of Henle the portion of a nephron that connects the proximal convoluted tubule to the distal convoluted tubule

lumen the narrow central cavity of blood vessels

lymph colourless fluid that circulates through the lymphatic vessels to be returned to the blood

lymphatic system a system of vessels that drains excess fluid from the tissues

lymph vessel a thin-walled tube with valves that carries lymph around the body

mechanical digestion the process whereby large pieces of food are broken down through chewing or muscular movement in the stomach

myocardial infarction a heart attack

microvilli tiny projections on the surface of villi that increase the surface area of the gut

myocyte cell a type of muscle cell

nephron the structure of the kidney where filtration of the blood occurs

oedema an excessive build-up of fluid in the body's tissues

oesophagus the muscular tube that transports food from mouth to stomach

organ a structure made up of different types of tissue working together

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

oxyhaemoglobin the combination of oxygen and haemoglobin that is carried around the body in red blood cells

pancreatic juice the secretions by the pancreas into the small intestine via the duodenum; contains amylase, trypsin, lipase and bicarbonate

parenchyma large, thin-walled cells that make up the cortex of the plant

peristalsis waves of muscular contractions that push food down the oesophagus

peritoneal dialysis dialysis occurring inside the body using the peritoneum as the membrane across which wastes can be removed

phloem a vascular tissue in plants, mainly responsible for the transport of sugars from leaves to the rest of the plant; it is composed of living cells

plaque a semi-hardened accumulation of substances

plasma the pale yellow liquid component of the blood that holds blood cells, proteins and nutrients in suspension

platelet a small cell fragment involved in the clotting property of the blood

polypeptide many amino acids linked together forming a protein or part of a protein

proximal tubule the section of the tubule in the nephron that leads from the Bowman's capsule to the loop of Henle

pulmonary circulation the system of blood vessels that leads to and from the lungs

pyloric sphincter the small muscular opening that controls the amount of food that can leave the stomach and enter the small intestine

rectum the final section of the large intestine, where wastes may be stored prior to evacuation

renal artery the branch of the aorta that brings blood (containing nitrogenous waste and water, blood proteins, red blood cells and minerals dissolved in the blood plasma) to the kidneys

renal pelvis the section of the kidney where urine is collected and directed to the ureter

root pressure the force that pushes water up the stem from the roots

septum the dividing wall that keeps the deoxygenated blood on the right side of the heart from mixing with the oxygenated blood on the left side

small intestine the longest part of the gastrointestinal tract; receives material from the stomach

sphincter a circular muscle that when constricted closes a natural body passage and relaxes as required to allow flow of substances through the passage

stent a small mesh tube that is used to treat narrow or weak arteries

stomata the openings in leaves, and some stems, that control the movement of gases into and out of the plant; singular is stoma (or sometimes stomate)

surface tension the force that creates the effect of a stretched membrane over liquid

surfactant the thin layer of fluid that covers the internal membrane of each alveolus

systemic circulation the general body system of blood vessels

terrestrial land dwelling

tissue a group of specialised cells working together to perform a specific function

trachea an organ that carries gases to the lungs via the bronchi and bronchioles; it is strengthened with rings of cartilage to stop it collapsing

tracheid an elongated cell in the xylem of plants; mature tracheids are dead cells

transpiration the loss of water from plants through evaporation

transpirational pull the force arising from the evaporation of water from leaves and transmitted down the xylem

transpiration stream a continuous column of water that runs the length of the stem of a plant

urea the compound to which most nitrogenous wastes (produced from the oxidation of amino acids) are converted; it is excreted in urine

vascular bundle a combined bundle of xylem and phloem tissues in plants

vascular tissue (in plants) the plant tissue devoted to the bulk transport of water, nutrients, sugars and other substances; comprising the xylem and phloem

vein a blood vessel that carries blood to the heart

vena cava the vein that delivers deoxygenated blood from the general body system to the right atrium

ventricle one of the two muscular chambers of the heart

vessel element one type of cell comprising xylem tissue of flowering plants; they have perforations at each end of the usually dead cells to allow the free flow of water

villi the projections from the surface of the small intestine that increases its surface area and thus increases absorption

water potential the capacity of water to do work based on the kinetic energy of its individual molecules; the work is done as water moves across selectively permeable membranes due to osmosis

xylem a vascular tissue in plants, mainly composed of dead cells, responsible for the bulk transport of water and nutrients from the roots to the rest of the plant

CHAPTER REVIEW QUESTIONS

Remembering

1 Name the two types of vascular tissues in plants.
2 Describe how vascular tissue is arranged in most plants.
3 List the organs that make up the following body systems.
   a Cardiovascular system
   b Circulatory system
   c Respiratory system
   d Digestive system
   e Excretory system

Understanding

4 Name the body systems that ensure all cells receive or achieve the following.
   a Oxygen
   b Amino acids
   c Lipids
   d Removal of waste products from the blood
5 The gut is a term commonly used to describe the gastrointestinal tract. Prepare a table that lists all the sections of the gut and describes what occurs in each section.
6 Describe the differences in structures involved in systemic and pulmonary circulation.

7 Valves are membranous structures found in some blood vessels and between various chambers of the heart. Explain how the material from which they are made helps them undertake their function.

8 Define the following terms and describe their role in the human kidney.

- **a** Renal pelvis
- **b** Nephron
- **c** Loop of Henle
- **d** Collecting duct

Applying

9 Suggest what the energy source is for the transport of water from the roots to the crown of a tall tree.

10 If you were shown a blood vessel attached to the heart, explain how you would know if it was an artery or a vein.

11 Draw a simplified diagram of the heart and show, using arrows, the direction of blood flow.

12 Devise a table that:

- **a** clearly identifies the common features of the circulatory systems of different animals
- **b** compares the differences found in the circulatory systems of different animals.

13 You have eaten a meal of fish. Fish contains a lot of protein and a small amount of fat. Outline how the structure and function of your digestive system will assist the delivery of amino acids to your cells.

14 If you suffered a major cut to an artery causing severe blood loss, part of your treatment after stopping the bleeding would be to wrap you in a thermal blanket and place an intravenous drip into a vein. Explain why these two steps are necessary.

Analysing

15 When transplanting plants from one place to another, it is important to take some of the natural soil still clinging to the roots. Suggest reasons for this, given what you have learned about root hairs.

16 Explain how the uptake of mineral ions differs from the uptake of water from the soil.

17 Is the material egested from the digestive system part of the internal or external environment? Give reasons for your answer.

18 Compare the human digestive system to that of one other organism (not a cow).

19 Suggest why the kidney uses more energy proportionally than the heart.

20 Explain how the kidneys assist in maintaining water balance in the blood.

21 Animals that live in hot, dry environments have nephrons that have a long loop of Henle. Explain how this is an adaptation to their environment.

Evaluating

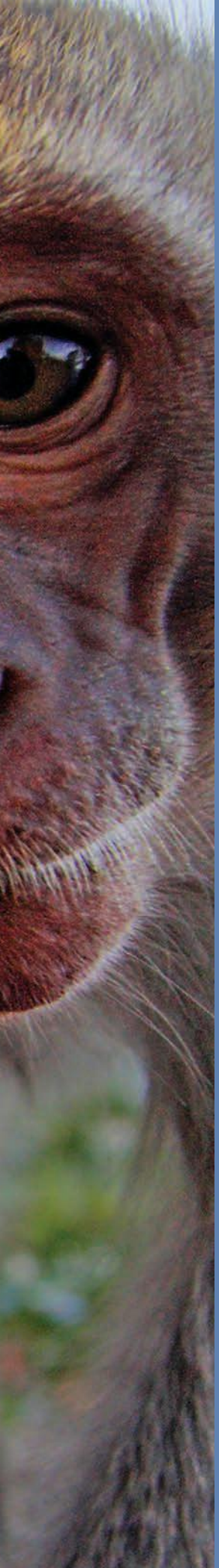
22 The major function of the large intestines is to absorb water. If you are suffering from diarrhoea you would absorb 10 mL of water over 4 hours. If you are suffering from constipation you would absorb 100 mL over 4 hours. Predict the amount of water you would absorb if you were not suffering from either condition.

23 When fat droplets meet, they clump together to form a large droplet. This happens in your arteries. Calcium and other minerals form a deposit on top of the fat, forming plaque. Explain why plaque build-up in the arteries could be life threatening.

24 Each year, many babies are born with a ventricular septal defect (VSD) where there is a hole in the septum dividing the ventricles. Explain how this could affect the blood being pumped out of the aorta. What do you think 'ASD' could mean?

Creating

25 Horses, cats and humans are all mammals. Their body tissues are remarkably similar in make-up, yet their food sources are very different. Horses are herbivores, cats are basically carnivores and most humans are omnivores. Explain how it is that their body tissues are so similar although their food is so different.



CHAPTER 4

SURVIVAL THROUGH ADAPTATIONS AND REGULATION

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

KEY KNOWLEDGE

Survival through adaptations and regulation

- the structural, physiological and behavioural adaptations that enhance an organism's survival and enable life to exist in a wide range of environments
- successful adaptations as models for biomimicry to solve human challenges
- how regulation of factors is needed to maintain a relatively constant internal environment, explained by the stimulus-response model and the use of homeostatic mechanisms including feedback loops
- factors regulated by homeostatic mechanisms in humans, including temperature, blood glucose and water balance
- malfunctions in homeostatic mechanisms that result in diseases, including Type 1 diabetes and hyperthyroidism in humans.

Investigation of an issue

- the 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 biological concepts specific to the investigation: definitions of key terms; use of appropriate biological terminology, conventions and representations
- the use of data representations, models and theories in organising and explaining observed phenomena and biological concepts, and their limitations

KEY SCIENCE SKILLS

Analyse and evaluate data, methods and scientific models

- organise, present and interpret data using schematic diagrams and flow charts, tables, bar charts, line graphs, ratios, percentages and calculations of mean
- explain how models are used to organise and understand observed phenomena and concepts related to biology, identifying limitations of the models

Draw evidence-based conclusions

- draw conclusions consistent with evidence and relevant to the question under investigation
- identify, describe and explain the limitations of conclusions, including identification of further evidence required
- discuss the implications of research findings and proposals

Communicate and explain scientific ideas

- use appropriate biological terminology, representations and conventions, including standard abbreviations, graphing conventions and units of measurement
- discuss relevant biological information, ideas, concepts, theories and models and the connections between them
- identify and explain formal biological terminology about investigations and concepts
- use clear, coherent and concise expression
- acknowledge sources of information and use standard scientific referencing conventions

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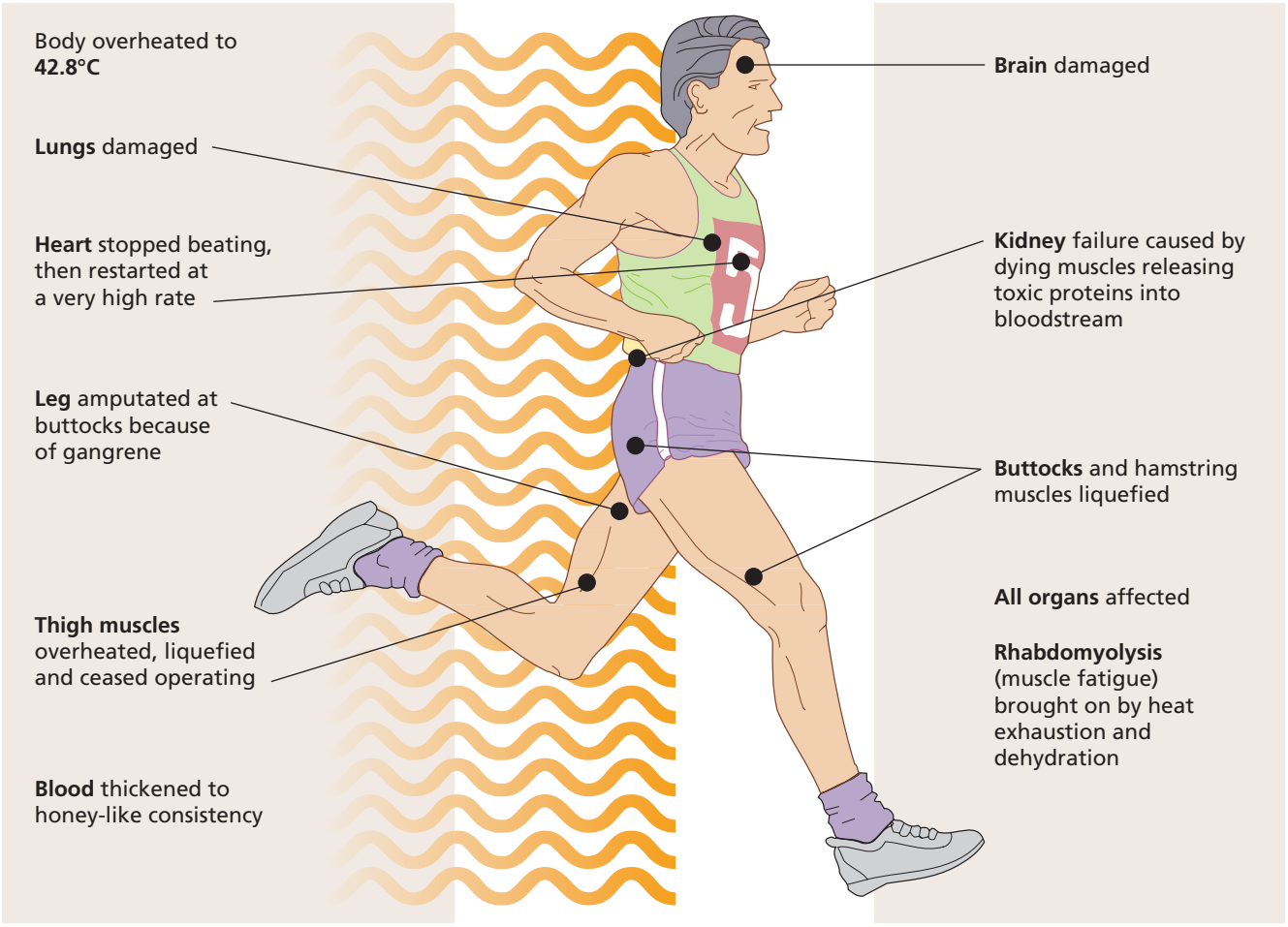
In 1988 Mark Dorrity went on an 8 km run in extreme heat in New South Wales. During the run, his body overheated to 42.8°C but he didn't drink water to stay hydrated. As a result, Mark's body could not regulate his temperature and water balance. His muscles generated more heat than could be lost from his body and Mark suffered a rare condition known as rhabdomyolysis. His thigh muscles liquefied and released toxic proteins into his blood, causing kidney failure. Dehydration resulted in thickening of the blood to a point where it could not flow freely in some parts of the body. Every organ in his body was affected; he became delirious, brain damage occurred, his lungs barely functioned and his heart stopped at least once. Within an hour, he collapsed into a three-month coma, during which he was on dialysis and had one leg amputated due to gangrene.

Under normal conditions Mark's body systems worked together to enable him to function comfortably, but in the extreme environmental conditions his body's ability to maintain heat balance became impaired. His judgement and behaviour overrode the warning signs; his coordinating systems were unable to regulate his physiological responses to heat. The conditions in his internal environment became intolerable.

Fortunately, few people engage in the kind of activity that Mark Dorrity did in such extreme conditions, though for many organisms these conditions are a feature of their daily lives. Complex organisms have strategies and mechanisms to keep internal conditions relatively stable. This allows for the necessary biochemical processes to be maintained.

This section explores the structural features, physiological mechanisms and behavioural responses that enhance an organism's survival and enable life to exist in a wide range of environments.

▼ Figure 4.1
A near fatal mistake



Survival in a range of environments

There are few places on Earth, if any, where environmental conditions are stable throughout the year and from one year to the next. Organisms must have appropriate structural, physiological (body functioning) and behavioural characteristics that enable them to successfully obtain their requirements, often in changing conditions. Change is a feature of existence and life forms have evolved to live in an extraordinary range of places.

Terrestrial environments differ from aquatic environments. Freshwater fish and water plants living in a billabong experience different environmental conditions from marine fish and seaweeds in the ocean. Polar bears of the Arctic have different conditions to deal with compared to the crocodiles and marsupials of the Northern Territory. Mammals, birds and vegetation of equatorial regions experience more consistent temperatures throughout the year, but precipitation can vary according to altitude and distance from the coast. Desert hopping mice, spinifex grass and cocoon frogs have to survive in hot deserts characterised by sparse rainfall and high temperatures that plummet during the night. In contrast, in Antarctica, despite seemingly inhospitable conditions of extreme cold and little rainfall, well-adapted plants and animals flourish.

Environmental factors

In everyday language, 'environment' tends to mean the physical space or surroundings in which an organism lives. Biologically, 'environment' means the sum total of all the factors that affect an organism. These can be categorised according to whether the factors are **abiotic** or **biotic**.

- Abiotic factors are physical and chemical factors such as temperature, light intensity, texture and pH of the soil, concentration of significant gases in water or air, and the availability of water.
- Biotic factors are to do with the presence or absence of other living things that affect an organism, such as more of their own kind, competitors, collaborators, predators, disease-causing organisms or parasites, and availability of mates.

Chapter 6 goes into more detail about biotic factors that affect an organism.

Tolerance limits

Think of the places where very few humans live. Places of extreme heat and little water, such as the desert, are sparsely populated without the assistance of air-conditioned dwellings. Likewise, Earth's frosty poles have very few inhabitants. These observations are due to the consequences for humans of experiencing prolonged periods of extremes of temperature that can result in heatstroke or **hyperthermia**.

For many abiotic factors such as temperature, a particular species has a level or **optimum range** for that factor and it may be broad or narrow depending on the species. The optimum range is the range in which the organism thrives and functions best. Outside that range, an organism enters a **tolerance range** where it can survive, but not thrive. If the conditions vary outside the optimum range, the organism will begin to suffer **physiological stress** (such as hyperthermia or **hypothermia** when the factor is temperature) and its functioning will be affected. This is the point at which the mechanisms the organism possesses to deal with the fluctuations in the abiotic factor are overwhelmed and if the situation does not change, the organism will not survive.

Light availability is another abiotic factor for which particular organisms have certain optimum ranges. Some plants, such as moss and many ferns, are 'shade-loving', while others require a high light intensity if they are to thrive. A shade-loving plant placed in bright light will not survive, and vice versa. Humidity, salinity, soil composition and

oxygen are some of many other examples of abiotic factors for which organisms have an optimum range and a tolerance range.

Environmental niches

In biological terms, a **niche** is a set of environmental conditions, particularly abiotic factors. An organism may be especially well suited to a particular environmental niche as all of the abiotic factors making up the niche are within the organism's optimum range. In this situation, the environmental conditions make up the organism's **preferred niche**, and the organism can thrive in the niche. Once conditions vary from the optimum range and enter the tolerance range for the organism, the environment becomes a **marginal niche** for an organism, where it can survive but not thrive. Outside the tolerance range, environmental conditions may make up an **unavailable niche**.

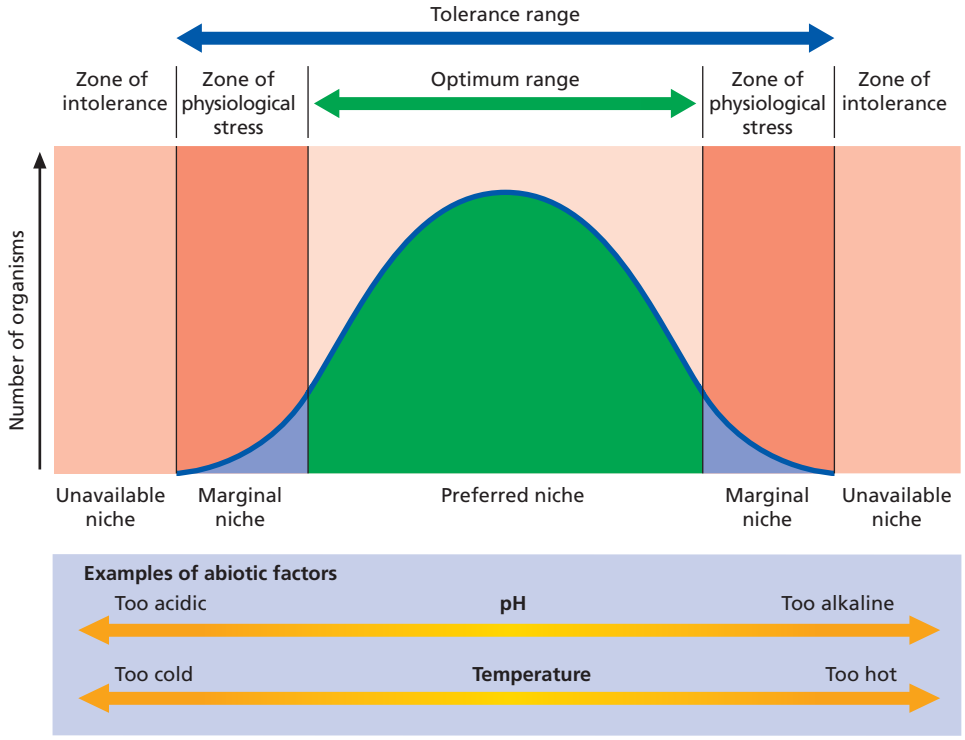


Figure 4.2
The optimum range for an abiotic factor is the range within which an organism functions best.

Adjusting to change

Conditions in the external environment place different pressures on organisms but they possess structures, behaviours and physiological features that enable them to live their lives in their particular habitat. When conditions change, organisms need to be able to adapt so they can survive outside their previous tolerance range. Some organisms can adjust to changing conditions if the changes are gradual. Some fish species can withstand slight changes in temperature as they move from place to place within a body of water. A skink in the desert will emerge in the morning and absorb the heat of the Sun. As the day progresses, its body temperature rises to the skink's optimum. When it reaches the upper limit of tolerance the skink will move into the shade.

A sessile plant, such as a mulga tree, spinifex or seaweed, has no capacity to move. It relies on its structure and physiology to survive in its environment. Even so, at a particular stage in its life cycle, a plant's seeds, spores or fruits can be dispersed to different – and perhaps more favourable – areas.

In some habitats, environmental conditions vary on a regular basis. If a swamp tends to dry up in summer, frogs and many invertebrates will burrow in the mud, seeds and eggs will lie dormant and birds will migrate to other areas where resources are more plentiful.

RECALL

- Organisms must keep their internal environments within narrow limits for survival. These are known as tolerance limits.
- Each organism has an optimum range in which it functions best; outside this range is the zone of physiological stress.

RECAP 4.1

1 List the three types of adaptations that enhance an organism's survival.

2 Define the following terms.
- a Tolerance range
- b Optimum range
- c Physiological stress

Maintaining a relatively constant internal environment

The relationship between the internal and external environments of a living thing is important. In the case of unicellular organisms such as *Paramecium*, *Amoeba* or microscopic algae, everything inside the plasma membrane constitutes the organism's internal environment. In a multicellular organism, internal environment refers to the conditions within its cells and in the extracellular fluid between its cells.

Organisms need to maintain a relatively constant internal state – a state of **homeostasis** – to survive in their environment. Why is the state of the internal environment so important? A number of conditions affect the way cells function. For example, the concentration in cells and tissue fluids of solutes such as glucose and hydrogen ions (pH) and gases such as oxygen and carbon dioxide affects cell metabolism.

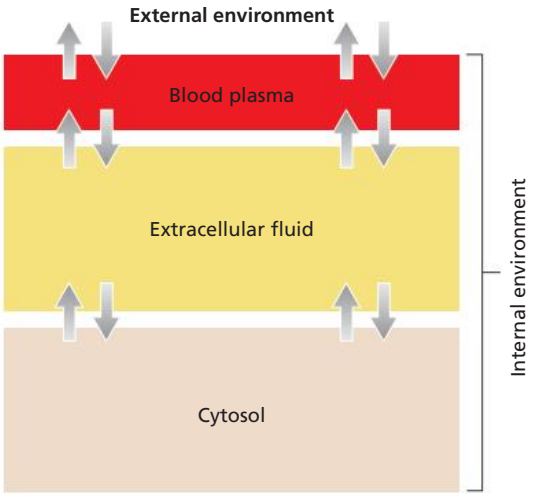


Figure 4.3▲
By constant movement of substances across membranes, organisms regulate their internal conditions despite changes to internal and external environmental conditions.

Homeostasis refers to the maintenance of a relatively constant internal environment within small tolerance limits, despite changes in the internal or external environment. The concentration of substances such as glucose, carbon dioxide and hydrogen ions – in cells, extracellular (interstitial) fluid and blood plasma – all impact cell function. Movement of materials across membranes is affected by water concentration, nutrients and ions – such as sodium, potassium and chloride – on either side of the membrane (Figure 4.3).

The activities of enzymes are affected by body temperature and pH. Biochemical processes can be disrupted or cells killed by quite small changes. Responding to these changes and correcting them back to normal is essential. The processes involved in homeostasis are called homeostatic mechanisms and, in complex organisms, involve most body systems.

Avoiding injury or death is clearly essential for the survival of the organism. Cells of an organism coordinate a response to immediate threats in the external environment, such as a lurking predator or falling rocks. A coordinated response requires signals from the external environment to be detected and conveyed to cells that then must respond appropriately.

Detecting stimuli

Organisms communicate constantly with their environment, both internal and external. An organism and its cells receive different types of information and respond in many different ways.

Signals may come from the external environment, other parts of the organism or from within the cell. **Stimuli** (singular, stimulus) may be physical (light, heat, pressure) or chemical (**hormones**, **neurotransmitters**). There are millions of external and internal **receptors**. Receptors are proteins, organs or cells that allow an organism to detect and respond to stimuli. The main types of receptors are: **chemoreceptors**, **mechanoreceptors**, **photoreceptors**, **thermoreceptors**, **nociceptors (pain receptors)** and **osmoreceptors** (Table 4.1).

Table 4.1 The main types of receptors

Stimulus	Receptor
Chemical stimuli	Chemoreceptor
Mechanical stimuli such as stretching or pressure	Mechanoreceptor
Light	Photoreceptor
Heat or cold	Thermoreceptor
Pain	Nociceptor
Water	Osmoreceptor

Signals from the external and internal environments

Organisms detect signals from their external environment, interpret these signals and coordinate a response for survival or development. **Exteroceptors** are highly specialised to receive signals from the external environment. They can work as individual receptors or together as a group, and can be distributed evenly over the body (e.g. pain receptors), located in specialised areas (e.g. taste buds) or concentrated in organs (e.g. the eye). Exteroceptors work by receiving information and converting it to a chemical signal that can then be relayed between body cells.

Interoceptors receive signals from within the body's internal environment. Examples of internal signals are an increase in carbon dioxide concentration or low pH levels. The **interstitial fluid** (also called extracellular fluid) that bathes the cells, and the blood plasma, creates the body's internal environment. Cells exchange substances across membranes via the interstitial fluid (Figure 4.4). With the aid of interoceptors, the internal environment is maintained within narrow limits, allowing maximum cellular efficiency. Table 4.2 on page 118 lists some examples of interoceptors and exteroceptors in the body.

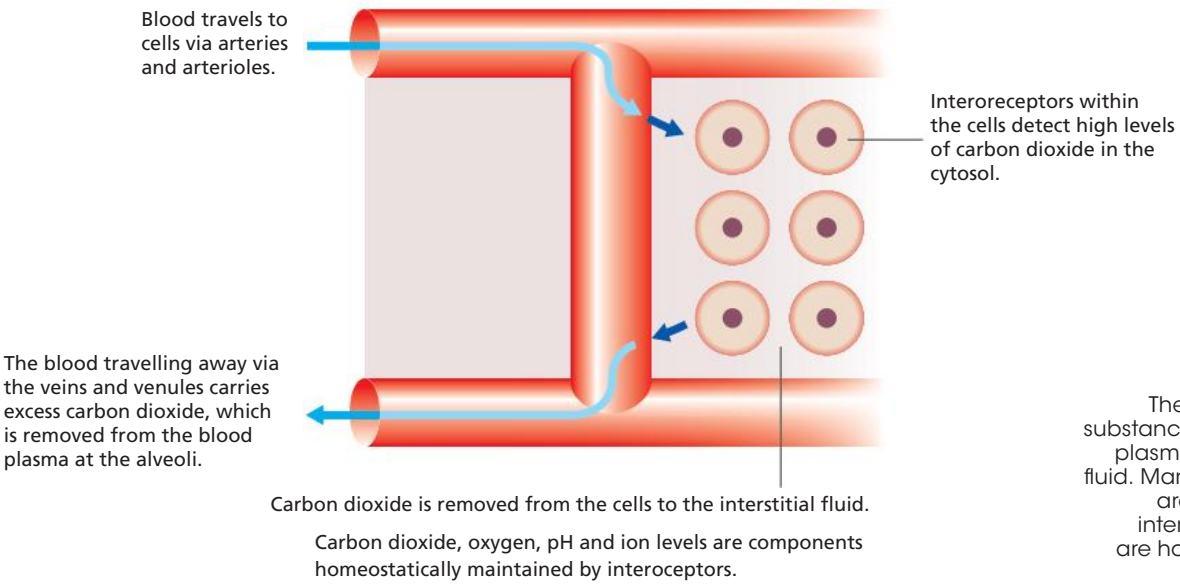


Figure 4.4 The exchange of substances from blood plasma to interstitial fluid. Many substances are detected by interoceptors and are homeostatically maintained.

Table 4.2 Some examples of exteroceptors and interoceptors

Type of receptor	Stimuli	Location in animals
Chemoreceptors	Exteroceptors: Substances that have smell (olfactory receptors) or taste	Nose, mouth
	Interoceptors: Oxygen and ion levels	Aorta, carotid arteries
Mechanoreceptors	Exteroceptors and interoceptors: Pressure, touch, tension, sound vibrations, balance	Ear, skin
Photoreceptors	Exteroceptors: Light	Eyes, light-sensitive cells in body surface of some invertebrates
Thermoreceptors	Exteroceptors: External temperature variations	Skin
	Interoceptors: Internal temperature variations	Hypothalamus
Pain receptors	Exteroceptors and interoceptors: Pain	Free nerve endings in the skin

RECALL

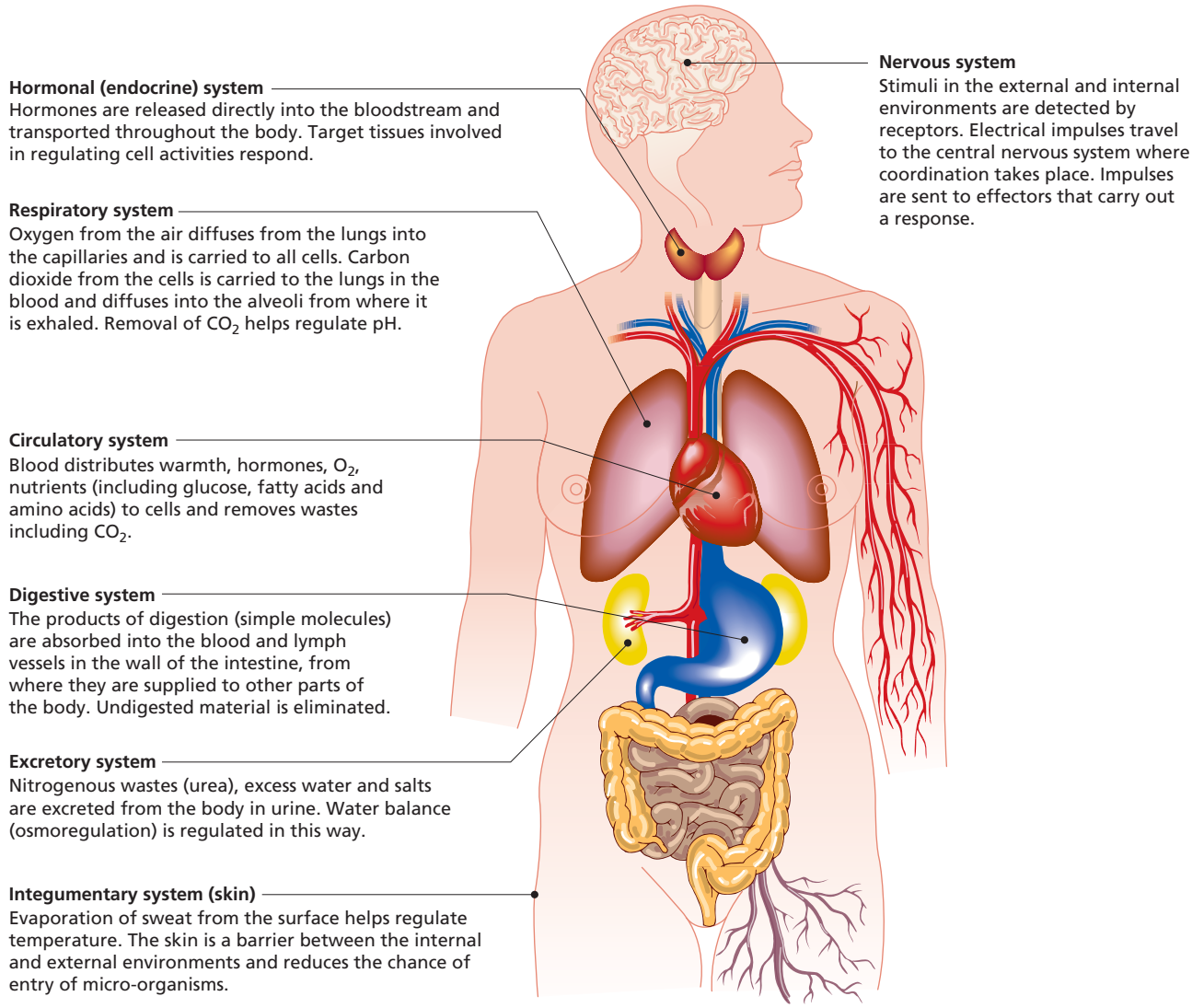
- Homeostasis is the maintenance of a relatively constant internal environment within small tolerance limits, despite changes in the external environment.
- There are six major groups of receptors: chemoreceptors, mechanoreceptors, photoreceptors, thermoreceptors, nociceptors and osmoreceptors.
- Organisms detect signals through interoceptors (internal signals) and exteroceptors (external signals).

RECAP 4.2

1. Define 'homeostasis' and outline its purpose.
2. Explain what constitutes the 'internal environment'.
3. Distinguish between exteroceptors and interoceptors.
4. Explain why it is important for an organism to be able to detect changes in its external environment. Give an example.

The principle of feedback

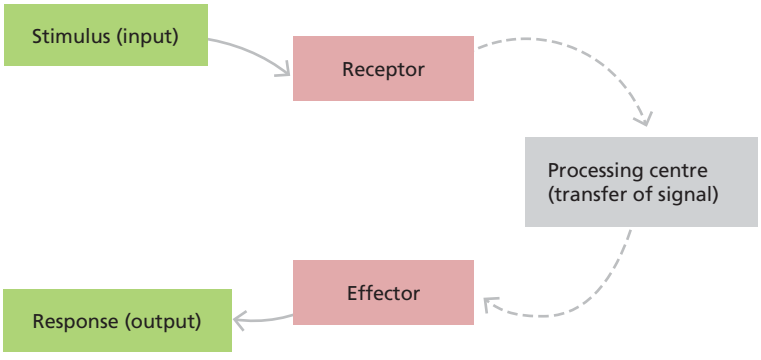
As previously discussed, organisms have narrow ranges in which they keep internal temperature and fluid concentration. Minor fluctuations around this optimal level occur continually; however, considerable disturbances from the optimum level can also occur. Diseases, extremes in the internal environment, trauma, inherited disorders and toxic substances can interfere with homeostasis. All disturbances must be controlled quickly for cells to continue to function effectively.



▲ **Figure 4.5** Homeostasis and human body systems

Signals about disturbances are fed to a control centre. The centre interprets and coordinates a specific response that either counteracts or reinforces the disturbance. These processes are referred to as **feedback mechanisms**. A feedback mechanism is triggered when a stimulus is detected by a receptor. The information is then processed and a message is conveyed to an **effector**, which carries out the response to the stimulus.

In analysing how cells and organisms respond to signals it is useful to apply a stimulus–response model. This model represents feedback mechanisms. In animals, the main body organs that respond to signals are glands or muscles. The receptor organs are different from the effector organs, so communication between cells to coordinate a response is essential.



▲ **Figure 4.6** The stimulus–response model relies on the transfer of information between the receptor and effector.

Negative feedback

Once a signal has been responded to, it is important that it is switched off. An over-response is a waste of energy and can often lead to cell damage. Three main strategies used by cells and organisms are:

1 disrupting the signal
2 removal of the original stimulus
3 responding in a way that alters the original signal, described as feedback.

When a bar of chocolate is ingested, blood glucose levels rise rapidly above the optimal level known as the **set point**. The body's response is to lower the blood glucose level to normal by removing glucose from the blood and converting it to **glycogen**. The level of glucose in the blood drops as it is stored away. Mechanisms that counteract the stimulus are referred to as **negative feedback** (Figure 4.7). On the other hand, exercising vigorously or fasting decreases blood glucose levels below the set point. The body responds by breaking down glycogen stores and returning blood glucose levels to normal (Figure 4.8).

Negative feedback is extremely important in homeostasis as the response always aims to restore the internal environment to a constant set of conditions.

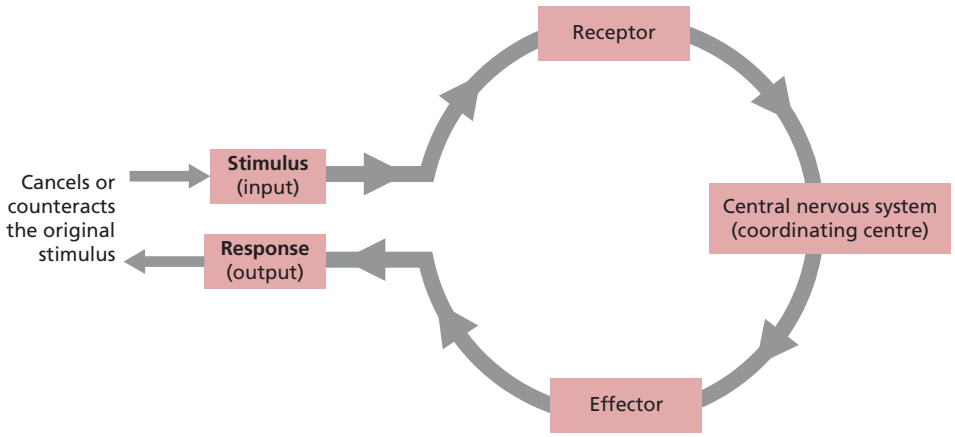


Figure 4.7 ▶ Negative feedback occurs when a response cancels or counteracts the original stimulus.

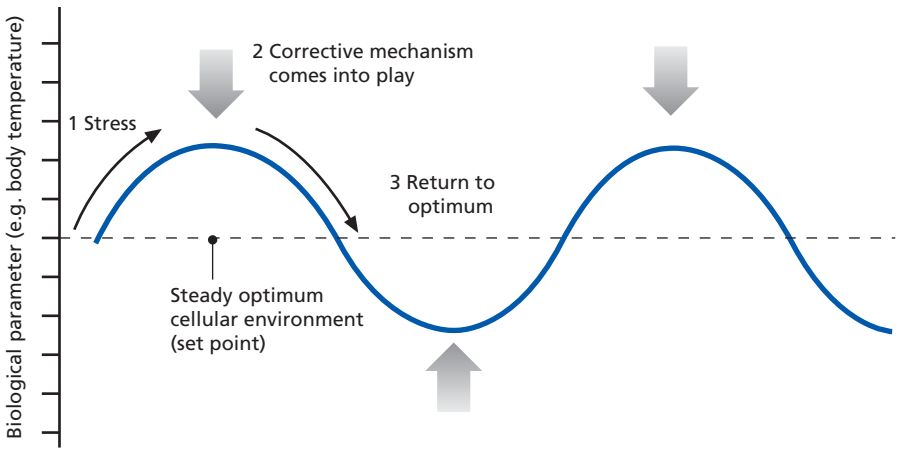


Figure 4.8 ▶ Set points and optimum conditions are maintained through negative feedback.

Positive feedback

If adjustments are made that reinforce the original stimulus, the mechanism is referred to as **positive feedback**. Positive feedback is necessary during some developmental processes. For example, the development of frogs and toads is controlled by the hormone **thyroxine**. Just before the tadpole changes (metamorphoses) into an adult frog, negative

feedback is changed into positive feedback. The concentration of thyroxine rises and triggers metamorphosis.

In terms of homeostasis, positive feedback can be harmful. When human body temperature rises during fever, a new and higher set point for temperature is established and the person may suffer from heatstroke. If the resetting of the set point continues upwards, cell function is impaired.

RECALL

- Feedback mechanisms are processes that respond to small disturbances to keep concentrations of substances within narrow limits for optimal cellular function.
- Negative feedback mechanisms result in returning changed conditions to their optimal level or set point.
- Positive feedback mechanisms reinforce the condition.

RECAP 4.3

1 Outline the stimulus–response model.
2 Define:
   a stimulus
   b receptor
   c effector
   d response.
3 Describe negative feedback.

Temperature regulation in humans

To understand how humans regulate their temperature, it is necessary to understand how heat is transferred. Put simply, if an organism is too hot, it must lose heat. If an organism is too cold, it must gain heat. Heat transfer depends on the temperature gradient between the internal and external environments. When there is a balance between heat gain and heat loss, the organism is said to be in **heat balance**, which is the purpose of **thermoregulation**. In humans, the heat balance results in a body core temperature of about 37°C. Humans manage thermoregulation in ways that usually involve the interaction of their physiology (the structures they have and how they function to facilitate the process) and their behaviour.

An organism that is hotter than its surroundings may lose heat energy in a combination of four ways, and an organism that is cooler than its surroundings will gain heat in the same ways: **conduction**, **convection**, **evaporation** and **radiation**. Conduction is the transfer of heat energy from a hotter object to a cooler object by direct contact. Convection transfers heat when hot air or water rises and is replaced by cooler air or water. Evaporation (in relation to organisms) is when water or sweat turns to vapour, cooling the skin. When heat is transferred from an object by infra-red waves, it is called radiation.

Apart from homeostatic mechanisms that involve the physiology of the animal, behaviours and structures can also contribute to maintaining a relatively stable body temperature.

Think about what happens to you if you experience hot conditions. Perhaps you sprawl out in the shade, exposing a large surface area from which heat can be lost. Your skin may look redder than usual and feel warm, and you may feel thirsty.

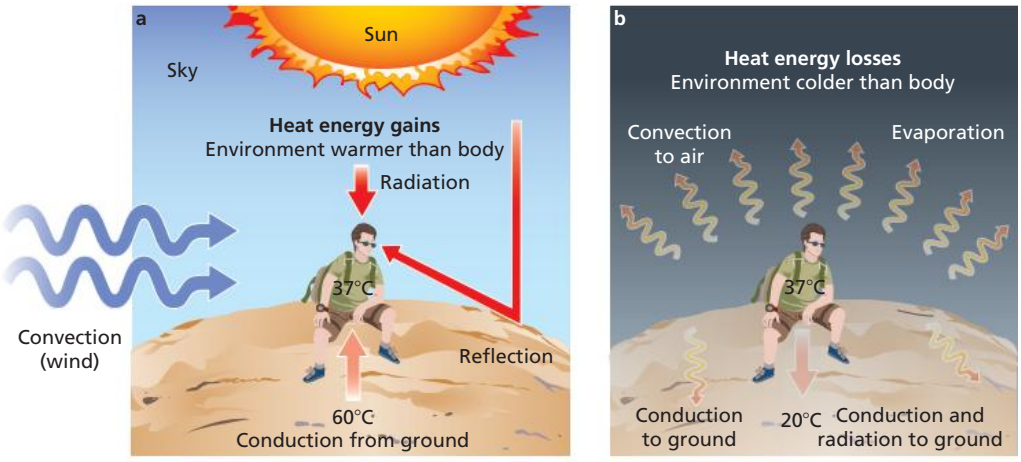


Figure 4.9 ▶
Heat transfer during (**a**) the day and (**b**) the night

Why is this? Nerves stimulate the arterioles to dilate, increasing the flow of warm blood to the surface, allowing heat to be lost in radiation. Sweat glands are very active, so evaporation helps cooling.

What happens when you are cold? Perhaps you shiver and generate heat. You may get goosebumps. Your skin feels cool because the arterioles constrict, reducing the flow of blood to the surface. How do you stand? Probably with your shoulders hunched and clasping your arms. If you feel uncomfortably cold, you could add another layer of insulation and then turn up the heater if you needed to. Figure 4.10 shows various homeostatic mechanisms a mammal such as a human uses to maintain its heat balance.

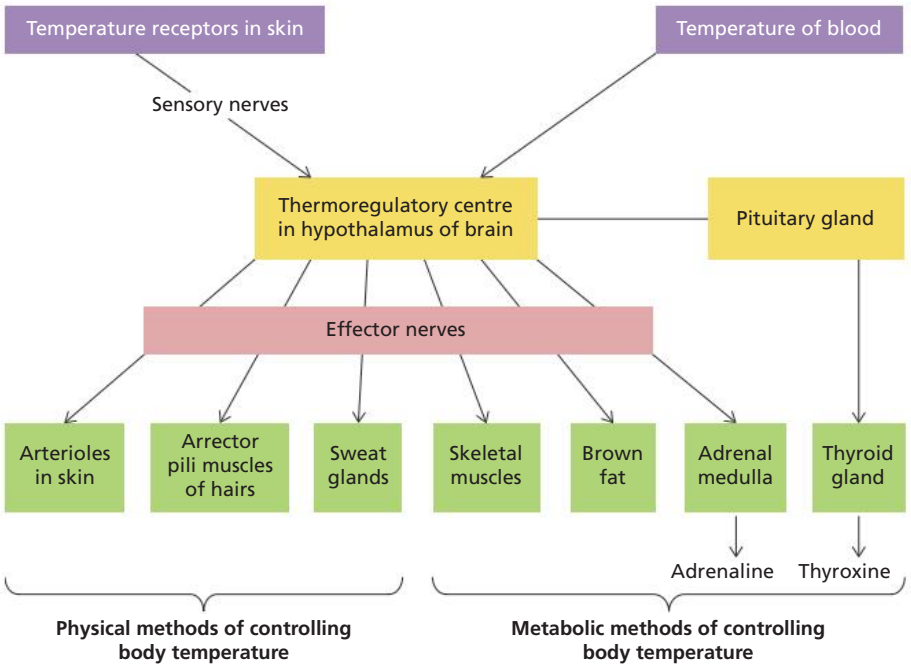


Figure 4.10 ▶
Mechanisms of controlling body temperature in a mammal

Keeping cool

Metabolism is the sum of chemical reactions that occur within an organism to maintain life. Metabolic activity is not only responsible for the breakdown or synthesis of molecules; it also creates internal body heat. An increase in metabolic activity increases internal temperature because of the energy released in the reactions.

Thermoreceptors detect the increased internal temperature during times of high metabolic activity, such as during exercise. Skin thermoreceptors will detect high

external temperatures such as on a hot summer's day. If the internal temperature increases beyond a certain level, a number of responses occur. Humans achieve heat loss in a variety of ways.

Hair on the skin is lowered by relaxation of the **arrector pili muscles** in the skin. Less air is trapped between the hairs, insulation is therefore reduced, and heat energy can be lost more readily by conduction, radiation and convection.

Nerve impulses stimulate the arterioles to dilate (**vasodilation**), which allows lots of blood to flow close to the skin's surface, and heat to escape through the skin.

Sweating occurs. Sweat glands open to release water and salt onto the skin. Evaporation of water from the moist skin cools the blood as it flows through capillaries near the surface. The cooling effect of sweating depends not only on the temperature of the surrounding air but also on its relative humidity. In humid conditions the air contains a high percentage of water. This reduces evaporation of sweat and hence reduces cooling of the blood. If there is air movement, the breeze can disperse the layer of humidity that builds up around the body after a long period of sweating. As well as cooling the body this encourages further evaporation to take place.

The metabolic rate decreases, so less heat energy is generated by the body. There is a limit to how far the metabolic rate can fall, though. A base rate must continue, so some heat energy will always be generated.

Structural and behavioural adaptations

Metabolic activity and physiological mechanisms are not the only processes that regulate the body's temperature. Structural features and behaviour also come into play.

The shape and size of an organism helps to maintain homeostasis and internal temperature. Exposing a large surface area to the environment allows heat to escape the body. This is seen clearly in other species. For example, the large surface area of an elephant's ears assists heat loss. Humans living in warm environments such as Africa tend to have a different body shape to those living in the subarctic regions. Members of the Masai tribe living in hot tropical East Africa are normally tall with slender bodies and long limbs (see Figure 4.11a, page 124). This body shape assists in the loss of body heat because of the relatively large surface area compared to body mass.

Humans can increase heat loss by changing their behaviour. The removal of clothing or moving into the shade are behaviours seen when an individual detects an increased body temperature.

RECALL

- Thermoregulation is essential for an organism's survival. Heat energy can be lost or gained in the following four ways: conduction, convection, evaporation and radiation.
- Physiological mechanisms humans employ to keep cool include flattening body hair, vasodilation, sweating and lowering metabolic activity.
- Structural and behavioural adaptations to keep cool include body shape and size, removal of clothing and moving out of the heat.

RECAP 4.4

1 Define the ways in which heat energy is transferred for humans and give examples of each.

2 Explain how heat balance is achieved.

3 What is vasodilation? Explain how it helps to maintain internal temperature.

Keeping warm

Consider what happens when a human is subjected to severe cold. Heat energy may be lost by the body. This can be counteracted by the following responses.

In many mammals, arrector pili muscles contract, raising hair into a more vertical position. Air gets trapped in the spaces between the hairs and, being a poor conductor of heat, the air serves as an insulator layer. In humans the body hair is much reduced, but clothes serve a similar insulating purpose. Even so, the arrector pili muscles contract just the same, resulting in 'goose bumps'.

Arterioles in the skin constrict (**vasoconstriction**). As a result the blood flow to the surface of the skin is reduced, thereby cutting down the loss of heat energy from the blood to the surroundings. You may have noticed how much paler your skin looks in cold conditions.

The metabolic rate increases, heating the inside of the body. A general increase in the metabolic rate is brought about by the hormones adrenaline and thyroxine which are produced in extra large amounts in cold conditions. The main organ to respond to these hormones is the liver, but the muscles also play a part. There is a general increase in muscle tone, and this may be followed by spasmodic contractions – shivering. Meals are often larger in winter. Compared to summer, a larger percentage of the food we eat in winter may be used for generating heat energy in resting conditions.

Structural and behavioural adaptations

The body shape of a Masai person would be a disadvantage in subarctic regions. Body heat needs to be efficiently maintained in this extremely cold environment. The native Inuit people in the far north typically have stocky bodies with short arms and legs. They have relatively less surface area compared to their body mass. The Inuits traditionally eat large quantities of high-calorie fatty foods. This is needed to fuel their higher metabolic rate, which produces extra body heat.

Notice the heavy clothing worn by the Inuit people in Figure 4.11b. This is an example of a behavioural response to the cold. People in such cold regions traditionally slept in a huddle with their bodies next to each other. Huddling reduces the group's overall surface-area-to-volume ratio, which reduces heat loss. People in cold conditions are often more active when outdoors.

Figure 4.11 ▼
(**a**) Masai people from East Africa are slender with long arms and legs. (**b**) Inuit people from the far north are stocky with short arms and legs.

a



Alamy/John Warburton-Lee Photography/Nigel Pavitt

b



Alamy/Jan Butchofsky

Newborn infants are more susceptible to cold than adults. There are a number of reasons for this. Newborns have a surface-area-to-volume ratio higher than that of adults, so they lose a greater proportion of their metabolic heat energy. They cannot shiver like adults either. Newborn infants don't have the behavioural adaptations of adults. They can't move away from cold areas or put on more clothes for instance. A structural adaptation in newborns is the presence of **brown fat**. Heat production in brown fat provides an infant with an alternative means of heat regulation. Although brown fat is also found in adults, there is a much higher amount in newborn infants.

EXPERIMENT 4.1

THE SKIN AND TEMPERATURE CONTROL

Mammal body temperature varies little. What are some of the adaptations that help mammals maintain a fairly constant body temperature?

Aim

To model and investigate heat loss from an exposed surface

Materials

- 4 × test tubes
- 4 × thermometers
- 4 × beakers
- funnel
- measuring cylinders
- cotton wool (or some other insulating material)
- cardboard cylinder (such as from a toilet roll)
- timer
- fan
- spray bottle of warm water

What are the risks in doing this experiment?	How can you manage these risks to stay safe?
Hot water can burn.	Use a funnel and fill test tubes carefully.

Procedure

Part A: Effect of insulation on heat loss

1. Take three test tubes, label them 'A', 'B' and 'C', and place each one into a separate beaker.
2. Surround test tube A with cotton wool or some other insulating material.
3. Place test tube B in a cardboard cylinder and wrap the outside of the cylinder with the same amount of insulating material as you used for tube A (so that there is a layer of air between the test tube and the insulation).
4. Cover the top of the cylinder so the air is trapped.
5. Test tube C has no insulating material around it.
6. Fill each of the three test tubes with 20 mL water at 80°C (Figure 4.12).
7. Insert a thermometer in each test tube and record the temperature as soon as possible after the water is added. In a table record the temperature every minute for 10 minutes.
8. Graph your results.

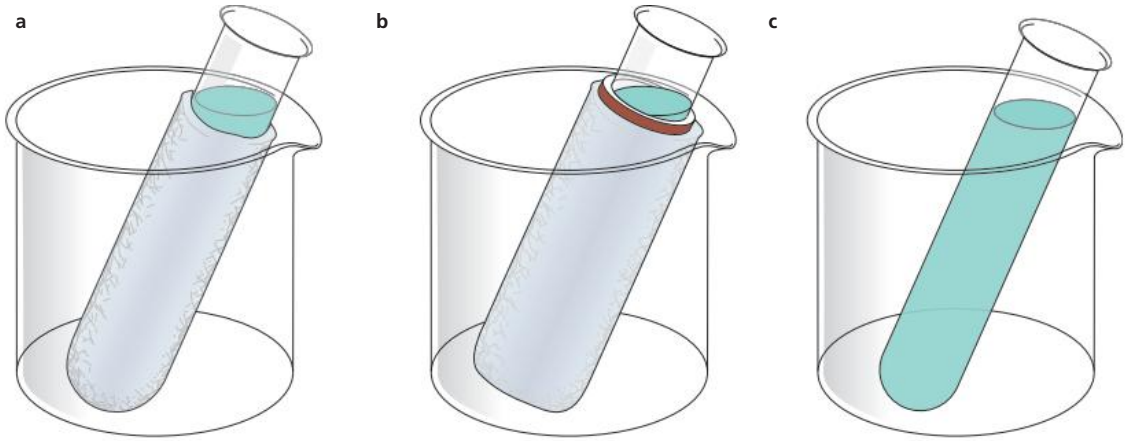


Figure 4.12 Experimental set-up to investigate the effect of insulation on heat loss

Part B: Effect of moisture on heat loss

1. Take four test tubes that have been wrapped in cotton wool and place each one in a separate beaker. Label them '1', '2', '3' and '4'.
2. Spray the outside of test tubes 1 and 3 with warm water.
3. Place test tubes 1 and 2 in front of a fan, and test tubes 3 and 4 in an area without air movement.
4. Fill each of the four test tubes with 20 mL water at 80°C.
5. Insert a thermometer in each test tube and record the temperature as soon as possible after the water is added. In a table, record the temperature every minute for 10 minutes.
6. Graph your results.

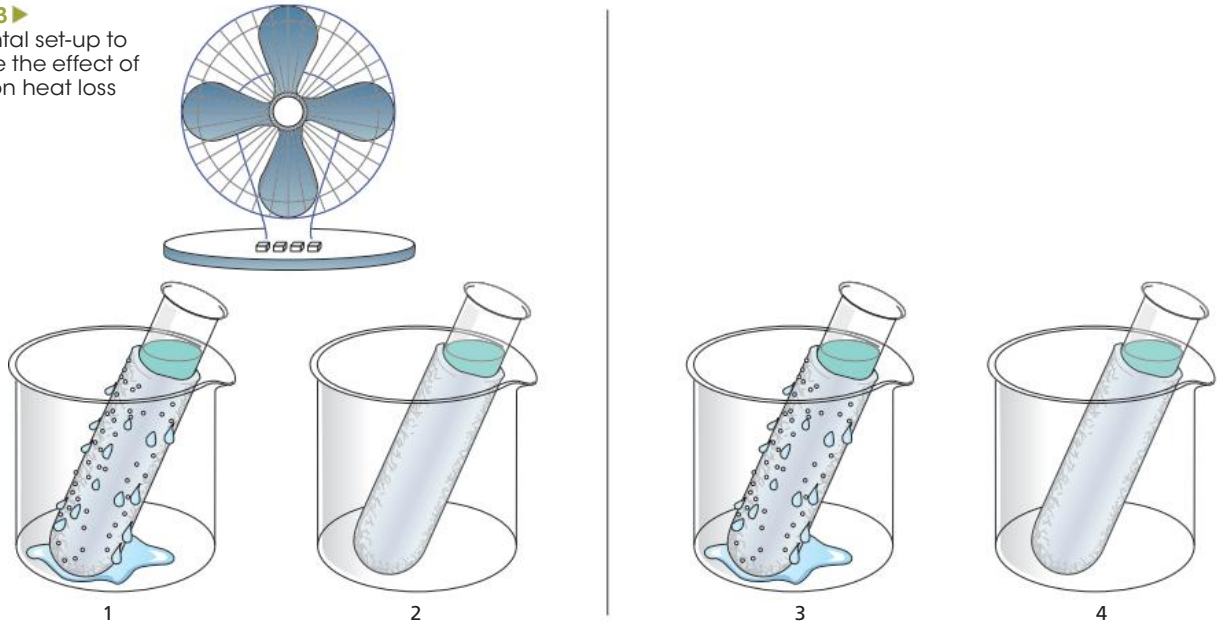


Figure 4.13 Experimental set-up to investigate the effect of moisture on heat loss

Results

Observations are to be recorded in tables and then graphed.

Analysis of results

1. Which test tube in Part A was the most effective at reducing heat loss? Suggest what makes this set-up most effective at reducing heat loss.
2. Which test tube in Part B was the most effective at increasing heat loss?

Discussion

1. What structural feature of mammals is the cotton wool simulating?
2. How can an insulating layer of air be achieved in mammals?
3. How can the results from test tube B be used to explain the observation that a cat looks larger on colder days?
4. Based on the results, suggest why an individual feels cooler on a hot windy day compared with a hot still day.
5. Using the observations collected in this experiment, explain why panting in dogs is an effective way of losing body heat.
6. Why are animals like frogs at greater risk of perishing on a hot windy day? Use the experimental results to support your answer.

Taking it further

1. Which part of the experiment modelled the role of perspiration in maintaining body temperature?
2. Were any experimental controls used in Part A and Part B of this experiment? If so, explain what these were and discuss their importance.
3. Draw a diagram of a negative feedback model, using the examples of thermoregulation investigated in this experiment. Are all components of a feedback model completely demonstrated in this experimental set-up? Explain your answer.
4. When the body temperature in mammals starts to drop, a number of things happen. Describe some of these physiological and behavioural responses. Are any of these responses being modelled in this experimental set-up? Explain.
5. When the body temperature in mammals starts to increase, different physiological and behavioural responses occur. Describe these responses. Are any of these responses being modelled in this experimental set-up? Explain.

Extension

1. Devise a method to test the effects of shivering on heat regulation. Use a method similar to the one in this experiment.
2. Explain why a person shivers during a fever even though their body temperature is above 37°C.
3. Why would a small mammal shiver more than a large mammal on a cold day?
4. A small mammal was found to eat more than its body weight in food in a 24-hour period compared with a larger mammal, which ate less than its body weight in food in the same time period. Explain why.

The hypothalamus as a thermostat

Skin thermoreceptors detect temperature changes in the surroundings. They detect whether the environment immediately outside the body is hot or cold. Responses to this include voluntary activities such as moving to a different area or altering clothing. It is the **hypothalamus**, an area of the brain, that acts as a thermostat for internal temperature. The hypothalamus is sensitive to the temperature of the blood flowing through it and responds by sending messages to the appropriate effectors. If the temperature of the blood is higher than normal, the thermoregulatory centre in the hypothalamus detects this and sets into motion the various processes that cool the body. On the other hand, if the temperature of the blood is below normal, the centre initiates the processes that warm the body.

Thermoregulation is an example of a homeostatic system involving negative feedback. Because it is controlled by negative feedback, the body temperature constantly fluctuates very slightly on either side of the set point.

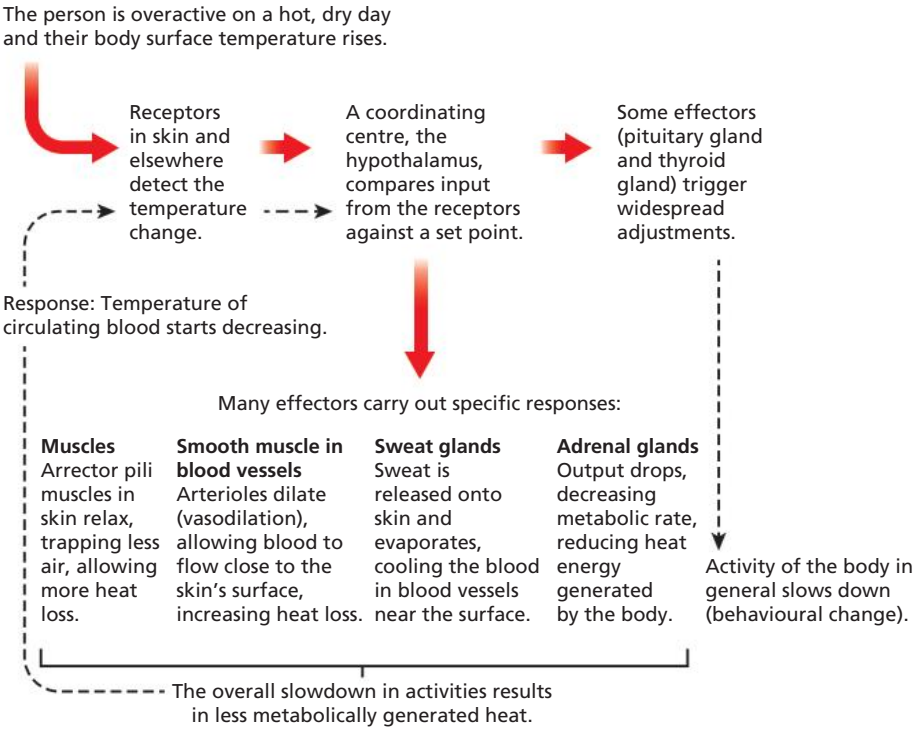


Figure 4.14 ▶ Homeostatic control of temperature on a hot day

RECALL

- Physiological mechanisms humans employ to keep warm include raising body hair, vasoconstriction, shivering and increasing metabolic activity.
- Structural and behavioural adaptations to keep warm include brown fat, body shape and size, adding clothing and moving out of the cold.
- The hypothalamus detects internal body temperature and initiates responses.

RECAP 4.5

1 Describe one structural and one behavioural adaptation of humans for retaining heat in cold environments.

2 Copy and complete Table 4.3 to compare a person's physiological response to temperature.

3 Explain why the hypothalamus is described as a thermostat.

Table 4.3 Simple stimulus–response mechanisms involved in thermoregulation

Stimulus	Physiological response	Effect
Increase in temperature		More heat lost through radiation
	Hairs flatten on skin, trapping less air	
Decrease in temperature	Constriction of blood vessels beneath the skin	
		Less heat loss through conduction
	Shivering	

A constant energy supply: Regulation of blood glucose levels

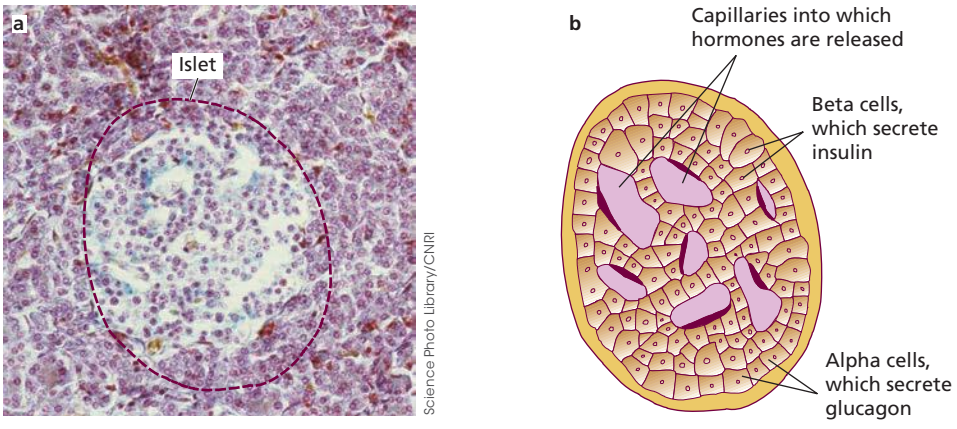
Glucose is the main source of chemical energy for most heterotrophs. They use the energy stored in its chemical bonds to make ATP, which can fuel the reactions a cell needs to carry out to survive. A constant supply of glucose is therefore necessary, and excess glucose is normally stored away in tissues. The normal range of glucose in human blood is about 3.0–7.7 mmol L^{-1}. Even after a heavy carbohydrate meal, eating chocolate or drinking lemonade, the level rarely rises above 8 mmol L^{-1}. Maintenance of a relatively constant level of blood glucose in the internal environment is essential for the effective functioning of cells and, therefore, of the individual. Movement of materials in and out of cells is affected by the difference in osmotic concentration on either side of membranes and glucose plays a role in this.

The concentration of glucose in the blood and tissue fluids at any time is determined by the balance between a number of processes occurring in the body.

- Glucose is ingested in the diet in the form of carbohydrates.
- In cellular respiration, glucose is broken down into carbon dioxide and water.
- Surplus glucose may be converted into glycogen, a storage carbohydrate in animals and stored, particularly in the liver.
- Surplus glucose may be converted into fat and stored in the tissues as fat deposits.
- Glucose may be produced from the breakdown of complex compounds, such as glycogen and fat.

The role of the pancreas

The level of glucose is maintained within tolerance limits by the opposing action of two hormones, **insulin** and **glucagon**. These hormones are secreted into the bloodstream by special groups of cells in the pancreas, called the islets of Langerhans (Figure 4.15), named after a young medical student who discovered them in 1869.



◀ **Figure 4.15**
(**a**) Insulin and glucagon are secreted by the islets of Langerhans in the pancreas (magnification × 200) (**b**) Generalised diagram of an islet

When blood glucose levels rise, such as after digesting sugars or carbohydrates, the hormone insulin is secreted by the beta cells in the islets of Langerhans in response. It travels via the bloodstream to all regions of the body, but its target cells are primarily the liver and muscle cells.

Insulin causes cells to respond in one of three ways.

1 Increasing the uptake of glucose from the blood by the cells
2 Converting glucose to glycogen and fat when there is a surplus
3 Inhibiting or reducing the conversion of glycogen to glucose

The response is to lower the overall concentration of glucose in the blood back to its set point. When this happens, the pancreatic cells then secrete less insulin so that the blood glucose level does not drop too far.

However, should the blood glucose level drop below the set point (**hypoglycaemia**), the alpha cells of the islets of Langerhans secrete the hormone glucagon. Glucagon has an opposite effect to that of insulin. It causes the cells of the liver to convert glycogen to glucose, and form glucose from non-carbohydrate sources such as fats. Glucagon also acts on the beta cells of the pancreas to inhibit the production of insulin. The net effect is an increase in the level of glucose in the blood back up to normal levels. When this happens, the alpha cells reduce their secretion of the chemical signal glucagon.

In the normal range of internal conditions, this finely balanced negative feedback mechanism self-adjusts to maintain an optimum level or set point for glucose (Figure 4.16).

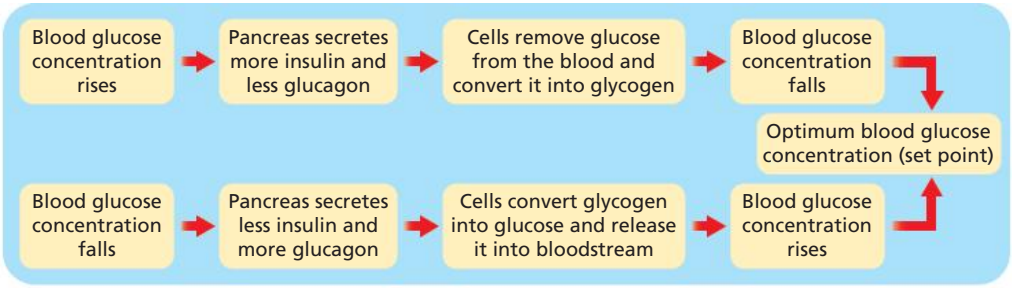


Figure 4.16 Maintaining glucose balance – the interaction of two hormones

RECALL

- A rise in blood glucose level stimulates the secretion of insulin from beta cells in the islets of Langerhans in the pancreas. The result is a reduction in blood glucose.
- A drop in blood glucose levels stimulates alpha cells in the islets of Langerhans to secrete glucagon. The effect of this is a rise in blood glucose.

RECAP 4.6

1 Name the cells in the pancreas that produce:
   a insulin
   b glucagon.
2 Describe three effects of glucagon.
3 Draw a flow diagram to illustrate the sequence of events that occurs when blood glucose levels rise after drinking a can of cola.

When the glucose homeostasis system malfunctions: Type 1 diabetes

Diabetes is a condition in which the body is unable to automatically regulate blood glucose levels, resulting in too much glucose in the blood. Type 1 diabetes results from a failure of the pancreas to produce insulin. In this condition, glucose remains in the bloodstream and is not taken up by tissues, so the body's cells are starved of this source of energy. The body recognises the problem and as a substitute burns its fats. Extensive fat burning can release by-products which are dangerous in high amounts.

Over time, high blood glucose levels may damage blood vessels and nerves. If the blood glucose concentration remains above optimum levels (**hyperglycaemia**), glucose is excreted in the urine. The person produces large amounts of urine and drinks large amounts of water to compensate. If untreated, the diabetic person may go into a coma and can die. Complications of diabetes are damage to the eyes, nerves and kidneys and an increase in the risk of heart attack, stroke, sexual impotence and foot problems. This damage can happen before a person knows that they have diabetes.

The exact cause of type 1 diabetes is not known but there seems to be a strong family link. It is thought that some kind of environmental factor such as a virus makes the immune system attack the insulin-producing cells of the pancreas in people with a genetic history of diabetes.

Type 1 diabetes can occur at any age but tends to develop in childhood. Currently, nothing can be done to prevent or cure type 1 diabetes but it can be successfully managed. People suffering from type 1 diabetes have to monitor their blood glucose levels regularly (see Figure 4.17) to ensure that they are maintained in the normal range. If the level of glucose is too high, they need to inject insulin.



Science Photo Library/Saturn Stills

Figure 4.17
Monitoring of blood glucose and injection of insulin are part of the daily routine of a person with type 1 diabetes.

If the level of glucose is too low (hypoglycaemia), such as when a diabetic person skips a meal, exercises heavily or takes too much insulin they need to quickly boost their sugar by eating things such as jelly beans or barley sugar. Diabetics can live a completely normal lifestyle provided they keep to their routine.

RECALL

- Type 1 diabetes results from the loss of beta cells in the pancreas.
- There is no known cause or cure for type 1 diabetes.
- Treatment of type 1 diabetes includes monitoring of blood glucose levels and insulin injections.

RECAP 4.7

1 Explain the effect of type 1 diabetes on blood glucose levels.
2 List three possible complications of type 1 diabetes.
3 Describe the actions to be taken in the cases of hyperglycaemia and hypoglycaemia.

Water balance

In our everyday life, we tend to take water for granted, but in times of drought and in times of flood, we become very aware of its significance. As long as there is a balance between supply and demand we don't often think about where water comes from. At a cellular level, this balance is critical for the wellbeing of living things.

Did you know that water makes up about 60–65% of your body mass? The percentage of water in infants is much higher, typically around 75–78%. Cell contents, blood and tissue fluid contain a variety of solutes dissolved in water. It is the medium in which nutrients and wastes are transported and in which digestive enzymes are active. Water is lost continually from the body in urine, faeces, through our sweat glands and tear ducts, and by evaporation over our mucous membranes (inside our mouth and nose). If you breathe against a cold window pane, fine droplets of water condense from the exhaled breath.

If the supply of water does not meet what is lost, the balance between solute and solvent concentrations in the tissue fluids cannot be regulated and many bodily functions are affected. Blood pressure can drop with loss in volume of blood, toxic wastes cannot be excreted effectively, the osmotic balance of cells is upset and enzyme activity is interfered with. Severe dehydration can lead to death.

Osmoregulation in humans

Refer back to Chapter 3 and Figure 3.32 for an introduction to the kidney.

The kidneys are the main organs of excretion. **Ammonia** is a nitrogenous (nitrogen-containing) waste product formed from the breakdown of protein molecules. Ammonia is toxic to cells, and a build-up of ammonia can affect pH severely. Humans must quickly convert ammonia to the less toxic substance, **urea**, so that waste nitrogen can be safely transported to the kidneys and excreted.

Urea and excess salts leave the body in the watery fluid, urine. By controlling how much water leaves in the urine, the water balance in the fluids of the body can be maintained. This control of water balance is **osmoregulation**, a homeostatic mechanism under hormonal feedback control (see Figure 4.18).

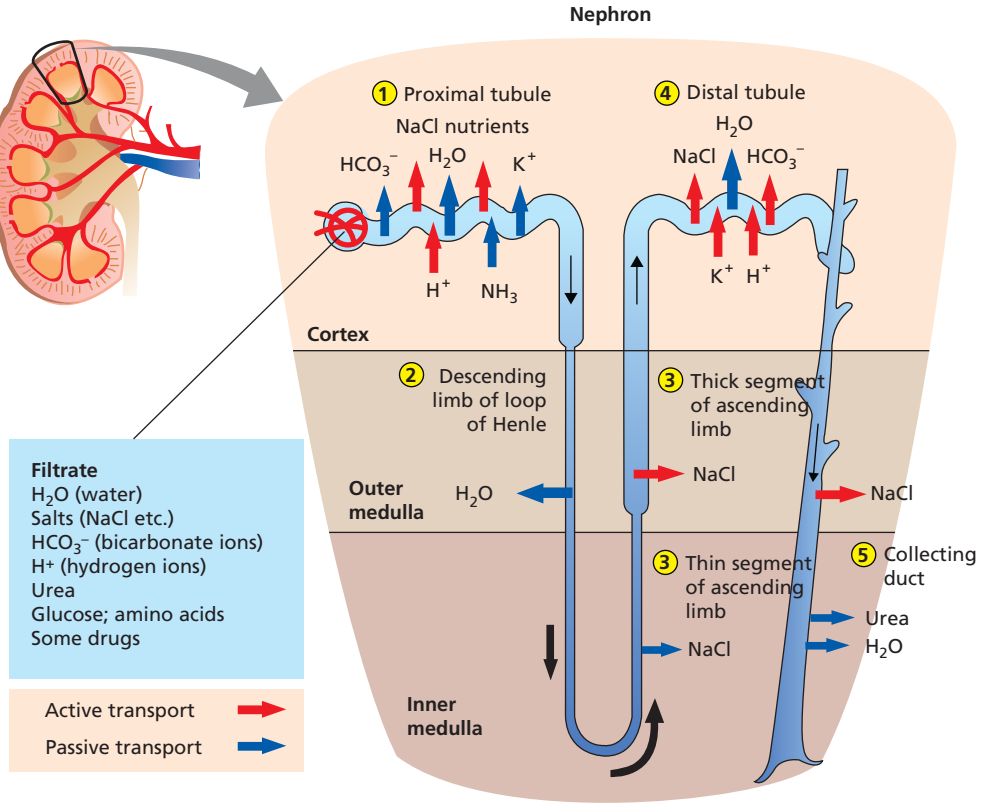


Figure 4.18 ▶
A mammalian kidney, showing the movement of water and salts in the nephron. Water is conserved when it is removed in the descending portion of the loop of Henle. The arrows show the movement of substances into and out of blood vessels.

The amount of water reabsorbed from the glomerular filtrate is matched to the body's needs. How concentrated or dilute the blood is affects its osmotic pressure and this, in turn, affects how water molecules move across membranes. If there is an excessive loss of fluids or an increased salt intake, the water concentration in the blood is low and the solute concentration is high (high osmotic pressure). More water needs to be reabsorbed from the glomerular filtrate into the blood. If there is a large intake of fluids, the blood becomes more dilute (low osmotic pressure) and less water is reabsorbed from the glomerular filtrate into the blood. This means that more water is expelled in urine and the blood's osmotic pressure returns to the homeostatic set point.

The mechanism of osmoregulation

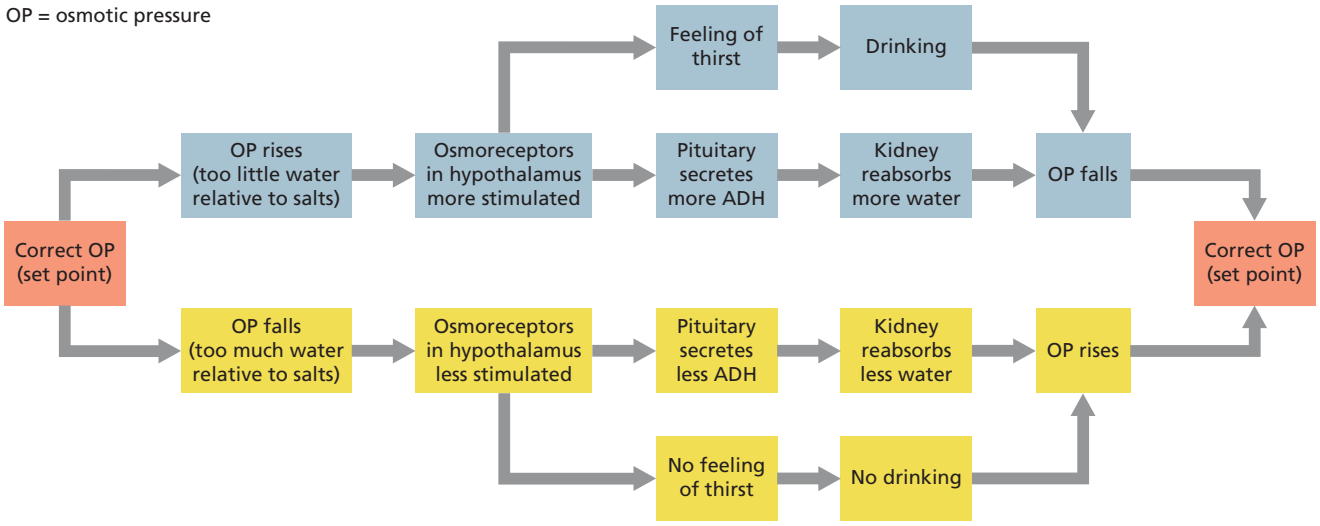
How does the kidney know how much water to reabsorb? The answer is that the osmotic pressure of the blood itself determines the reabsorptive activities of the kidney.

If a person loses a lot of water through sweating or takes in an excessive amount of salt, or even if the person simply hasn't drunk any water for a while, osmoreceptors in the hypothalamus of the brain detect the rise in osmotic pressure of the blood. When the receptors are stimulated, the hypothalamus sends a message to the pituitary gland, which is situated in the brain below the hypothalamus. The pituitary gland releases an **antidiuretic** (urine-reducing) **hormone** (ADH; also called **vasopressin**) into the bloodstream. The hormone is carried to the kidney, where it increases the permeability of cells lining the collecting ducts, thus facilitating the osmotic movement of water into the surrounding blood. As a result, less urine is produced and it is more concentrated.

Urine production continues, although at a reduced rate. So increased reabsorption cannot increase the amount of water in the body, it only slows down the rate at which the osmotic pressure increases. To return the osmotic pressure of the blood to normal, more water must be taken in. A response to increased osmotic pressure is the person feeling thirsty and drinking.

Drinking a large volume results in the osmotic pressure of the blood falling below its normal value. The osmoreceptors are now less stimulated than before. As a result less ADH is produced, less water is reabsorbed by the kidney and more copious and dilute urine is produced.

▼ **Figure 4.19**
A flow diagram summarising osmoregulation in humans



RECALL

- Osmoregulation is the process by which the osmotic pressure of the blood and tissue fluids is kept relatively constant.
- The kidney plays a major role in maintaining water balance by producing dilute urine when water is plentiful and producing a more concentrated urine when less water is available.
- Osmoreceptors in the hypothalamus detect osmotic pressure.
- Reabsorption of water is under the control of antidiuretic hormone secreted by the pituitary gland.

RECAP 4.8

1 Explain why maintaining the water concentration in the body is important.
2 Identify the nitrogenous waste produced in humans and how it is eliminated.
3 Describe the homeostatic response to high osmotic pressure in the blood.
4 Describe the homeostatic response to low osmotic pressure in the blood.

ACTIVITY 4.1

WATER BALANCE IN ANIMALS

Aim

To study water regulation in humans

What to do

Read the following information and answer the questions.

Antidiuretic hormone (ADH, also known as vasopressin) is a protein whose primary function is to retain water in the body of humans. Osmoreceptors in the hypothalamus detect the variations in the concentration of blood solutes, and the hypothalamus causes the release of ADH from the posterior pituitary gland. ADH diffuses into the capillaries and is carried to target tissues: the distal tubules and collecting ducts of the kidneys, the sweat glands, and the smooth muscles of small blood vessels in which it causes blood vessel constriction.

Table 4.4 Factors that affect concentration of ADH

Concentration of ADH (pg mL^{-1})	Output of urine (litres per day)	Sweat gland activity	Blood pressure
0.5	15.0	High levels of sweat	Decreased
3.6	1.5	Moderate amounts of sweat	No change
4.7	0.5	Very little sweat	Increased

1 Various factors are found to affect the secretion of ADH. Vomiting, diarrhoea, stress and cigarette smoking all cause an increase in the levels of ADH.
   a What effects on urine output, sweating and blood pressure would you expect during these times?
   b Describe another everyday situation that would cause the same effects.
2 What effects would high alcohol consumption have on levels of ADH and consequent body functions?
3 Relate changes in blood pressure to the action of ADH, which contracts the smooth muscle in small blood vessels.

4 Describe what happens to the ADH levels when the osmotic concentration of extracellular fluid is:
   a high
   b low.
5 Explain why water balance in humans is described as a negative feedback mechanism.
6 Draw a diagram of a stimulus–response model to demonstrate water balance in humans. Include the stimulus, receptor, control centre, transmission of message, effectors and response.

Coordinating development and regulating metabolism: Thyroid hormones

Are you someone who can eat anything and never put on weight? Always have energy to burn? On the other hand, do you just have to look at chocolate and your waistline expands? Do you constantly feel tired and have difficulty concentrating? What controls our energy levels and how quickly we burn up the kilojoules? There are many factors but one of the most significant is the action of the thyroid hormones.

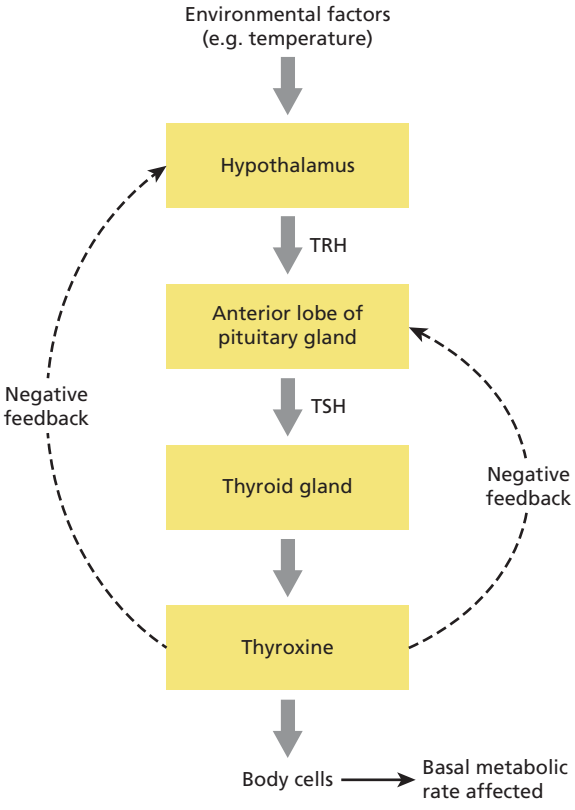
Thyroid hormones, often called 'thyroxines', are secreted by the thyroid gland, which is situated in the neck close to the larynx, or voice box. Thyroxine is derived from the amino acid tyrosine and the element iodine. It affects three main physiological processes – cellular differentiation, growth and metabolism. As you can imagine, there are very few cells that are not affected by these hormones. However, thyroxine has different effects in different cells and at different stages of development. For example, thyroxine:

- increases the metabolic activities within most tissues – it is one of the main regulators of the body's **basal metabolic rate**
- is known to be critical for the development of the brain in foetuses and newborn babies
- has direct effects on muscle growth and bone development
- has significant effects on the cardiovascular, reproductive and central nervous systems.

Control of thyroxine production

As thyroxine has such far-reaching and fundamentally important effects on cells, it is important that its production is tightly regulated. It must be secreted at a constant rate so that its levels in the bloodstream are sufficient to maintain basal metabolic rates. However, there also needs to be a mechanism for the level of thyroxine to vary at certain times as the needs of the body change. This is achieved by a tightly controlled negative feedback system involving three different glands. This is summarised in Figure 4.20.

Thyroxine synthesis and secretion is triggered by a hormone produced by the pituitary gland, which is called **thyroid-stimulating hormone (TSH)**. The production of TSH is, in turn, regulated by the action of thyroxine.



▼ **Figure 4.20** Thyroxine production is controlled through two negative feedback loops. Thyroxine inhibits the secretion of thyroid-stimulating hormone (TSH) from the pituitary gland and also the secretion of thyrotrophin-releasing hormone (TRH) from the hypothalamus.

When there is a slight excess of thyroxine in the blood, the pituitary responds by secreting less TSH. This, in turn, signals the thyroid gland to produce less thyroxine, thus lowering the level in the blood. In response, the pituitary gland secretes more TSH and the cycle continues.

To accommodate the changing needs of the body, the secretion of TSH by the pituitary gland is regulated by the action of the hypothalamus, which is part of the brain. It secretes another hormone, **thyrotrophin-releasing hormone (TRH)**, which stimulates the production of TSH by the pituitary gland. Once thyroxine levels have reached the level required, higher levels inhibit TRH secretion, which leads to a reduction in the secretion of TSH, which then signals the thyroid to produce less thyroxine and so on.

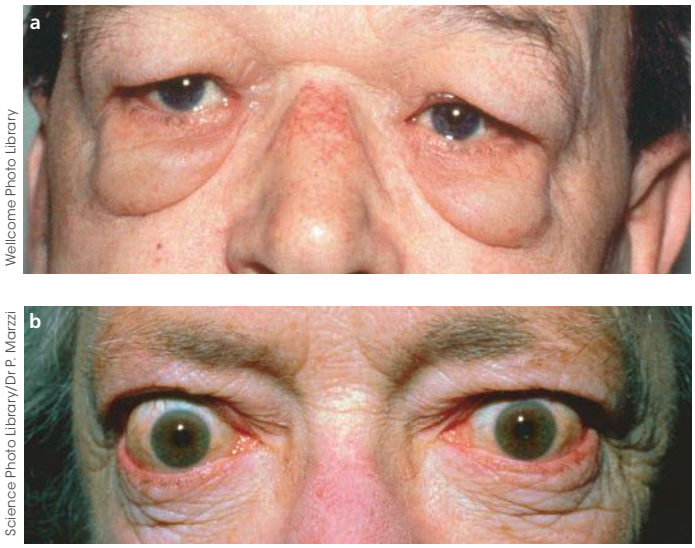
The hypothalamus is sensitive to a number of different stimuli, such as temperature. In cold seasons it releases more TRH, signalling the pituitary to secrete more TSH, thus leading to higher levels of thyroxine and a higher metabolic rate, helping the body to maintain a constant temperature. Similarly, its responsiveness to temperature helps in gearing growth and reproduction in animals that reproduce seasonally.

Malfunctions in the thyroid hormone system

Malfunctions in the production and control of thyroxine secretion can have significant impacts on health and development.

Hyperthyroidism is caused by the secretion of too much thyroxine by an overactive thyroid gland. This leads to a higher than normal basal metabolic rate, and can occur as a result of an immune system disorder called Grave's disease or local inflammation. Symptoms include feeling hot, weight loss, an accelerated pulse rate and a general feeling of restlessness. People with hyperthyroidism often have trouble sleeping and, in severe cases, can suffer shortness of breath, chest pain and muscle weakness. There are several different causes and treatment options include radioactive iodine, which is taken up by cells of the thyroid gland and kills them, surgery to remove all or a portion of the overactive thyroid gland, or drugs to reduce the ability of the thyroid gland to use iodine in the production of thyroxine.

Due to the negative feedback mechanisms involved in thyroid hormone regulation by TSH and TRH, people being treated for hyperthyroidism must have their blood thyroxine and TSH levels measured regularly to ensure they do not develop **hypothyroidism**.



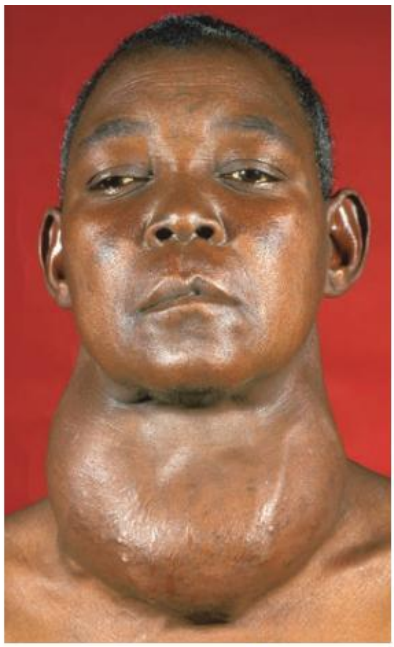
Wellcome Photo Library

Science Photo Library/Dr P. Marazzi

Figure 4.21 ▶
(**a**) People suffering from too little thyroxine (hypothyroidism) often show puffiness around the eyes and coarsening of the skin. (**b**) Protrusion of the eyeballs (exophthalmia) is a symptom of hyperthyroidism, when the thyroid gland produces too much thyroxine.

Hypothyroidism occurs when there is a deficiency of thyroxine. This may be caused by the thyroid gland not being active enough, or by a shortage of iodine in the diet. People with hypothyroidism have symptoms associated with a slow metabolism – fatigue, weight gain, sensitivity to cold, muscle cramps, depression and poor concentration. Hypothyroidism is extremely common, with millions of people worldwide being affected but not knowing it. Treatment usually involves taking thyroxine supplements orally.

In some instances the thyroid gland can swell up to form a **goitre** (Figure 4.22). The goitre can lead to problems with breathing and swallowing. A number of factors can cause the thyroid gland to enlarge. For example, if there is a problem in normal hormone synthesis within the thyroid gland, it cannot respond appropriately to TSH signals from the pituitary and increase thyroxine production. If thyroxine levels stay low, the pituitary will secrete more TSH, further stimulating the thyroid gland to produce more thyroxine, which it cannot do effectively. Eventually the thyroid will respond by producing more cells to try to increase thyroxine production, leading to enlargement. The only effective treatment for severe cases of goitre is surgery.



Science Photo Library/Dr M A Ansary

▲ **Figure 4.22** Reduced or impaired production of thyroxine by the thyroid gland can cause it to enlarge to form a goitre.

RECALL

- Thyroxine hormones are tightly regulated by negative feedback to maintain the basal metabolic rate.
- Hyperthyroidism is caused when too much thyroxine is secreted and hypothyroidism is caused when too little thyroxine is secreted.

RECAP 4.9

1 Explain how thyroxine production is an example of homeostasis.

2 Describe the symptoms of hyperthyroidism.

Biomimicry: Nature inspiring design

Considering the complexity and success of biological systems such as the homeostatic mechanisms described above, it is not surprising that nature has inspired scientists and inventors on many occasions. Electrical engineer George deMestral returned home from a walk in the Swiss countryside in 1941 covered with cocklebur sticky seeds. He examined them under a microscope and found each cocklebur used hundreds of tiny barbed hooks to secure themselves to the clothing fibres. deMestral wondered if a synthetic version might make a useful fastener. The result was the development of Velcro fasteners. Today, there is widespread use of Velcro with anything that needs temporary but secure fastening.

Biomimicry is a new and exciting concept taking design inspiration from nature. People look to natural biological designs or processes for good ideas to imitate in creating sustainable designs for products, processes and even policies.

The core idea of biomimicry is that a sustainable, highly functional world already exists. Nature has solved many of the current problems that challenge



iStock.com/luxiangjian4711



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Figure 4.23 ▲
Nature's ingenious method for seed dispersal inspired the development of Velcro

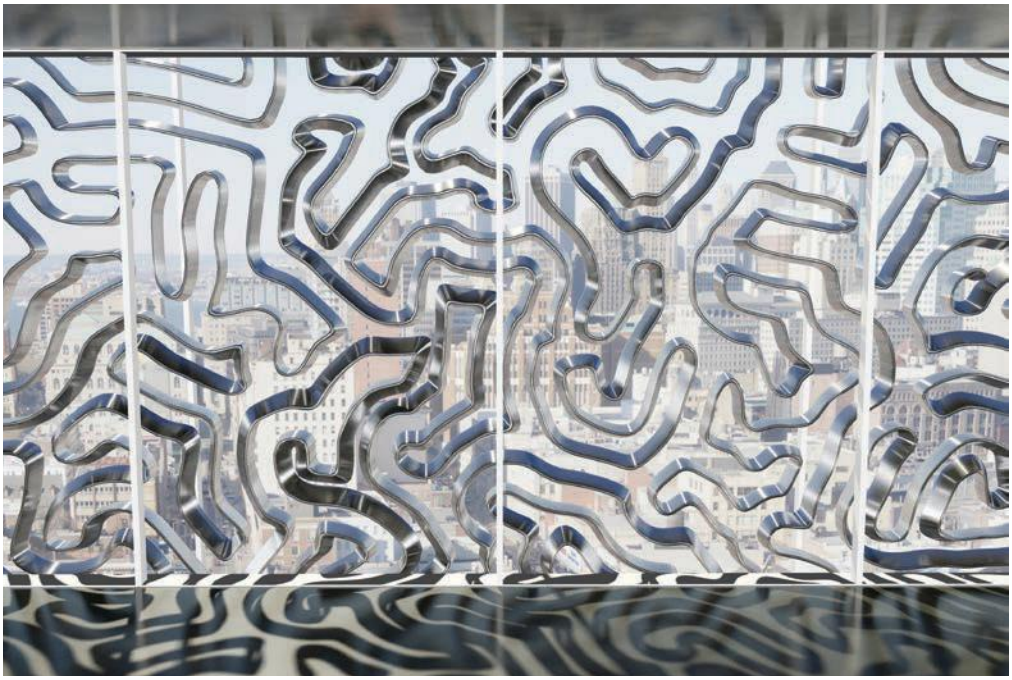
humans to build a sustainable way of life. Over a great deal of time, organisms have evolved physiological, structural and behavioural strategies for survival. It is these strategies that can be investigated and modelled in human design concepts.

Science and technology can look at nature and find practical inspiration for everything from medical technology and engineering to architectural design. There are many examples of biomimicry such as temperature regulation in buildings, water conservation and energy sustainability. There is promise of many more inventions inspired by nature.

As we have seen, thermoregulation in humans involves a number of responses to stimuli resulting in a steady internal temperature. Can this be used as a model for buildings? Architectural researchers Martina Decker and Peter Yeadon have designed a double-skin façade system for large buildings that can regulate interior temperatures. The system that includes electrically driven artificial muscles responds to temperature changes in the environment. When the sunlight warms up the building at certain times of the day the muscle assembly can create shade inside the building. When temperatures drop, they contract to allow more sunlight inside the building to warm up the interior rooms.

Osmoregulation in the kidney relies on differences in osmotic pressure in the blood and glomerular filtrate. Aquaporins are proteins in plasma membranes that facilitate rapid, highly selective water transport. Materials have been created using the features of aquaporins and principles of osmoregulation. One proposal for the use of these materials is in the international space station (ISS). As only water is allowed through the aquaporin membrane it is ideal for use in water filtration systems, in particular the onboard space suit system.

Figure 4.24 ▶
Interior perspective of the Homeostatic Facade System | Ribbons of DEAP muscles open and close to control solar heat gain through a building's double skin glass façade | Courtesy of Decker Yeadon



Decker Yeadon

The design process

Biomimicry uses much the same method as all design processes. The addition is investigating natural models. A biomimicry design brief involves five stages.

1 Define the purpose of the design and the reason it is needed.
2 Discover how nature would perform this function.
3 Identify a natural model.
4 Reproduce the biological strategy in the product.
5 Evaluate the design against a biological model.

RECALL

- Biomimicry is an approach that uses natural biological designs and processes.
- Human design challenges can often be solved by using biological models.

RECAP 4.10

1 Define 'biomimicry'.
2 List three examples of biomimicry.
3 Explain how the design process of biomimicry differs from a standard design brief.

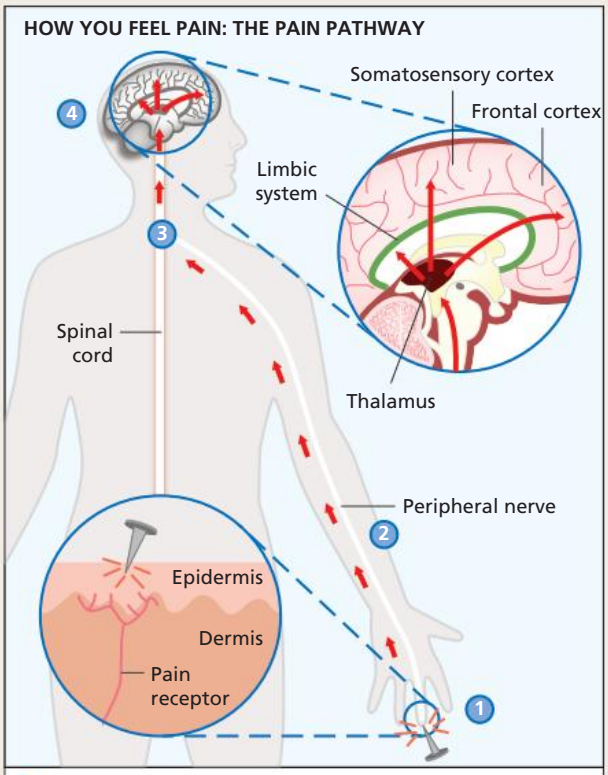
Investigation of an issue: The use and abuse of pain killers

Refer to Chapter 11 for more information on the investigation of an issue.

Jacqueline suffers from chronic pain. It started in secondary school. Occasionally the muscle in her right hip slipped, causing searing pain, and she couldn't move. She started to take a combination of painkillers every few hours to manage the pain. Things became worse over the next two years and eventually she could no longer attend school. Many similar stories of chronic pain are found on the advocacy website, Pain Australia. A report by the MBF foundation (2007) revealed that one in five Australians suffered with chronic pain at a cost of $34.3 billion to the Australian economy annually (Table 4.5).

Table 4.5 Financial costs of chronic pain (data sourced from 2007 MBF foundation report)

	Cost ($ millions)
Health system	6981.0
Lower employee productivity	7841.2
Employee absenteeism	3810.5
Carer costs	1285.4
Aids and modifications	331.7
Deadweight loss (includes lost tax revenue, social welfare payments)	2574.0
Burden of disease (loss of wellbeing and quality of life, early death)	11507
Total financial cost	**34330.8**



1. Pain receptors (nocireceptors) in the skin are activated by tissue damage.
2. A signal travels up the peripheral nerve to the spinal cord.
3. Within the spinal cord, chemical messengers (neurotransmitters) are released. These activate other nerves that pass signals to the brain.
4. The thalamus relays the signals to the somatosensory cortex (sensation), frontal cortex (thinking) and limbic system (emotional response).

▲ **Figure 4.25** How pain is perceived

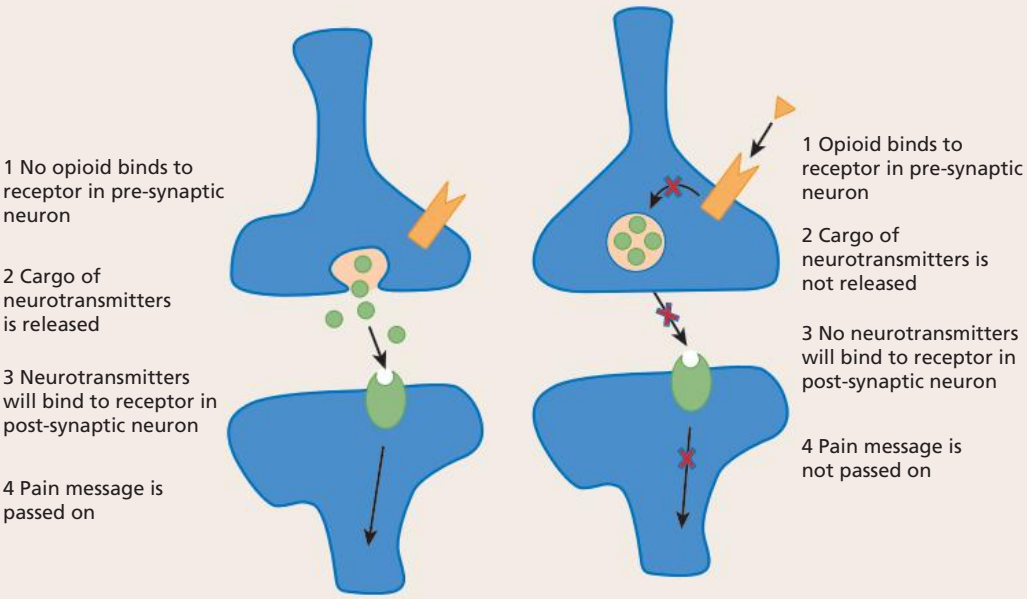
What is chronic pain?

Pain acts as a warning to our body to respond to a harmful stimulus. Figure 4.25 shows how pain messages are received by sensory neurons that transmit the message along nerve pathways to the brain. The brain registers the problem and sends messages to fix it. At the same time chemicals are released to reduce the pain message. Persistent injury can lead to changes in the nervous system so pain signals are amplified and prolonged, causing chronic pain.

The current treatment for chronic pain

There are small gaps called synapses between neurons in nerve pathways. Figure 4.26 reveals how pain messages are transferred across this gap to neighbouring neurons. Opiates, found naturally in poppies, can stop messages from crossing this gap (Figure 4.27). This stops the pain message from reaching the brain.

Opiate pain killers have a dark side. They can cause side effects. They bind to neurons lining the gut, causing constipation, and neurons in the brain stem that control breathing, meaning that an overdose can cause suffocation. They also bind to neurons in the brain that are linked to reward pathways, leading to feelings of euphoria that make opiates highly addictive.

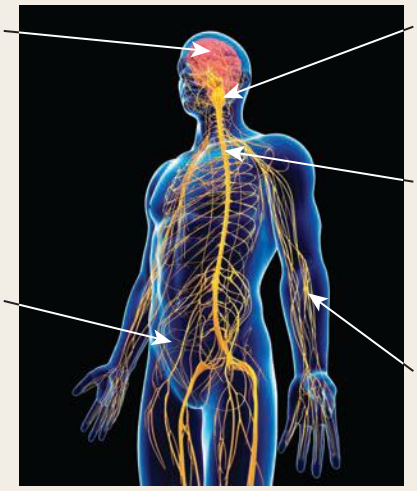


▲ **Figure 4.26** A pain-stimulated neuron releases chemical messengers to pass a pain message on to the next neuron in a nerve pathway.

Opioid receptors are dispersed throughout the body, but a few key regions are involved in the major effects (and side effects) of opioid drugs.

Brain Opioids bind to receptors expressed in many parts of the brain, including the cerebellum, nucleus accumbens and hypothalamus. Many of these regions are involved in pain perception, emotion, reward and addiction.

Intestine Opioid receptors are expressed in neurons regulating peristalsis. Inhibition of these cells upon opioid binding leads to another side effect of opioid medications – constipation.



Brain stem Opioid activity in the brain stem can affect breathing by quieting neurons that control respiration. Respiratory depression is a dangerous side effect of opioid drugs, and is commonly cited as the cause of death in cases of opioid overdose.

Spinal cord The transmission of pain signals in the spinal cord, especially in a region called the dorsal horn, is dampened by opioids binding to receptors on these cells. This is one intended target of opioid treatments and a mechanism of the drugs' unrivalled analgesic properties.

Peripheral neurons Pain-sensing neurons send messages from the periphery to the spinal cord. Binding opioid receptors in these neurons is another way that opioid drugs curb pain sensations.

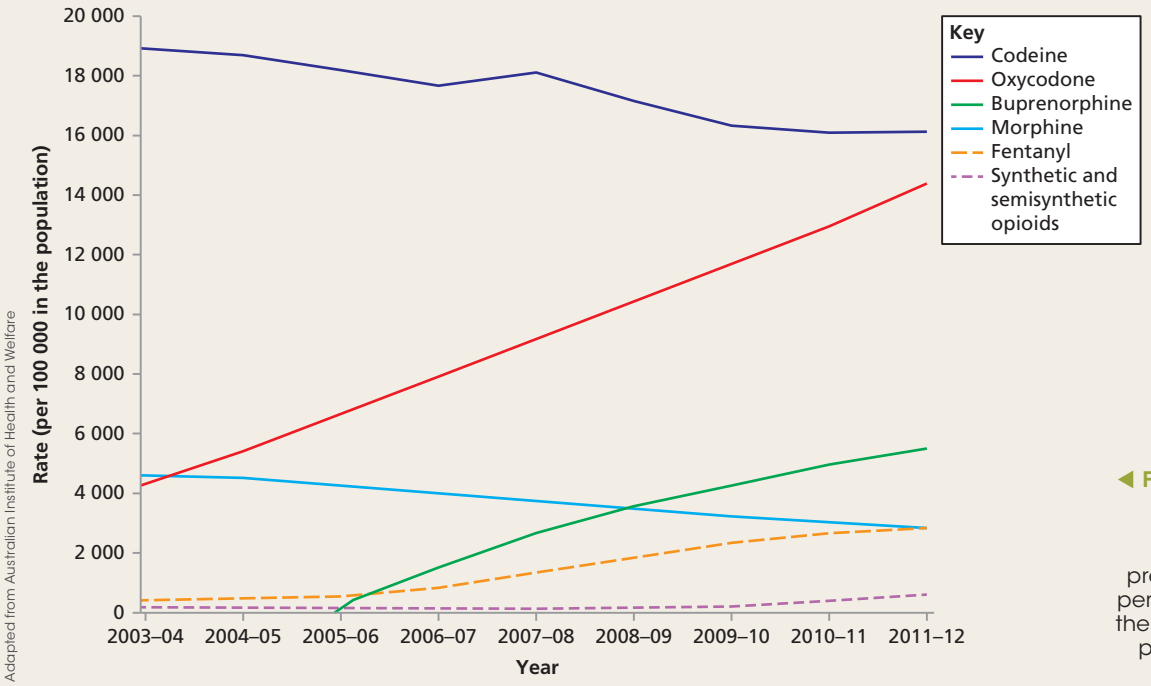
Science Photo Library/Pixologicstudio

▲ **Figure 4.27**
Opiates bind to specific receptors in the membrane of neurons, stopping the neuron from releasing its cargo of chemical messengers and blocking transfer of the pain message.

Your turn: Investigating methods to address issues associated with the use of opiate pain killers

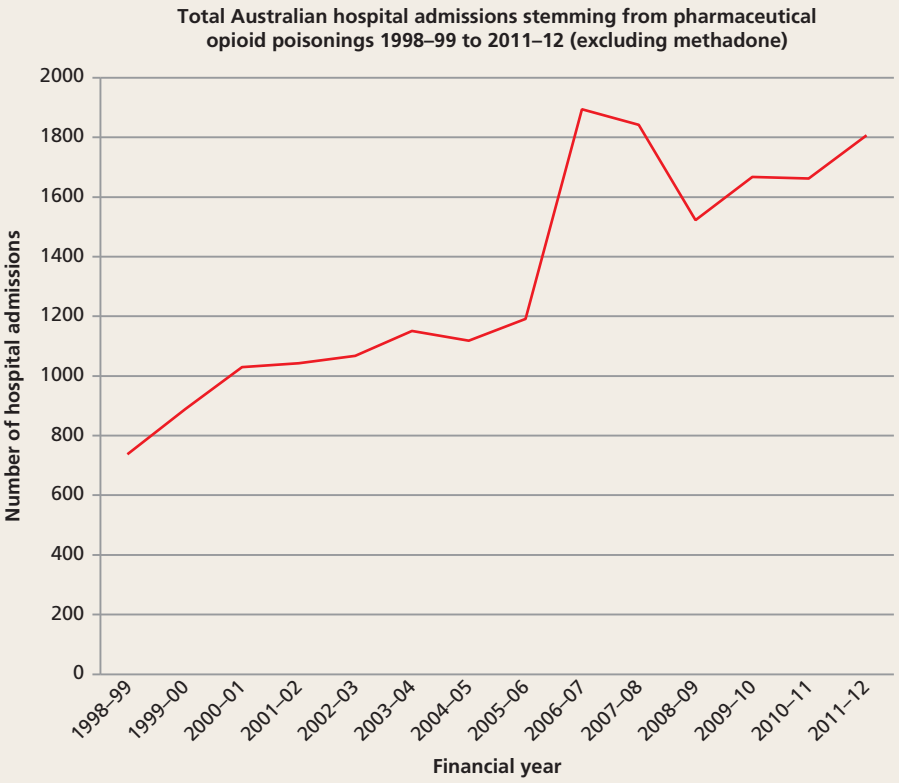
Scientists use language, representations and conventions that are accepted standards for communicating their work. You will practise these standards to clearly explain concepts and ideas represented in graphics. These graphics explore issues surrounding the use of opiates to treat chronic pain.

Task 1: Use this guideline to describe the information in each of Figure 4.28 and Figure 4.29 (page 142).



Adapted from Australian Institute of Health and Welfare

◀ **Figure 4.28** Number of opiate pain killer prescriptions per 100 000 in the Australian population, 2003–2012



Source: national Centre for Education and Training on Addiction (2015). Secondary analysis of Australian Institute of Health and Welfare Hospital Separations data base. Adelaide: NCETA, Flinders University

◀ **Figure 4.29** Poisoning by selected narcotics in Australia, 1998–2008

Step 1: Describe the study that was conducted by referring to the title. If possible include a brief description of how the study was performed and the authority of the study (who conducted the study and why).

Step 2: State what is being measured on the *x* axis, including units of measurement.

Step 3: State what is being measured on the *y* axis, including units of measurement.

Step 4: Concisely but accurately describe the trend for the six drugs tested. Describe rates of increase or decrease if a parameter is measured over time. Speculate on why these trends are observed.

Step 5: Draw attention to information of particular interest to the idea you are investigating. Use exact numbers to make this clear to your audience. For example, 'between 2014 and 2015 the rate of use rose significantly from 200 to 10000 per 100000.'

Task 2: Construct a flowchart or diagram to concisely capture the following information for your audience.

Nicholas, Lee and Roche (2011) reported a 21-fold increase in oxycodone-related deaths between 2000 (4 deaths) and 2009 (97 deaths). They also found that 50% of deaths were in patients prescribed the drug while 25% were extra-medical drug users, those who use the drug to get a high.

To address the issues of oxycodone addiction and misuse, the company Purdu Pharma designed OxyContin, a semisynthetic opiate pain killer with a slow-release mechanism preventing immediate highs. However, crushing the tablet enabled abusers to override the slow-release mechanism. The drug company conducted further research and in 2014 a new form of OxyContin was released. It could not be crushed and had a marshmallow consistency if mixed with water, preventing drug misuse as it could not be injected.

Other methods have been implemented to curb the increased misuse of the drug. New government policy aims to stop the practice of doctor shopping, where people move from doctor to doctor to get prescriptions for the drug. However, this cannot prevent the illegal trade of the drug. The best possible solution will come from scientific research, and the quest to find an effective pain killer that is not addictive.

Task 3: To contextualise the issues associated with using opiates to treat chronic pain, describe the benefits of chronic pain management, the possible problems associated with long-term opiate use and the implications of these problems for:

1. patients
2. doctors
3. governments.

Task 4: The information in Table 4.5 can be presented more concisely using a pie chart. This allows an audience to easily view relative proportions of factors contributing to the economic burden of chronic pain. Use a graphing program, such as Microsoft Excel, to construct a pie chart for this data. Use the steps outlined in task 1 to describe the information found in this graphic.

Task 5: Construct a physical model or animation to clearly explain chronic pain and how opiate pain killers treat chronic pain. Compose a script to use with this representation.

Task 6: You've been asked to give a 15-minute presentation on this issue in your local community, which includes audience members with chronic pain. Prepare an outline for your presentation.

References

Nicholas R., Lee N. & Roche A. (2011) *Pharmaceutical drug misuse in Australia: Complex problems, balanced responses.* Adelaide, SA: National Centre for Education and Training on Addiction (NCETA), Flinders University, Adelaide.

Pain Australia (2015) *Your stories.* Retrieved from http://www.painaustralia.org.au/consumers/your-stories.html

Roxburgh A., Ritter A., Slade T. & Burns L. (2011) Prescription of opioid analgesics and related harms in Australia. *Medical Journal of Australia,* 195(5): 280–4.

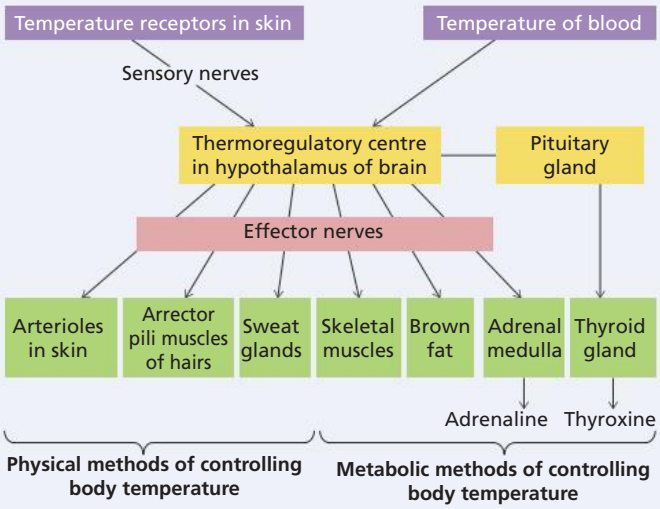
The MBF Foundation (2007) *The high price of pain: the economic impact of persistent pain in Australia.* Retrieved from http://www.painaustralia.org.au/images/pain_australia/MBF%20Economic%20Impact.pdf

CONCEPT SUMMARY

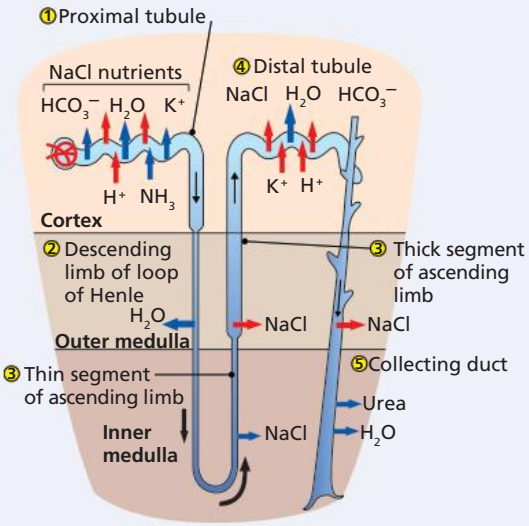
Homeostasis

Thermoregulation

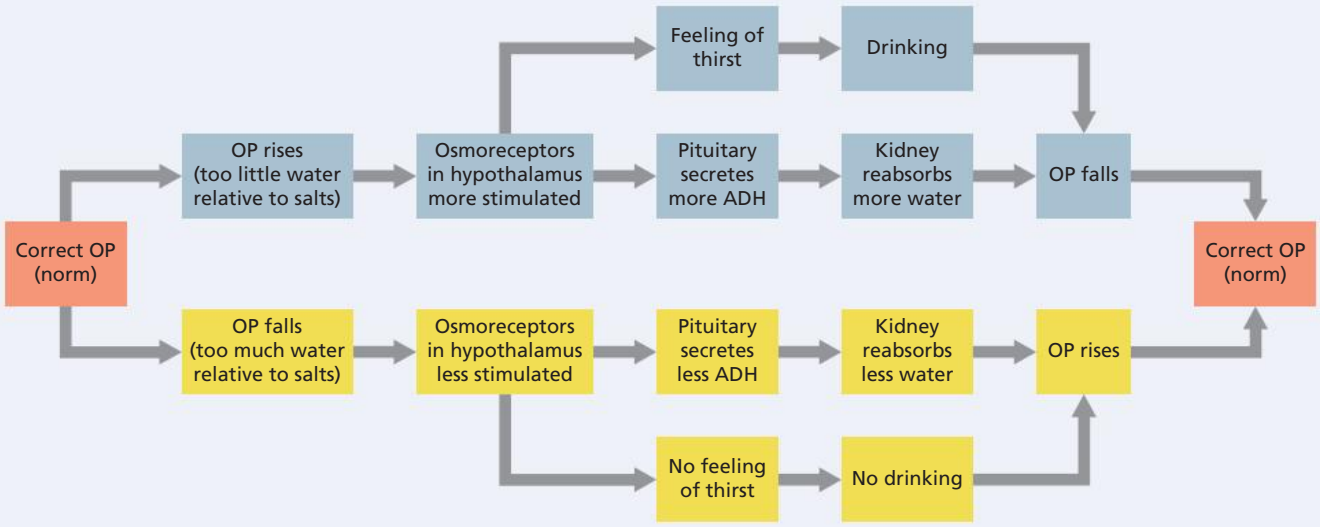
- Mechanisms of heat transfer
- Physiological adaptations
- Behavioural adaptations



Osmoregulation



Water reabsorption occurs in the nephron
Osmoregulation occurs in response to hypothalamic detection of osmotic pressure



OP = Osmotic pressure

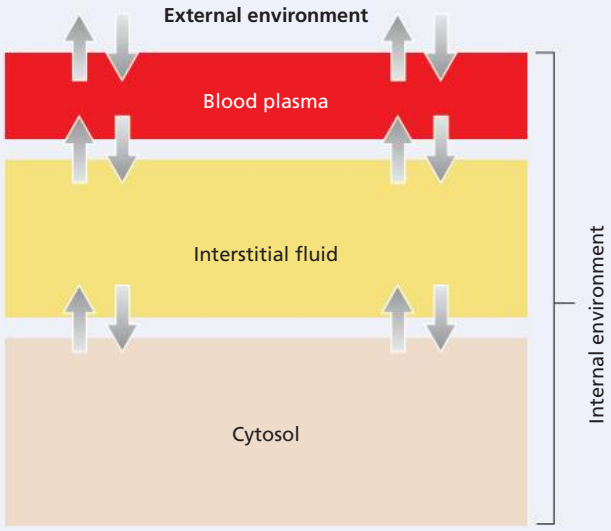
Factors that affect homeostasis

- Abiotic: temperature, light, water, soil and gases
- Biotic: other organisms in the environment

Biomimicry

Biomimicry is an approach that uses natural biological designs and processes. It is inspired by natural mechanisms of homeostasis, such as thermoregulation and osmoregulation.

The internal environment

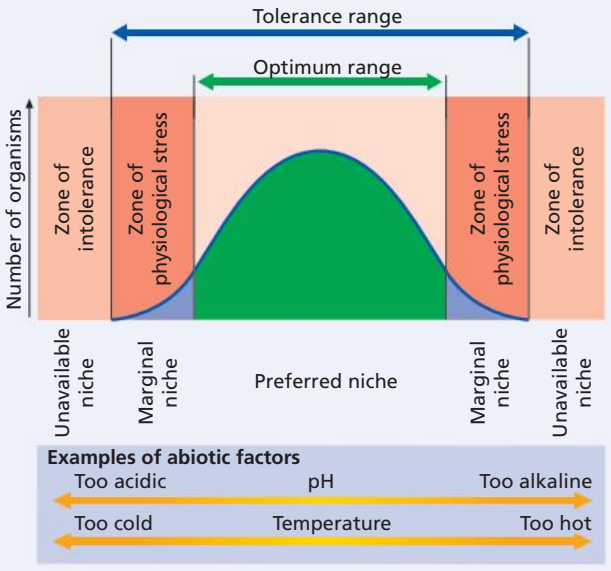


Tolerance limits

- Optimum range
- Tolerance range
- Physiological stress

Environmental niche

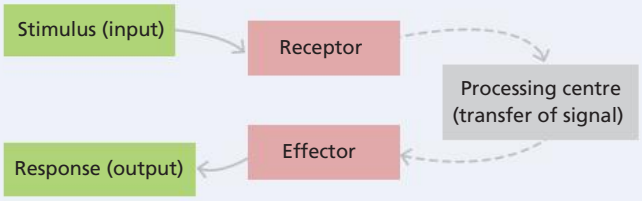
- Preferred niche
- Marginal niche
- Unavailable niche



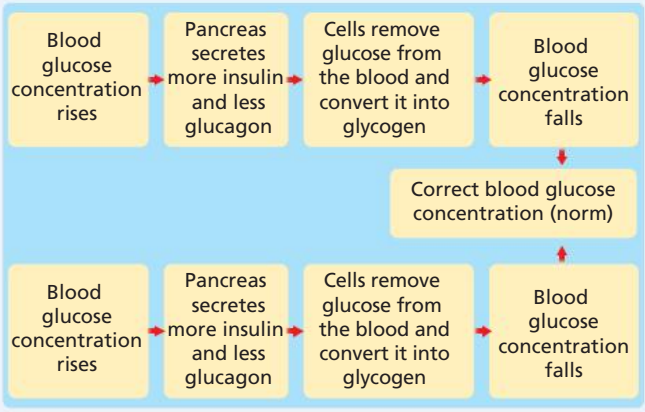
Stimulus–response model

- Stimulus
- Receptor
- Effector
- Response
- Feedback

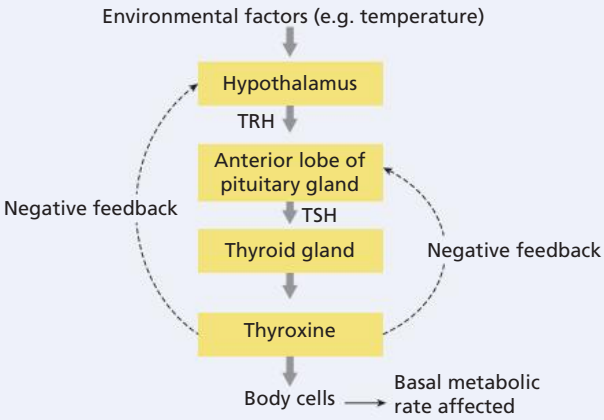
Interoceptors
Exteroceptors
Receptors for different stimuli



Blood glucose regulation



Development and metabolism regulation



Thyroxine:

- regulates basal metabolic rate
- regulates brain development
- affects muscle and bone growth
- affects cardiovascular, reproductive and CN systems

CHAPTER GLOSSARY

abiotic factor a physical or chemical environmental factor

ammonia a toxic form of nitrogenous waste produced as a by-product of protein digestion

antidiuretic hormone hormone that affects how much water is reabsorbed into the collecting tubules in the kidneys

arrector pili muscle small muscle attached to hair follicles.

basal metabolic rate the rate at which the body uses energy while at rest to maintain vital functions

biomimicry the design and production of materials, structures and systems that are modelled on biological entities and processes

biotic factor a factor related to the effect a living organism has on another living organism

brown fat a type of fat involved in the rapid production of heat

chemoreceptor a sensory cell or organ that detects chemical stimuli

conduction the transfer of heat energy from a relatively hot object to a relatively cool object by direct contact

convection the transfer of heat by means of rising currents of warm air or liquid

effector an organ, cell or protein that acts in response to a stimulus

evaporation the process in which liquid water changes to water vapour through heating

exteroceptor a receptor that receives signals from the external environment

feedback mechanism a mechanism in which the output or response affects the input or stimulus

glucagon a hormone formed in the pancreas that promotes the breakdown of glycogen to glucose in the liver

glycogen an important energy-storing polysaccharide

goitre a swelling in the neck caused by an enlarged thyroid gland

heat balance when there is a balance between heat gain and heat loss

homeostasis the maintenance of a relatively constant internal environment within small tolerance limits, despite changes in the external environment

hormone a chemical messenger

hyperglycaemia elevated blood sugar levels

hyperthermia a state in which the internal temperature rises above the set point

hyperthyroidism high levels of thyroxine

hypoglycaemia a state in which the blood glucose level drops below the set point

hypothalamus a region of the brain

hypothermia a state in which the internal temperature falls below the set point

hypothyroidism low levels of thyroxine

insulin a hormone produced in the pancreas by the islets of Langerhans, which regulates the amount of glucose in the blood.

interoceptor a receptor that receives signals from the internal environment

interstitial fluid fluid that lies in the spaces between cells; also known as extracellular fluid

marginal niche a set of environmental conditions in which an organism can survive but not thrive

mechanoreceptor a sensory cell or organ that detects mechanical stimuli such as touch, pressure, vibration or tension

metabolism the sum of all chemical reactions occurring within an organism to maintain life

negative feedback a response to a stimulus that counteracts the stimulus and reverses the direction of the change

neurotransmitter chemical that transmits or carries a nerve impulse to another nerve

niche the set of environmental conditions an organism lives in

nociceptor pain receptor

optimum range the narrow range within the tolerance range an organism has for a particular factor, at which the organism functions best

osmoreceptor a receptor that responds to changes in the osmotic pressure of the blood

osmoregulation processes by which internal water and solute concentrations are maintained despite fluctuations in the external environment

pain receptor a sensory cell or organ that detects pain signals

photoreceptor a sensory cell or organ that detects light signals

physiological stress stress caused when an organism experiences conditions outside its tolerance range

positive feedback when a change of variable (stimulus) occurs, a response that changes the variable even more in the same direction

preferred niche a set of environmental conditions in which an organism can thrive

radiation the transfer of heat from a hot object by infrared waves

receptor a structure that detects or receives a stimulus

set point optimal level

stimulus (plural stimuli) a signal that causes a response

thermoreceptor a sensory cell or organ that detects changes in temperature

thermoregulation temperature regulation

thyroid stimulating hormone (TSH) a hormone produced by the pituitary gland in response to signals from the hypothalamus

thyroxine a hormone produced by the thyroid gland

tolerance range the range within which an organism can function and reproduce

unavailable niche environmental conditions that are outside the tolerance range of an organism

urea a toxic form of nitrogenous waste found in mammals as a result of protein breakdown

vasoconstriction decrease in the diameter (narrowing) of blood vessels, particularly arterioles

vasodilation dilation (widening) of blood vessels, particularly arterioles

vasopressin an antidiuretic hormone responsible for increased permeability of the distal tubules of the kidney, increasing water reabsorption and reducing urine volume

CHAPTER REVIEW QUESTIONS

Remembering

1 Using an example, explain the principle of negative feedback.
2 Name three organs of the body involved in homeostasis and briefly explain what they do.
3 Distinguish between hyperthyroidism and hypothyroidism.

Understanding

4 Clarify how positive and negative feedback are different. Suggest why positive feedback is generally not associated with homeostasis.
5 Homeostasis maintains a constant internal environment necessary for survival. Name a component that is under homeostatic control and explain why it must be regulated.
6 Explain the significance when exteroceptors and interoceptors fail.
7 Draw a table to summarise examples of structural, physiological and behavioural adaptations a mammal has to regulate temperature.

Applying

8 Compare the stimulus–response model of regulation with the negative feedback model of regulation. Use only annotated diagrams in your answer. Give one named example of each kind of regulation.
9 Explain how body shape aids thermoregulation.
10 Name a group of humans that live in conditions of either extreme cold or extreme heat. Draw a concept map to summarise the structural, physiological and behavioural adaptations they have to regulate their temperature.
11 Explain why we should not ignore the feeling of thirst.
12 Refer to page 113 relating to Mark Dorrity. Consider in more detail the mechanisms involved in heat regulation and water balance.
   a Describe and explain how Mark's body temperature would be regulated under normal conditions. Why was Mark's regulatory mechanism not able to cope with the extreme conditions experienced? Include labelled diagrams to support your answer.
   b Explain the causes of Mark's blood thickening. What would be the effects of this thickening?
   c Describe the mechanism by which water balance is normally maintained in humans. Include diagrams to support your answer.

Analysing

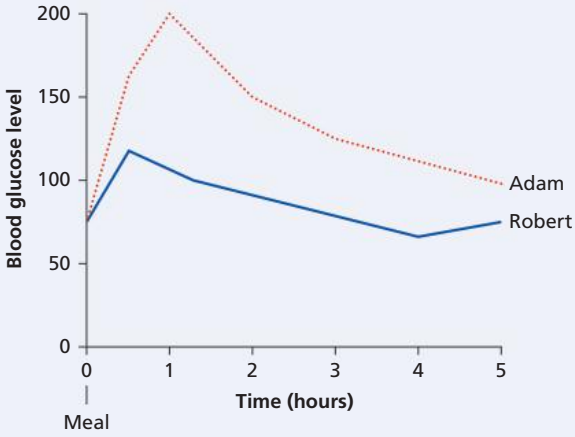
13 Imagine you are crossing a road while a car is travelling along it towards you. Draw a stimulus–response model to illustrate what happens. Decide whether this is an example of homeostasis, giving reasons for your decision.
14 Predict the effect on the quantity and composition of a person's urine of:
   a drinking a large amount of water
   b eating a very salty meal.
15 Explain the effect on the body's homeostatic processes of removing the pancreas.

Evaluating

16 Two men ate an identical meal and their blood glucose levels were recorded over a five-hour period. The results are shown in Figure 4.30. Identify which individual's blood glucose was under homeostatic control. Justify your response.

17 A person visits a doctor and a blood test is ordered. The blood is analysed and the results show a higher than normal level of thyroxine.

- **a** Predict the symptoms of the person.
- **b** Use a diagram to illustrate the possible cause of increased thyroxine levels in terms of homeostatic control.
- **c** Suggest a treatment to relieve the symptoms.



▲ **Figure 4.30**
Blood glucose levels over a five-hour period

Creating

18 Humans must wear clothes in the depths of winter in order to survive, while other organisms do not. Propose some design modifications to the human body that would allow us to survive months of freezing temperatures without clothing.

19 Two expeditions are being organised, one to the South Pole, the other to the Sahara. Design the clothes and food for each expedition and explain why they would be suitable.

20 Using the biomimicry design process, create a design for a product based on one of the concepts of homeostatic regulation that you have learnt about in this chapter.



CHAPTER 5
ORGANISING BIODIVERSITY

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

KEY KNOWLEDGE

Organising biodiversity

- classification of biodiversity, past and present, into taxonomic groups based on shared morphological and molecular characteristics, and naming using binomial nomenclature
- strategies for managing Earth's biodiversity to support the conservation of species and as a reservoir for the bio-prospecting of new food sources and medicinal drugs.

Investigation of an issue

- the 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 biological concepts specific to the investigation: definitions of key terms; use of appropriate biological terminology, conventions and representations
- the use of data representations, models and theories in organising and explaining observed phenomena and biological concepts, and their limitations
- the nature of evidence and information: distinction between opinion, anecdote and evidence, weak and strong evidence, and scientific and non-scientific ideas; and validity, reliability and authority of data including sources of possible errors or bias

KEY SCIENCE SKILLS

Analyse and evaluate data, methods and scientific models

- take a qualitative approach when identifying and analysing experimental data with reference to accuracy, precision, reliability, validity, uncertainty and errors (random and systematic)
- explain the merit of replicating procedures and the effects of sample sizes in obtaining reliable data
- evaluate investigative procedures and possible sources of bias, and suggest improvements
- explain how models are used to organise and understand observed phenomena and concepts related to biology, identifying limitations of the models

Draw evidence-based conclusions

- determine to what extent evidence from an investigation supports the purpose of the investigation, and make recommendations, as appropriate, for modifying or extending the investigation
- critically evaluate various types of information related to biology from journal articles, mass media and opinions presented in the public domain

Communicate and explain scientific ideas

- use appropriate biological terminology, representations and conventions, including standard abbreviations, graphing conventions and units of measurement
- discuss relevant biological information, ideas, concepts, theories and models and the connections between them

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Alamy/The Art Archive

Figure 5.1 ▲
One of John Gould's illustrations of a cassowary

At the time of the exploration and settlement of Australia by Europeans, the science of natural history was at its height. The naturalists who described, collected and classified plants and animals were amazed by the sheer number of new species discovered in Australia. It is from the diverse plant life found there that Captain Cook's landing point at Botany Bay takes its name. The exploration of Australia provided opportunities, as well as challenges, for the naturalists of the 18th and 19th centuries.

One such challenge was how to make sense of the flora and fauna in Australia. Initially, European explorers described Australian animals in terms of those they were familiar with. They wrote of wolves (actually dingoes), badgers (wombats) and raccoons (wallabies). Eventually, naturalists realised that the plants and animals of Australia were so different from those of Europe that they needed their own names.

Some naturalists based their work on specimens and sketches brought back from Australia. Others, however, made the voyages out themselves. British ornithologist John Gould made this journey with his wife Elizabeth – a sketch artist. Over a period of two years spent in Australia, the Goulds described around 300 new species of birds. While initially focusing on birds, John Gould became so interested in Australian mammals during his stay that he also spent considerable time describing and classifying them. The Goulds' contribution to the classification of Australian wildlife was phenomenal.

Why do we classify organisms?

Classification systems are a method of sorting, so that similar or related organisms are grouped together. Throughout this chapter you will learn how biologists use similarities and differences to classify organisms, but why we do need to do this?

Classification of organisms is done for several reasons. First, the diversity of life on Earth is so enormous that classifying organisms is a way of organising information. Organisation of information about organisms then allows for patterns and trends to be observed, and relationships between organisms to be better understood. And so the second reason to classify organisms is to allow biologists to analyse information about organisms.

Finally, classifying organisms allows biologists to communicate with one another. Classification systems allow biologists to identify organisms that have already been discovered. Using standardised systems around the world allows biologists to compare their findings with one another. Because science is a field that relies heavily on worldwide collaboration, a standardised classification system is of the utmost importance.

Classification systems as scientific tools

Classification systems are tools used by scientists to help make it possible to see patterns and relationships. Classification systems do this by simplifying information that would otherwise be too complex to analyse. While this is the reason that classification systems work, it is also a limitation of these systems. As you continue in your biology studies, keep in mind that the classification systems used are artificial structures and are not perfect. They continue to evolve as scientific knowledge grows.

One way to view classification systems is as complicated theories about the way that organisms are related. These proposed explanations can change when new data comes to light. Throughout this chapter you will encounter several examples of classification changing as a result of new evidence.

RECALL

- Classification systems are a method of grouping related organisms together.
- Reasons for classification include organising, analysing and communicating information about organisms.
- Classification systems are proposed explanations about relatedness of organisms and can change as a result of new evidence.

RECAP 5.1

1 List three reasons why biologists use classification systems.

2 Explain why biological classification systems can be thought of as theories.

Levels of classification

Scientists classify organisms into a number of groups that form a hierarchy or series of nested levels. These groups are known as **taxa** or **taxonomic levels**. The names of the major taxa, from largest to smallest, are Domain, Kingdom, Phylum, Class, Order, Family, Genus and Species. At each taxonomic level, organisms can be further grouped according to features that they share. Each organism is therefore able to be defined by the taxa to which it belongs.

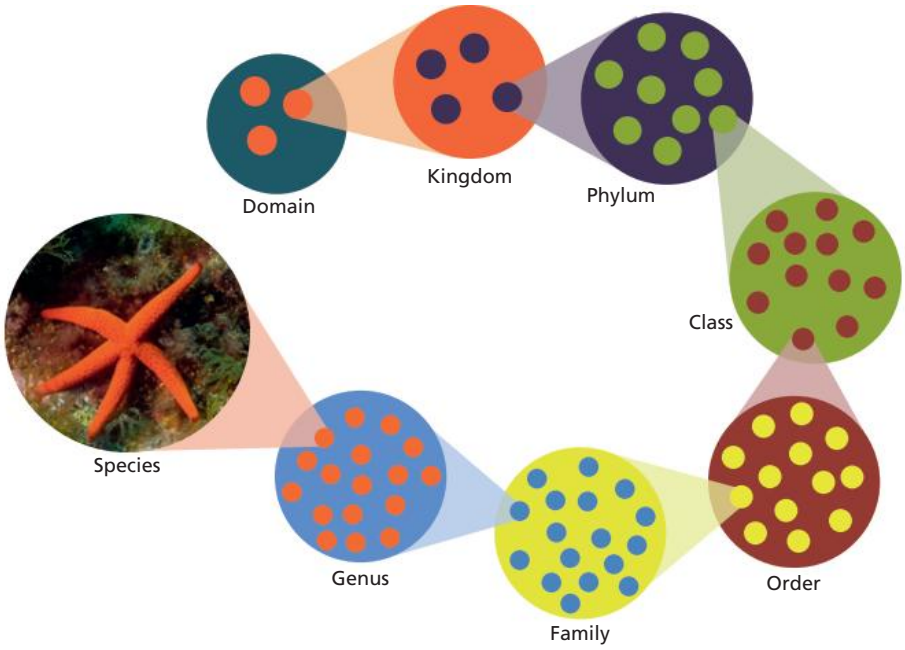
The higher taxonomic levels are larger groupings and show more diversity between individuals than lower levels. For example, the Class Amphibia, to which all frogs belong, is a large group of more than 7000 species that also contains other organisms such as toads and salamanders. The Genus *Rana* is a smaller taxa within the Class Amphibia and contains around 90 different species of frog.

Initially, organisms are classified into very large groups called domains. The domains are then divided up into kingdoms. Organisms within a kingdom can be further grouped according to the features that they share. This grouping is called a phylum; for example, the Phylum Chordata includes all living things that at some stage of their development possess a dorsal notochord ('dorsal' = back, 'notochord' = primitive backbone), gill slits and a hollow dorsal nerve cord. Humans belong to this phylum.

Organisms within a phylum can be further grouped according to similar features. These smaller groupings are called 'classes'. For example, any members of the Phylum Chordata that nourish their young on milk produced by the female (such as dogs, humans and kangaroos) are grouped within the Class Mammalia.

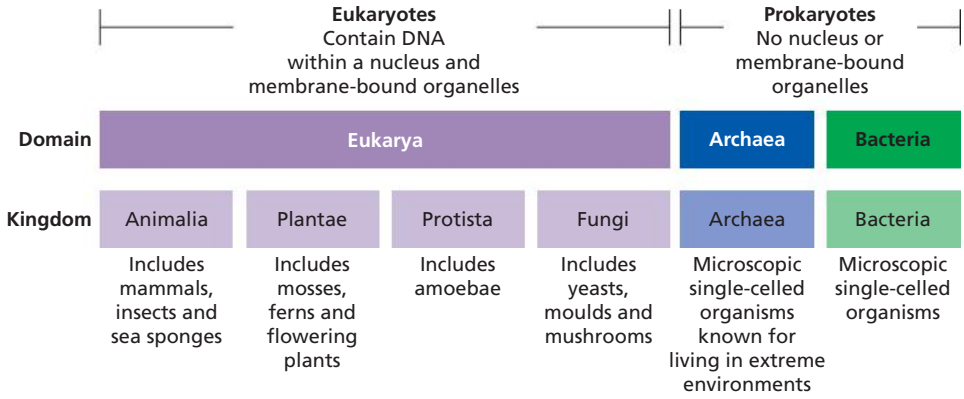
Organisms within a class can be further grouped into orders according to similar features. Humans are grouped within the Order Primate along with monkeys, orangutans, chimpanzees and gorillas. Orders are subdivided into families, which can be further subdivided into genera (singular, 'genus'). Finally, genera are further subdivided into species. The order of this hierarchy is shown in Figure 5.2.

Figure 5.2 ▶
The hierarchy of the taxa. Each taxonomic level can be divided into multiple groups in the level below.



The initial division of life into three domains (Figure 5.3) is based on cellular **characteristics**. Members of Domain Eukarya, called **eukaryotes**, contain their **DNA (deoxyribonucleic acid)** within a nucleus and have other membrane-bound compartments called **organelles** within their cells. Domains Archaea and Bacteria contain **prokaryotes**: organisms that lack these features. Prokaryotes are microscopic, single-celled organisms. Despite this superficial similarity, organisms in Domains Archaea and Bacteria have differences in the way DNA is stored and how proteins are synthesised, which means that they are classified in separate domains. Many of the members of Domain Archaea live in extreme environments (such as areas of high salt or temperature).

Figure 5.3 ▶
The initial divisions of life: the domains and kingdoms



There are four kingdoms in Domain Eukarya: Animalia, Plantae, Protista and Fungi. You may be familiar with many of the organisms within these kingdoms. Kingdom Animalia contains all of the animals, including some that are single-celled. Plants (Kingdom Plantae) have cell walls that contain cellulose and obtain energy from the sun using organelles called chloroplasts. Yeasts, mushrooms and moulds all belong to Kingdom Fungi and are characterised by having cell walls made of a specific polysaccharide (chitin). The protists (Kingdom Protista) are a diverse group of organisms that are mostly single-celled and live in aqueous environments.

There is still debate among **taxonomists** as to how these groups should be divided. The Archaea and Bacteria used to be considered as part of a single kingdom, the Monera, and this terminology is sometimes still used. Other taxonomists have suggested different kingdoms.

Naming organisms: The binomial system

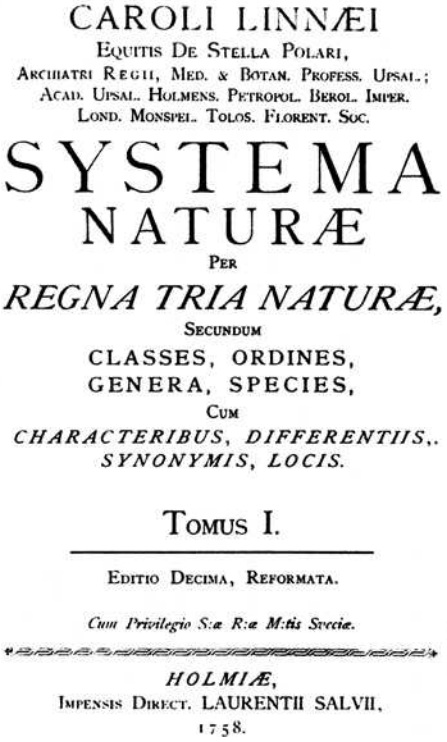
There are multiple ways of naming organisms. Most organisms have at least two names: a common name and a scientific name. Common names (such as 'grasswren' or 'echidna') may refer to individual species or to larger taxonomic groups. They can vary between languages and are not always used consistently. The scientific name (or binomial name) is used by scientists around the world and refers to a single species.

A binomial name consists of two parts: a generic name and a specific name. The first part (generic name) denotes the genus and is common to all organisms within that genus, while the second part is unique to a single species. For example, golden wattle, Australia's floral emblem, has the name *Acacia pycnantha*. Related species of wattle such as black wattle (*Acacia mearnsii*) and tan wattle (*Acacia hemiteles*) share the same first part of their name: *Acacia*. However, the different second part of the name (specific name) indicates that these are different species.

Binomial names are written using Latin grammar, but can come from various sources. Sometimes they describe features of the organism. For example, the binomial name for the short-beaked echidna (*Tachyglossus aculeatus*) means 'fast-tongued and covered with spines'. In other cases species may be named after a distinguished person, a location or a mythological character. The binomial name for humans, *Homo sapiens*, comes from the Latin phrase for 'wise man'.

The **binomial system** of naming organisms was developed by 18th-century Swedish botanist and zoologist, Carl Linnaeus. Before Linnaeus introduced the binomial system, organisms had descriptive Latin names that could be very long. His system revolutionised the way that scientists describe and communicate about organisms. Considered the father of modern taxonomy, Linnaeus first used this system in his book *Systema Naturae* in which he classified organisms into kingdoms, classes, organisms, genera and species. These taxa are different from the ones we use today, but Linnaeus' work formed the basis of the system we still use. Over his lifetime, Linnaeus named and described more than 10 000 species of animals and plants. In recognition of his substantial scientific contributions, Linnaeus was made a member of the nobility in 1761 and changed his name to Carl von Linné.

There are conventions for writing scientific names. The names are usually written in italics and the first part of the name, but not the second part, is capitalised. When the name of a species has already been mentioned, the first part can be abbreviated. For example, the name of the bacterium *Escherichia coli* can be abbreviated to *E. coli* when it is written for the second time. Sometimes you may see sp. (singular) or spp. (plural) in place of the second part of the name. These are used when the author is not referring to a particular species. For example, *Lasiorhinus* sp. means 'a member of Genus *Lasiorhinus* (hairy-nosed wombats)' and *Macropus* spp. refers to 'members of Genus *Macropus* (kangaroos)'.


CAROLI LINNÆI
EQUITIS DE STELLA POLARI,
ARCHIATRI REGII, MED. & BOTAN. PROFESS. UPSAL.;
ACAD. UPSAL. HOLMENS. PETROPOL. BEROL. IMPER.
LOND. MONSPEL. TOLOS. FLORENT. SOC.

SYSTEMA
NATURÆ
PER
REGNA TRIA NATURÆ,
SECUNDUM
CLASSES, ORDINES,
GENERA, SPECIES,
CUM
CHARACTERIBUS, DIFFERENTIIS,
SYNONYMIS, LOCIS.

TOMUS I.

EDITIO DECIMA, REFORMATA.

Cum Privilegio S:æ R:æ M:tis Svecie.

HOLMIÆ,
IMPENSIS DIRECT. LAURENTII SALVII,
1758.

Alamy/INTERFOTO

▲ **Figure 5.4** The title page from Linnaeus' pivotal 10th edition of *Systema Naturae*

RECALL

- Organisms are classified into a hierarchy of groups called taxa. The names of the taxa are Domain, Kingdom, Phylum, Class, Order, Family, Genus and Species.
- All organisms have a binomial (scientific) name. Binomial names consist of two parts: the first denotes the genus and the second is specific to the species.

RECAP 5.2

1 Describe Linnaeus' contribution to biological classification.
2 List the kingdoms that make up Domain Eukarya.
3 Define 'taxonomic level'.
4 Explain the relationship between a phylum and a class.

Classification is based on the characteristics of organisms

Classification never stops. Taxonomists' opinions differ; some will lump species together and others will reclassify a species to split it into new species. At the same time, new species are regularly being discovered. We will now explore the characteristics that taxonomists use to group organisms.

Characteristics are features that can be used to describe an organism. Classification is based on the idea that members of the same group share characteristics that are not present in members outside the group. Platypuses, for example, have a backbone, are covered in fur and lay eggs. All of these are characteristics that are used to classify platypuses into Phylum Chordata (with other vertebrates), Class Mammalia (with other animals with fur) and Order Monotremata (with echidnas; the other egg-laying mammals). Order Monetremata is further divided based on the characteristics of its members. Echidnas and platypuses have many different characteristics, so they have their own families and genera.

Physical characteristics

When creating the classification system presented in *Systema Naturae*, Linnaeus used the physical characteristics of organisms as the basis for his groups. Taxonomists today still use physical characteristics to classify organisms. Almost any aspects of an organism that you can describe could be used in this way.

Can you think of some of the physical characteristics that could be used to define humans? Examples include the fact that humans have cells that contain a nucleus, possess a backbone and have hair. You will learn later on how these physical features are used to classify humans.

Reproductive methods

Chapter 8 goes into more detail about sexual and asexual reproduction.

The ability to reproduce is a fundamental characteristic of life on Earth. It is unsurprising that there is considerable variation in how organisms do this. Methods of reproduction are an important characteristic that can be used to classify organisms.

One major difference between organisms is whether they reproduce sexually (with mixing of gametes from two individuals) or asexually. There are species of both plants and

animals that reproduce each way. Some species are able to reproduce both sexually and asexually depending on environmental conditions.

Among mammals (animals that produce milk for their young and have fur), the method of reproduction is used to separate three main groups. Eutherian (or placental) mammals give birth to live young after a gestation period during which the foetus develops inside the mother. The majority of mammals are included in this group. Marsupials give birth to live young at a very early developmental stage. This group of animals, which are predominantly found in Australia, includes kangaroos, koalas and possums. These young then develop in a pouch on the belly of the mother until they are mature enough to survive outside. Monotremes are a very small group of mammals made up of echidnas and platypuses, which lay eggs.



iStock.com/mburt

▲ **Figure 5.5**
A kangaroo suckling her joey. Like all other mammals, kangaroos have fur and produce milk.

Molecular sequences

More recently, the sequences of molecules such as DNA and protein have also been used to classify organisms. Even though they cannot be directly seen, molecular sequences are still distinct characteristics. Now that technology allows for the measurement of these sequences, they can also be used in classification.

Learn more about the use of gene sequencing in Chapter 9.

DNA is made up of a sequence of four bases: adenine (A), thymine (T), cytosine (C) and guanine (G). The order of these bases determines the physical features of an organism. Individuals within a species have some differences in the order of these bases. However, these differences are much smaller than the differences in sequence between organisms of different species. By looking at the similarities and differences between DNA sequences, scientists can help to classify organisms.

DNA evidence has been particularly useful when morphological evidence is not clear. The classification of the red panda (*Ailurus fulgens*) was a topic of debate for many years. At different points in time it had been considered part of the Family Ursidae (bears) and Family Procyonidae (raccoons) because it shared physical characteristics with members of both families. DNA evidence has suggested that the red panda is sufficiently different to be considered its own family, called Ailuridae.

▼ **Figure 5.6**
The red panda is in a family all on its own: Family Ailuridae.



Shutterstock.com/Joe Ravi

Similar to DNA, information about protein structure can also be used in classification. Proteins are made up of sequences of **amino acids** and the order of these amino acids can be used to help classify organisms. Table 5.1 shows the sequence of the first 38–40 amino acids in the protein cytochrome c for five different animals. These sequences have been aligned so you can compare them. Each letter stands for a different amino acid. You can see that when an animal has a different amino acid to that in the human sequence, it has been coloured red.

Table 5.1 The first 38–40 amino acids in the protein cytochrome c

Human (*Homo sapiens*)	MG--DVEKGK	KIFIMKCSQC	HTVEKGGKHK	TGPNLHGLFG
Chimpanzee (*Pan troglodytes*)	MG--DVEKGK	KIFIMKCSQC	HTVEKGGKHK	TGPNLHGLFG
Emu (*Dromaius novaehollandiae*)	MG--DIEKGK	KIFVQKCSQC	HTVEKGGKHK	TGPNLNGLFG
Lamprey (*Lampetra tridentata*)	MG--DVEKGK	KVFVQKCSQC	HTVEKAGKHK	TGPNLSGLFG
Fruit fly (*Drosophila melanogaster*)	MGSGDAENGK	KIFVQKCAQC	HTYEVGGKHK	VGPNLGGVVG

You will notice that the amino acid sequences for humans and chimpanzees are identical. This supports the classification of humans and chimpanzees into the same order (Primates). Humans are less similar to emus than they are to chimpanzees. As such, although they are in the same phylum (Chordata), they are in different classes. Emus have four amino acids that differ from humans in this sequence, supporting their difference in classification. Fruit flies have 13 amino acids that differ from humans. This supports the fact that, unlike all the other animals listed, fruit flies are in Phylum Arthropoda.

The study of bioinformatics combines mathematical modelling, computer science and biology to compare molecular sequences on a very large scale. The development of specialised computer programs has been very important in enabling scientists to further explore the relationships between organisms.



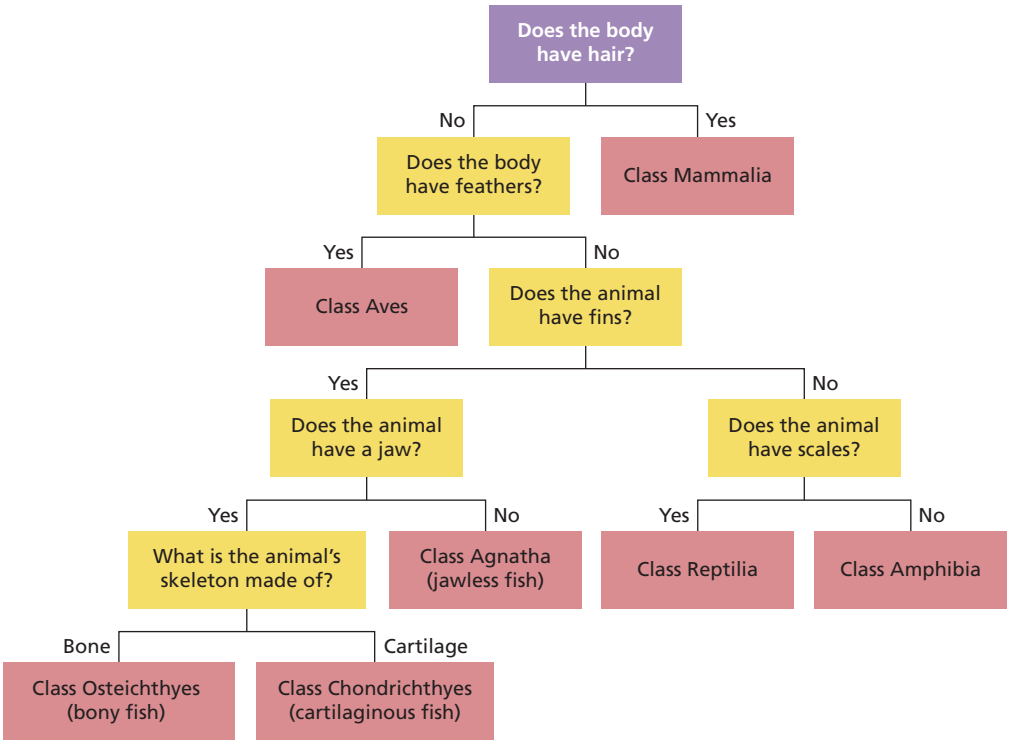
Tim Alexander

Figure 5.7 ▲
This species of sea snail is commonly found in Australian waters. A dichotomous key can be used to classify it.

Classification keys

Imagine you are exploring a rockpool and find a sea snail that you want to learn more about. The first step is to identify the snail, but how would you do this? One way would be to use a **field guide**, a book containing pictures and descriptions of plants and animals in a particular area. If there are a lot of options, it can be hard to be confident that you have found the correct organism. Furthermore, field guides often only identify organisms down to order. A more scientific option is to use a **classification key**. These are tools used by scientists to identify organisms that have already been discovered. Using information about the physical features and habitats of organisms, classification keys guide scientists through the identification process.

At the start of a classification key the user is given a choice between several options that describe the organism to be identified. Each choice leads to more options to choose between. The user continues to make choices until they reach an endpoint. Most classification keys are **dichotomous**, meaning that at each step the user has to choose between two options (Figure 5.8).



◀ Figure 5.8
A dichotomous key for identifying the class of vertebrate animals

Imagine if Figure 5.8 had hundreds of branches. Dichotomous keys can be very long so it is not always practical to present them this way. Most keys are presented as a list with the pairs of choices numbered. A simple dichotomous key for classifying animals into phyla is shown below.

1a	Body symmetrical	go to 2
1b	Body asymmetrical with no structure/organs	Phylum Porifera
2a	Body with multiple planes of symmetry (radial symmetry)	go to 3
2b	Body with a single plane of symmetry (bilateral symmetry)	go to 4
3a	Tentacles present, body soft	Phylum Cnidaria
3b	No tentacles, body hard and rough	Phylum Echinodermata
4a	Body divided up into segments (segmented)	go to 5
4b	Body unsegmented	go to 6
5a	Body divided into 2–3 segments; jointed legs present	Phylum Arthropoda
5b	Body divided into many segments; jointed legs absent	Phylum Annelida
6a	Body with internal or external shell	Phylum Mollusca
6b	Body without shell	go to 7
7a	Body flat and worm-like	Phylum Platyhelminthe
7b	Body not worm-like	Phylum Chordata

We can use this key to identify the phylum of a sea snail (Figure 5.7). The body is symmetrical with a single plane of symmetry so we choose option 1a and then 2b. The body is unsegmented so we choose option 4b, which directs us to pair 6. The sea snail has a shell so we choose option 6a, which identifies the sea snail as belonging to Phylum Mollusca. A more detailed key is needed to identify the further taxa.

One of the difficulties with dichotomous keys is that if the user cannot choose between two options, they become 'stuck' and cannot keep going. To help overcome this problem, many keys are now available on the Internet or as computer software. These digital keys allow users to input information about the organism's features in any order. The program eliminates options until enough information has been entered to uniquely identify the organism.

EXPERIMENT 5.1

IDENTIFYING INSECTS

In this experiment you will use two types of keys to aid in the identification of some Australian insects. You will use a dichotomous key, as well as a digital key, to identify these insects. These keys will allow you to identify the insects down to order. Further keys would be needed to identify the family, genus and species.

Aim

To practise using classification keys

Materials

- preserved insect specimens and/or appropriate photos and diagrams of insects
- stereo (dissecting) microscope
- computer with access to the weblink
- forceps
- dissecting needle
- hand lens

WHAT GROUP DO I HAVE? INSECT ORDERS OF AUSTRALIA

A matrix key to identify Australian insects down to their order.

Procedure

1. Familiarise yourself with some of the terms used to describe insect parts (shown in Figures 5.10, 5.11 and 5.12). The digital key contains further images that help explain the terms used.
2. Using the written key shown below, 'key out' each specimen to identify the order to which they belong. You can use the stereo microscope, forceps and dissecting needle to help you look more closely at the insects.
3. Repeat the process using the digital key. To use the digital key, you should select any features you can identify. Orders that the insect could belong to are shown in 'entities remaining'. Continue to select features until only a single order remains.
4. Record your results in a table like Table 5.2 on page 161.

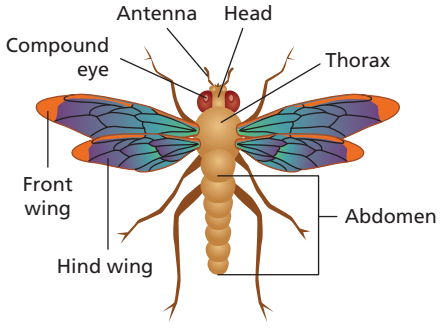


Figure 5.9 ▲
The main parts of a typical insect

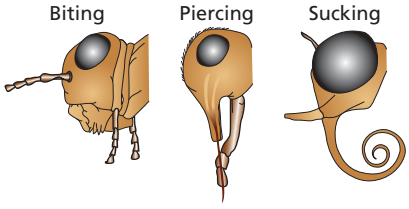


Figure 5.10 ▲
Insect mouth parts

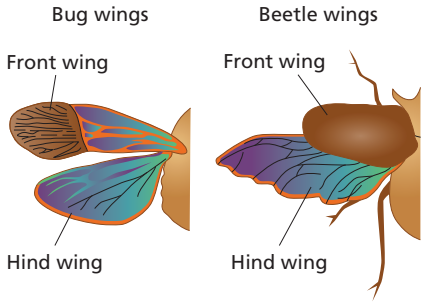


Figure 5.11 ▲
A comparison of beetle wings and bug wings

1a	Winged insects	go to 2
1b	Wingless adult insects	go to 25
2a	Two pairs of wings, one of the pairs being either partly or wholly hardened, or parchment-like (papery) and opaque (non-transparent)	go to 3

2b	One pair of wings or two pairs resembling one another in appearance and texture	go to 12
3a	Front wings forming a pair of hard covers meeting in a straight line down the centre of the back. Mouthparts of biting type (unsuitable for sucking)	go to 4
3b	Front wings overlapping (not meeting in a straight line down the back). Hind wings membranous and often fan-like	go to 6
4a	Front wings very short, covering less than half the abdomen	go to 5
4b	Front wings covering all or most of the abdomen. Beetles	Order Coleoptera
5a	Abdomen with two hardened pincer-like (or forceps-like) extensions behind. Earwigs	Order Dermaptera
5b	Abdomen without a pair of pincer-like (or forceps-like) extensions behind, though often with a pair of short segmented processes. Some beetles	Order Coleoptera
6a	Each front wing divided into two sections sharply marked off from each other, the fore-section being leathery and opaque, the hind-section membranous. Mouthparts in the form of a jointed piercing tube (suitable for sucking). Bugs	Order Hemiptera
6b	Front wings parchment-like, more or less uniform in texture	go to 7
7a	Mouthparts of piercing type. Hind wings not fan-like. Most planthoppers and froghoppers	Order Hemiptera
7b	Mouthparts of biting type. Hind wings fan-like	go to 8
8a	Hind legs much longer than other legs, suited to leaping. Grasshoppers and crickets	Order Orthoptera
8b	All legs more or less equal in length	go to 9
9a	Broad, flattened insects with legs pressed close to the body. Usually rapid runners. Head partly or completely hidden when viewed from above. Cockroaches	Order Blattodea
9b	Elongated, slow-moving insects with extended legs and a clearly visible head	go to 10
10a	Front legs markedly different in shape from the other legs	go to 11
10b	Front legs similar to other legs; the first segment of the thorax (the segment bearing the front legs) very short; second segment of the thorax very long. Stick insects, phasmatids	Order Phasmatodea
11a	Front legs greatly broadened and adapted for digging. Front wings very short and round. Mole-crickets	Order Orthoptera
11b	Front legs adapted for securing prey. First segment of thorax (segment bearing the front legs) very long. Mantids	Order Mantodea
12a	One pair of wings. (Hind wings are reduced to a pair of balancers, which are often obscured by a pair of scale-like processes arising from the side of the thorax.) True flies	Order Diptera
12b	Two pairs of wings	go to 13
13a	Wings and body completely covered with fine scales or hairs visible at low magnification (though occasionally part or whole of the wing may lack scales)	go to 14
13b	No scales or hairs visible at low magnification	go to 16
14a	Insects resembling moths, but with hairy wings (scales rub off). Mouthparts never in the form of a sucking tube	go to 15
14b	Insects with fine scales covering the wings and body. (The wings of a few species are partly or wholly transparent.) Mouthparts often in the form of a long sucking tube held coiled like a watch spring. Butterflies and moths	Order Lepidoptera
15a	Distinct, biting mouthparts. Wings with numerous short cross-veins leading from one of the main wing veins to the front margin of the wings. Pattern of wing veins very complex with much branching and numerous cross-veins. Some lacewings	Order Neuroptera
15b	Mouthparts non-functional. Wing veins much simpler, without the series of cross-veins between the long wing vein and the front margin of the wings. Caddisflies	Order Trichoptera

16a	Mouthparts in the form of a piercing tube only (often folded underneath)	go to 17
16b	Distinct, separate mouthparts suited for biting, or some mouthparts forming a sucking tube and some used for manipulation	go to 18
17a	Very small elongated insects, with a short, piercing beak and very narrow wings with long fringes of hairs. Nearly always found on the buds and flowers of plants. Thrips	Order Thysanoptera
17b	Small, medium or large insects with mouthparts in the form of a long, piercing beak; wings of normal width, without long fringes of hairs. Aphids, psyllids (lerps), cicadas, etc.	Order Hemiptera
18a	Stiff wings, with thick wing veins. Hind wings linked to front wings by a row of hooks (use a hand lens). Abdomen connected to the thorax by a 'waist', which is often very narrow. Sawflies, wasps, ants, bees	Order Hymenoptera
18b	Wings not linked by a row of hooks	go to 19
19a	Insects with long, segmented filaments extending from the end of the body	go to 20
19b	Insects without long, segmented filaments extending from the end of the body	go to 21
20a	Front wings distinctly narrower than the hind wings, which are partly or almost entirely fan-like; antennae long. Stoneflies	Order Plecoptera
20b	Front wings much broader than hind wings; antennae extremely short and bristle-like. Mayflies	Order Ephemeroptera
21a	Wing veins very simple with few cross-veins. Pale, soft-bodied insects with very weak flight. Termites	Order Isoptera
21b	Wing veins more complex with numerous cross-veins and much branching	go to 22
22a	Antennae extremely short and bristle-like; eyes very large, taking up most of the head. Wing venation extremely complex. Wings held stiffly to the sides (dragonflies), or held over the abdomen (damselflies) when the insect is at rest. Dragonflies and damselflies	Order Odonata
22b	Antennae of more normal length, often very long. (If they are short, they are never bristle-like.) Eyes of more normal size	go to 23
23a	Wings without a series of cross-veins linking the long wing veins to the front margin of the wings. Wings long and thin; legs usually very long; head elongated into a snout. Scorpionflies	Order Mecoptera
23b	Wings with numerous short veins linking one of the main long wing veins to the front margin of the wings. Wing venation usually very complex with much branching and numerous cross-veins	go to 24
24a	Main veins in wings branch near ends. Wings held tent-like over abdomen when insect is at rest. Lacewings and ant-lions	Order Neuroptera
24b	Main veins in wings unbranched near ends. Wings folded flat over abdomen when at rest. Alderflies or dobsonflies	Order Megaloptera
25a	Minute insects with a 'spring' present at the tip of the abdomen, enabling the insect to spring strongly. Springtails	Order Collembola
25b	Insects not possessing this spring	go to 26
26a	Insects with pincer-like or forcep-like processes extending from the tip of the abdomen	go to 27
26b	Abdomen without processes, or with processes coming from the tips of the abdomen and divided into segments	go to 28
27a	Segments of the abdomen clearly separated from each other by membranous sections. Body very soft. Mouthparts internal, not visible externally. Japygids	Order Diplura
27b	Abdominal segments telescoped to some extent so that membranous parts between segments not visible dorsally. Mouthparts of biting type and clearly visible. Earwigs	Order Dermaptera
28a	Abdomen with long, segmented, thread-like processes (filaments) extending from the tip	go to 29

28b	Tip of abdomen without processes, or with short ones	go to 30
29a	Three filaments; body often covered with silvery scales (which rub off). Silverfish	Order Thysanura
29b	Two filaments; body bare (without scales)	Order Diplura
30a	Soft-bodied, pale insects parasitic on the feathers of birds or the hair of mammals. Lice	Order Phthiraptera
30b	Other insects. If parasitic on the bodies of birds or mammals then not particularly soft-bodied or pale	go to 31
31a	Body strongly compressed from side to side; hind legs long and suited to leaping. Parasitic on the bodies of birds or mammals. Fleas	Order Siphonaptera
31b	Body not strongly compressed from side to side; not parasitic on birds and mammals	go to 32
32a	Minute insects, with pale, soft bodies, found among old books and papers or neglected museum specimens; rapid runners. Booklice	Order Psocoptera
32b	Larger insects of different appearance and habits	go to 33
33a	Abdomen constricted to form a 'wasp waist'. Ants and wingless wasps	Order Hymenoptera
33b	Abdomen broadly joined to thorax (no 'wasp waist')	go to 34
34a	Mouthparts of biting type	go to 35
34b	Mouthparts not of biting type	go to 38
35a	Hind legs much longer than other legs, and suited to leaping. Wingless grasshoppers	Order Orthoptera
35b	All legs more or less equal in length	go to 36
36a	Pale, soft-bodied, slow-moving insects tunnelling in soil or timber, often living in colonies made up of several distinct castes. Termites	Order Isoptera
36b	Insects differing in appearance and habits from 36a	go to 37
37a	Large, broadly flattened insects with legs pressed close to the body; usually rapid runners. Head partly or completely hidden when viewed from above. Wingless cockroaches	Order Blattodea
37b	Elongated stick-like insects with the first segment of the thorax (the segment bearing the front legs) short and the second segment of thorax very long. Phasmatids	Order Phasmatodea
38a	Very furry, slow-moving insects with an abdomen much larger than head and thorax. Some female moths	Order Lepidoptera
38b	Insects without a hairy covering	go to 39
39a	Very small, slow moving insects with long, thin legs. Abdomen with a pair of short tubes on the back through which wax is secreted. Aphids	Order Hemiptera
39b	Insects of different form, without tubes on the back	go to 40
40a	Head with a distinct neck. Wingless flies	Order Diptera
40b	Head usually set into thorax. Many bugs	Order Hemiptera

Results

Table 5.2 Insects identified using the keys

Specimen number	Order identified (written key)	Order identified (digital key)
Example specimen	Lepidoptera	Lepidoptera

Analysis of results

1 Were you able to identify all specimens using both keys? If not, identify where you became 'stuck'.
2 Did both keys identify the insects as belonging to the same order? If not, suggest some reasons why this might have occurred.

Discussion

1 List three of the features that were used to identify the insects.
2 If you wanted to confirm your identification, suggest some other resources you could use to do this.
3 Compare and contrast the features of the written key and the digital key you used. Do you prefer one over the other?

Taking it further

1 The weblink also contains keys that allow you to identify the family of insects within a particular order. Identify what family your insects belong to.

RECALL

- All living organisms can be classified based on physical traits, reproductive method and/or molecular sequences.
- Dichotomous keys are tools used to identify organisms. They involve choosing from a series of paired options until an organism is identified.

RECAP 5.3

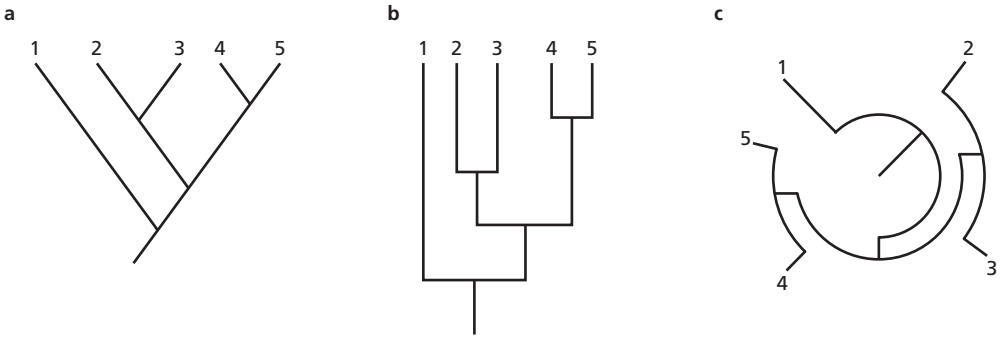
1 List three different types of characteristics that can be used to classify organisms.
2 Explain how protein structure can be used to classify organisms.
3 Explain what a dichotomous key is.

Classification reflects evolutionary relationships

Unit 4 Biology discusses the process of evolution and how organisms are related.

All organisms on Earth are related to one another, meaning that at some point in time they shared a **common ancestor**. Over generations, populations change as organisms adapt to their environments. These slow, incremental changes are referred to as evolution and can result in the formation of new species. Consequently, multiple species can develop from the same common ancestor. The more recently that two species shared a common ancestor, the more closely related they are and the more features they will have in common. When we classify organisms, we are also figuring out how they are related to one another. Two birds within the same genus, for example, are more closely related to one another than either bird is to animals in a different class.

These relationships can be shown in diagrams called **phylogenetic trees**. Like trees, these diagrams follow a branching pattern. You can think of each organism as a leaf on the tree and each branch point representing the most recent ancestor shared by two organisms. The more closely related two species are, the more recently they shared a common ancestor. Higher taxonomic levels branch off from one another earlier than lower levels. Figure 5.12 shows some of the different ways phylogenetic trees can be drawn. This tree shows that species 2 and 3 are closely related and that both of these are



◀ **Figure 5.12**
Three different ways of drawing phylogenetic trees. Type c is useful when trees are very large.

more closely related to species 4 and 5 than to species 1. You can see that even though each of these shows the same branching pattern, they look quite different.

You will notice that dichotomous keys also show a branching pattern. Unlike phylogenetic trees, the branches in a dichotomous key do not necessarily reflect how organisms are related.

Cladistics

Phylogenetic trees are commonly constructed using a technique called **cladistics**. Phylogenetic trees made using this technique are known as **cladograms**. Cladistics relies on several assumptions.

- The more closely related two organisms are, the more characteristics they will share.
- Some characteristics that are shared by a group will not be present in more distantly related groups.
- When there are multiple possible ways that organisms can be related, the simplest explanation is the most likely to be correct. This is because if a feature is shared between organisms, it is more likely that this feature evolved once in a common ancestor than independently for each organism. You will see an example of this in the following text.

Figure 5.13 on page 164 is an example of a cladogram and shows the relationship between major plant groups. The first step in constructing a cladogram is to create a table of the characteristics to be used. This table is known as a **character matrix**. In the character matrix used to build this cladogram (Table 5.3) you can see that '+' is used to indicate when a characteristic is present and '−' when it is absent.

The groups can then be arranged in different ways until the simplest cladogram is found. An alternative way of arranging the major plant groups based on the same

Table 5.3 Character matrix of major plant groups

	Bryophytes (includes mosses)	Pteridophytes (includes ferns)	Gymnosperms (includes conifers and cycads)	Angiosperms (flowering plants)
Performs photosynthesis	+	+	+	+
Has vascular tissue (xylem and phloem)	−	+	+	+
Produces seeds	−	−	+	+
Seeds enclosed in an ovary	−	−	−	+

character matrix (Table 5.3) is shown in Figure 5.14. For this cladogram to be correct, the presence of seeds would have had to evolve twice, once for the gymnosperms and separately for the angiosperms. This is unlikely, so Figure 5.13 is considered to be the most likely arrangement.

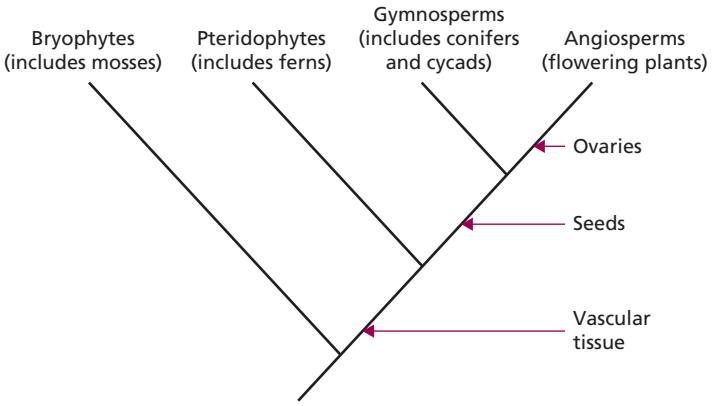


Figure 5.13 ▶
A cladogram showing the evolutionary relationship between major plant groups. The arrows indicate when each characteristic evolved.

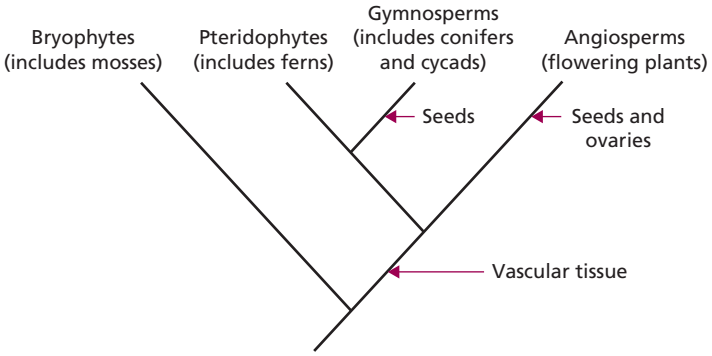


Figure 5.14 ▶
An alternative cladogram showing the relationship between major plant groups. This option is far less likely to have occurred.

Taxonomists try to ensure that classification reflects the evolutionary relationships between organisms. Ideally, each taxonomic group contains all of the organisms descended from the same common ancestor. When looking at a cladogram, this means that a group contains all of the organisms on a branch. When this occurs, that group is called a **clade** (or can be referred to as **monophyletic**).

Three classes of animals are shown in the cladogram in Figure 5.15. You can see that both Class Aves and Class Mammalia are clades because they contain all of the animals

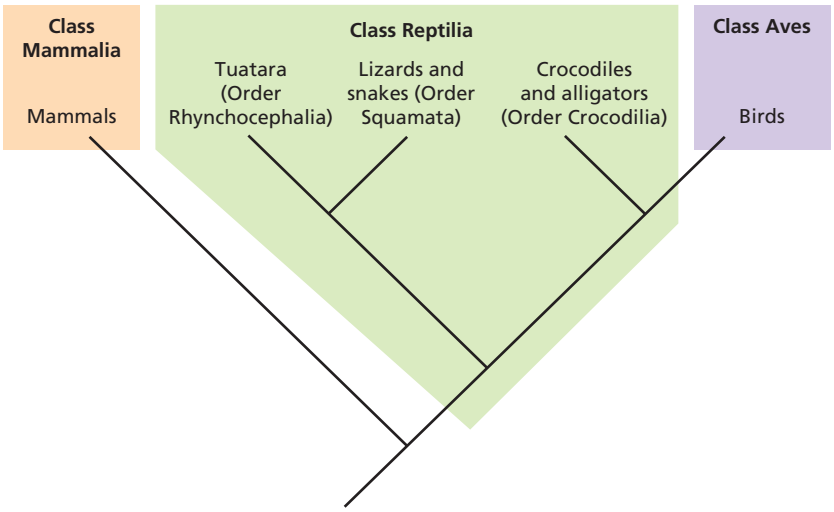


Figure 5.15 ▶
Cladogram showing the major classes of amniotes. Classes Aves and Mammalia are monophyletic/clades; Class Reptilia is paraphyletic.

on that branch. Class Reptilia, however, is not a clade. This is because it does not contain birds, which also descended from a reptilian ancestor. Class Reptilia can be called a **paraphyletic** group. This arrangement has occurred because birds and reptiles were classified into separate classes before their evolutionary relationships were known. More recently, it has been determined that birds evolved from dinosaurs and as such, share a recent common ancestor with crocodiles and alligators. Some scientists have suggested that these taxonomic groups need to be reclassified to ensure that all are clades.

ACTIVITY 5.1

CONSTRUCTING A CLADOGRAM

Aim

To complete a character matrix and use it to construct a cladogram

You will need

- photos of each of the following: starfish, snail, bee, cow, duck and turtle

What to do

1. Create a character matrix that can be used to distinguish between the organisms. Use a '+' to indicate that a feature is present and a '–' if it is absent. Table 5.4 shows some suggested characteristics, but you will need to decide on some others to use.

Table 5.4 Character matrix

	Starfish	Snail	Bee	Cow	Duck	Turtle
Bilateral symmetry						
Has a backbone						
Gives birth to live young						

2. Find an animal that differs from another by only one (or very few) characteristics. Place these as an initial branch.
3. Place the rest of the animals on the cladogram into the simplest arrangement (the arrangement that is most likely to have evolved).
4. Check your arrangement by marking at each branch point what characteristics have evolved in that branch. Remember, you are aiming to have an arrangement that means no characters needed to evolve twice.

What did you discover?

1. Circle a clade (monophyletic group) on your cladogram.
2. Were there multiple ways you could construct the cladogram? How did you choose your arrangement?
3. How has this activity improved your understanding of what a cladogram represents?

One of the limitations of cladistics occurs when unrelated organisms have evolved similar characteristics independently. This can occur with organisms that inhabit similar habitats in different parts of the world, as in the case of marsupial moles and African golden moles. Marsupial moles (*Notoryctes typhlops*) that live in central Australian sandy deserts look remarkably like African golden moles (*Chlorotalpa* spp.). They have almost identical size and body shape. Both are blind and lack external ears, have several spade-like claws on their front feet, a horny shield protecting the snout, a stubby tail and silky fur (Figure 5.16 on page 166). Should marsupial moles and golden moles be grouped

together? Not if we think about their method of reproduction. Like other marsupials, marsupial moles give birth to live young at an extremely young age. These young then develop in a specialised pouch until they are mature enough to survive outside. Golden moles are placental mammals, meaning that their young develop inside the mother until the time of birth. Golden moles cannot be grouped with marsupials even though, externally, marsupial moles and golden moles look almost identical to the naked eye.

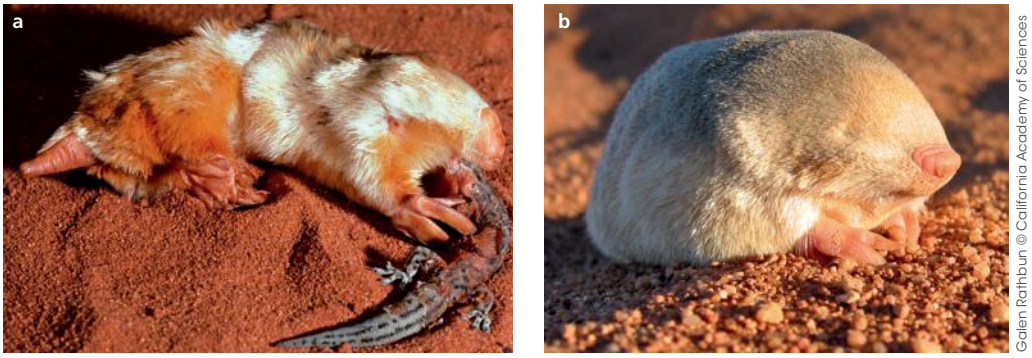


Figure 5.16 ▶
(**a**) Marsupial moles and (**b**) golden moles are superficially similar, but have evolved their characteristics independently.

It is important to understand that cladograms represent theories about the way that organisms are related. Like all scientific theories, they can be confirmed or challenged when more evidence is available. Cladograms can, and do, change as our understanding of these relationships improves. Figure 5.17 shows two possible cladograms for the evolution of the three groups of mammals: placental mammals, marsupials and monotremes. Most evidence based on the physical characteristics supports cladogram A. However, there is some evidence based on teeth and molecular data that suggests that monotremes and marsupials are more similar to one another than either is to placental mammals. This would support cladogram B. Has there been a verdict? Yes – molecular sequencing of DNA supports cladogram A, which is now widely accepted as the most likely evolutionary relationship.

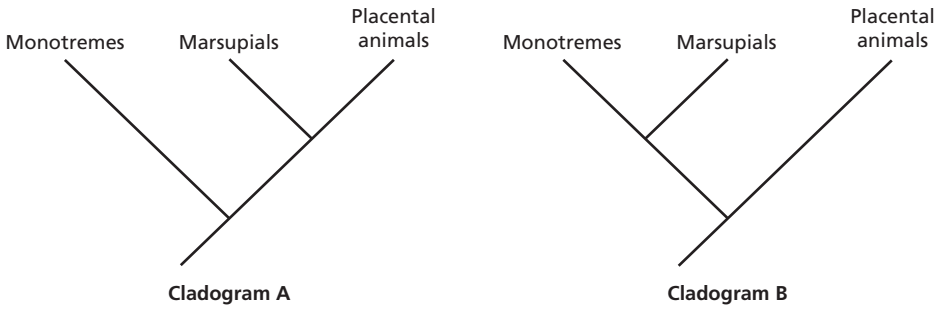


Figure 5.17 ▶
These two cladograms show the evolution of monotremes, marsupials and placental mammals; cladogram A is currently regarded as correct.

The impact of new technologies on taxonomy

DNA technology is covered in Unit 4 Biology.

New technologies have transformed cladistics and taxonomy. One of the most important developments has been the use of DNA technology to provide new and highly detailed information about evolutionary relationships. In some cases DNA evidence has supported previous hypotheses about these relationships, but in other cases it has led to reclassification of organisms. Additionally, because some changes in DNA occur at a predictable rate, DNA technology has allowed scientists to understand when certain groups evolved.

The information provided from DNA evidence is so detailed that classification systems have changed to reflect this. It is now possible to classify organisms down to many more levels than the traditionally recognised taxa. The prefixes 'super-' (above) and 'sub-' (below) can be added to existing taxa to create additional ranks (e.g. subphylum), and some newer taxa (e.g. tribe) are also recognised. Some scientists have argued that because of this complexity, the taxa are no longer relevant and have suggested replacing it with a system called the 'PhyloCode'. The PhyloCode assigns a name to a clade along with a definition of the members, but does not assign a rank to these names. For example, Mammalia could be defined as the clade originating with the most recent common ancestor of humans and platypuses.

RECALL

- Organisms are classified into groups that reflect their evolutionary history. This classification is based on the fact that related organisms share characteristics.
- Evolutionary relationships can be shown using phylogenetic trees.
- Classification and phylogenetic trees can change as new evidence becomes available. In particular, technological advancement has made new evidence available and changed the way these trees are constructed.

RECAP 5.4

1. List the three assumptions that are used in the construction of cladograms.
2. Define 'monophyletic'.
3. Explain why some taxonomists have suggested that the taxa containing birds and reptiles should be reorganised.
4. Sometimes multiple cladograms could be constructed for a character matrix. Explain how scientists decide between these different cladograms.

Maintaining biodiversity

Populations with reduced diversity face increased risk of extinction, so efforts at conservation are usually focused on maintaining genetic diversity. When large-scale extinctions occur not all species are lost, and some seem to be at more risk than others. Rapid extinction events can lead to the loss of larger organisms rather than smaller ones. Large populations can be more resilient than small populations, probably because the population has a more diverse gene pool. Having a large enough population with a diverse gene pool means that some individuals in the population may be better suited to changing environments, helping the species survive environmental challenges.

Speciation and conservation: The Eastern barred bandicoot

The Eastern barred bandicoot (*P. gunnii*) belongs to the marsupial family *Peramelidae*. It is small (body about 300 mm, tail 200 mm), grey-brown in colour, with four pale stripes or 'bars' on its hindquarters. It has three claws on the front feet, which it uses for digging, while the back feet are long, similar to those of a kangaroo.

Populations of the Eastern barred bandicoot were once common over a wide area of south-western Victoria. Numbers were reduced dramatically in the 1900s and now



Corbis/Steve Kaufman

Figure 5.18 ▲
The Eastern barred bandicoot (*Perameles gunnii*)

the Eastern barred bandicoot is isolated to a small area around Hamilton, numbering less than 200. This resulted from a change in environmental conditions (e.g. clearing of woodlands, growing exotic pasture grasses, grazing by domestic stock, introduction of rabbits and foxes), which severely reduced its available habitat in Victoria. Numbers of the Eastern barred bandicoot throughout most of Tasmania, however, are still healthy.

Conservation plans for the Eastern barred bandicoot depend heavily on how populations are classified. A **subspecies** is a level of classification below species, referring to races of a species that are fairly permanently geographically isolated from each other and may in future diverge to become two different species. Because of the relatively healthy bandicoot populations in Tasmania it is not regarded as an endangered species. If the Victorian population was identified as a different species, or subspecies, then it could be recognised independently for conservation purposes.

A number of studies have been conducted on the Victorian and Tasmanian populations in an attempt to protect the Victorian population. The bandicoots were trapped, small blood samples were taken and the animals were released immediately into the same areas. The blood was snap frozen and later DNA was analysed. The average percentage difference in DNA within the populations around Hamilton was found to be about 23%, and for those in Tasmania was 21.8%. The average percentage difference between the Hamilton and Tasmanian populations was 44.8%.

There is no doubt that the two populations have diverged to some extent due to geographical isolation. But are the two populations separate subspecies? The answer to these questions is vital to how the conservation of these two populations of Eastern barred bandicoots is managed.



Shutterstock.com/Matthew Dixon

Figure 5.19 ▲
Retaining green corridors assists wildlife conservation by providing a chance for species movement and gene flow.

Conservation reserves

One approach to conserving species is to set up reserves where they are protected from human influence and predation. However, it can be difficult to determine how these should be set up and managed. How large do they need to be and what area do they need to cover? Is a single large reserve required or is it preferable to set up several smaller reserves? What population size of the endangered species is needed to ensure long-term survival?

The yellow-bellied glider, *Petaurus australis*, is a rare, nocturnal marsupial. Its range extends from south-western Victoria up along the eastern coast of Australia to the rainforests north of Cairns. The Federal Government initiated a National Recovery Plan, which has identified a number of areas that need to be researched. These include understanding how the fragmentation of habitats currently suitable for the glider affects the dispersal of gliders between these areas, and how this affects breeding patterns within the whole population.

Studies have shown that these gliders live in small social groups occupying individual home ranges of between 25 and 85 hectares. Also, individual habitats need to be able to accommodate at least 150 glider groups to be sustainable in the long term. Based on these calculations it was determined that a forest area of between 10 000 and 35 000 hectares would be required to sustain such groups. This is a large area and could be used as a guide to providing minimum sizes for forest reserves along the eastern coast of Australia,

to allow for the conservation of many other plants and animals, which may be able to survive in a range of smaller areas.

Small reserves and wildlife corridors

One possible way to overcome the problems of isolated conservation areas is to provide linking **wildlife corridors** (also known as habitat or green corridors) of natural landscape. These allow animals to move to new locations when resources become scarce, to facilitate seasonal migration and to permit interbreeding, ensuring that there is sufficient gene flow between different parts of the isolated populations. This solution is controversial as some environmental experts claim that green corridors will not be adequate for conservation of endangered species.

RECALL

- Populations with reduced diversity face an increased risk of extinction.
- Identifying genetic relatedness assists in developing conservation strategies.
- An approach to species conservation is setting up wildlife reserves.

RECAP 5.5

1 Explain why the identification of the two possible subspecies of bandicoot is important for their conservation.
2 Outline how forest fragmentation can affect species diversity.
3 Describe how wildlife corridors are intended to maintain species diversity.

Investigation of an issue: Citizen scientists contribute to studies in biodiversity

Refer to Chapter 11 for more information on the investigation of an issue.

Homo sapiens are a highly evolved and successful species but our success is coming at a cost to biodiversity on Earth. Why should we care? Because biodiversity is the planet's life support system. It is important for maintaining balance in ecosystems, it offers resources and medicines, and it enriches our lives with beauty. We all have a moral obligation to care for our planet.

There are many methods used to sample biodiversity and they often involve field work, where scientists visit habitats day and night to observe, collect and identify species. This is very labour intensive so many research projects in environmental science now rely on citizen science, where members of the public contribute to the research. The Atlas of Living Australia has a number of citizen science projects designed to monitor biodiversity. Citizen scientist Stuart Harris discovered a new Australian species, the peacock spider (*Marratus harrisi*), through participating in a citizen science project (Figure 5.20a on page 170). Citizen science can also be used to protect areas known for their biodiversity. DeforestACTION is a global project where students monitor a 30m^2 piece of forest in Borneo, looking for illegal logging action (Figure 5.20b).

Involvement of citizens in data collection can compromise data quality as the skills and perceptions of the people involved can vary widely. Sources of error can include misidentification of species, and incorrect number of sightings, location or collection date recorded. These errors can be due to inexperience, misconduct or data entry error, and can impact the **validity** of the study. With this in mind, scientists must design the research project and the tasks enacted by citizen scientists to maximise accuracy and precision.

Smartphone technologies are a boon to citizen science projects that are interested in measuring species distribution or the biodiversity of an ecosystem. Tools can be designed so that the citizen scientist uploads images of flora and fauna to a project and GPS technology provides the location at which each photograph was taken. Experts can then identify each species and add this data to their project.

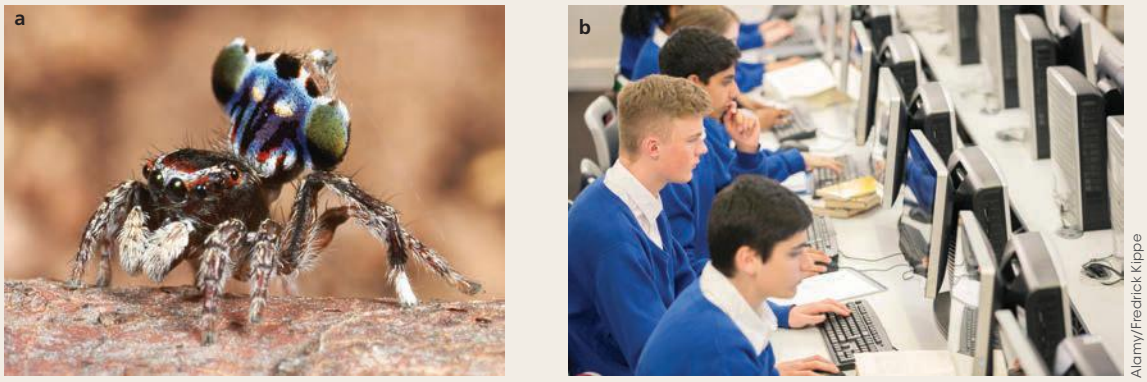


Figure 5.20 ▲
(**a**) Citizen scientist Stuart Harris discovered this new species of spider, named *Marratus harrisi* in his honour. (**b**) DeforestACTION is a global project where students monitor satellite images of a 30 m^2 piece of forest in Borneo, looking for illegal logging action.

Table 5.5 provides a checklist of methods to consider when designing or evaluating a citizen science project.

Table 5.5 Methods to increase the validity of a citizen science project (adapted from Wiggins et al. (2011))

Method to increase validity	Importance to experimental design in reducing error
Replication	Increasing the number of citizens involved and the number of measurements taken in a given area provides stronger statistics.
Controls	Past data can act as a control letting us know if unexpected data emerges in the study. Unexpected data should be examined for accuracy and reliability.
Equipment	All citizens should use the same equipment (measuring tools and data entry method) to collect data. This equipment should be accurate, reliable and easy to use.
Training	Data collection training should be provided and can include face-to-face time with experts, videos, information packs, instruction manuals and webinars.
Participants	Participants should be tested and rated for accuracy in data collection.
Data collection	If citizens are collecting data, they should provide digital information such as photographs, audio, GPS readings, and descriptive data if possible.
Unusual data	Unusual data should be identified and scrutinised further to determine whether it stays in the study or gets filtered out.
Citizen scientists	It should be possible to contact citizens in order to verify data, to invite them to participate in ongoing and future studies, to acknowledge data, and to provide feedback on accuracy of data collection.
Data analysis	Experts or fellow contributors should review data.

Using citizens to monitor the distribution of kelp forests

Along the southern shores of Australia you can find kelp forests that teem with life. Many ocean species visit the kelp forests to breed safely and use the protected waters as a nursery. It is important to maintain the biodiversity of these ocean forests. They contribute to tourism as anglers and scuba divers are attracted to these areas of diversity and beauty. They contribute to fisheries as crayfish and abalone thrive in kelp forests. Professor Peter Steinberg, marine scientist at the University of New South Wales, believes that kelp forests are worth billions economically. He is one of the principal research scientists involved with a project titled Explore the Seafloor, designed to monitor the distribution of kelp.

Kelp forests are under threat from rising ocean temperatures and invasive sea urchins. Factors such as coastal development, overfishing of keystone species (see Chapter 6, page 193 for more on keystone species) and pollution also affect kelp. In areas where kelp has disappeared the result is catastrophic. Whole ecosystems break down and all that remains is barren rock.

An Australian team of scientists want to measure the impact of various threats on kelp ecosystems. They need to establish a baseline for their study. They want to know where kelp forests currently grow, including the depth of kelp forests and their distribution along coastlines. Automated underwater vehicles (AUVs) are being used to take high-resolution, overlapping images of the sea floor in particular locations. Many thousands of images are ready for analysis by citizen scientists. A website, Explore the Seafloor, has been designed to allow citizen scientists to analyse collected images.



Created by ABC Science as part of National Science Week 2013

▲ **Figure 5.21**
Explore the Seafloor website

To participate in the study, citizen scientists need to provide their name, country, age, gender, education level and contact email. Participants are then given a tutorial that explains how to identify kelp and to distinguish it from other similar organisms. The tutorial then explains how participants mark photos to show that kelp is present. Figure 5.21 depicts a screenshot of the user experience. A list of frequently asked questions (FAQs) is provided to troubleshoot issues. If an appropriate answer cannot be found, a form is available that can be sent to the team of scientists.

Using citizens in the quest to find new antibiotics

A battleground lies beneath Earth's crust. The soil is teaming with microbes, fungi and bacteria that are competing to get nutrients from the organic matter dropped by plants and animals. Some microbes have evolved to produce substances that stop the growth of their competitors. These substances are called antimicrobials. If they halt the growth of bacteria they are called antibiotics. Alexander Fleming discovered the first antibiotic in 1928. He named it 'penicillin', after the fungus that produced it, *Penicillium notatum*. Following this a number of antibiotics were discovered and we can now treat most bacterial infections. However, a problem is emerging. Bacteria are becoming resistant to our current antibiotics. We need to find new antibiotics to treat infections such as treatment-resistant tuberculosis caused by resistant bacteria.

A team of scientists from the Brady Laboratory at Rockefeller University, New York are asking citizen scientists to send in their dirt. They don't want just any dirt. They want dirt from relatively unexplored places like hot springs and caves. The microbes in these places experience extreme environments so they are more likely to produce unique compounds that are unknown to humans.

The scientists are conducting an observational study to measure microbial biodiversity. When they receive dirt samples, they copy and sequence DNA from living organisms in the soil. DNA data is then added to public databases so anyone can access the data. This data will reveal new genes of interest that could be used to guide the discovery of new antibiotics.

Over to you: ensuring that citizen science projects are valid

Task 1: For the two citizen science projects described (kelp forest distribution and antibiotic discovery), design a brief presentation to defend the project design to a group of scientists. Your presentation should communicate the following.

- The context, describing the importance, impact and authority of the study
- Possible sources of error in data collection and how the study design accounts for these to improve validity of the study. Use Table 5.5 to evaluate the validity of the study. Suggest how the study might be improved to make it more valid.

Task 2: Design your own citizen science project that could be used to measure or protect biodiversity in your area. Your design should provide the context for the study and methods to reduce error in data collection by citizen scientists, and therefore increase the validity of the study.

References

Wiggins A., Newman G., Stevenson R.D. & Crowston K. (2011) *Mechanisms for data quality and validation in citizen science.* Workshop at the IEEE eScience Conference. Retrieved from http://crowston.syr.edu/system/files/PID2090593.pdf

CONCEPT SUMMARY

Classification

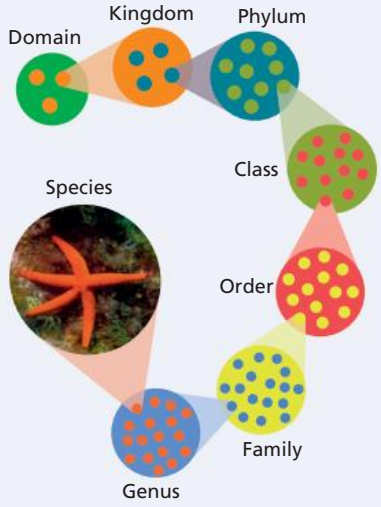
Why classify organisms?

To organise, analyse and communicate information

Bases for classifying organisms

- Physical characteristics
- Reproductive methods
- Molecular similarity (homology)

Levels of classification



	Eukaryotes: Contain DNA within a nucleus and membrane-bound organelles				Prokaryotes: No nucleus or membrane-bound organelles	
Domain	Eukarya				Archaea	Bacteria
Kingdom	Animalia	Plantae	Protista	Fungi	Archaea	Bacteria
	Includes mammals, insects and sea sponges	Includes mosses, ferns and flowering plants	Includes amoebae	Includes yeasts, moulds and mushrooms	Microscopic single-celled organisms known for living in extreme environments	Microscopic single-celled organisms

Binomial system

All organisms have a binomial (scientific) name. Binomial names consist of two parts:

- the first denotes the genus
- the second is specific to the species.

Biodiversity

Risk of extinction

Populations with reduced diversity face increased risk of extinction

Conservation of biodiversity

Aims to maintain genetic diversity of populations

Isolation of populations

Even if the biodiversity of a species is conserved, it is biodiversity of populations that is important because individuals from different populations may not be able to reproduce.

Conservation reserves

- Offer protection from human influence and predation.
- Difficult to determine necessary size.

Wildlife corridors

Allow individuals to travel in safety, connecting populations in reproductive terms



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Classifying organisms

Dichotomous keys

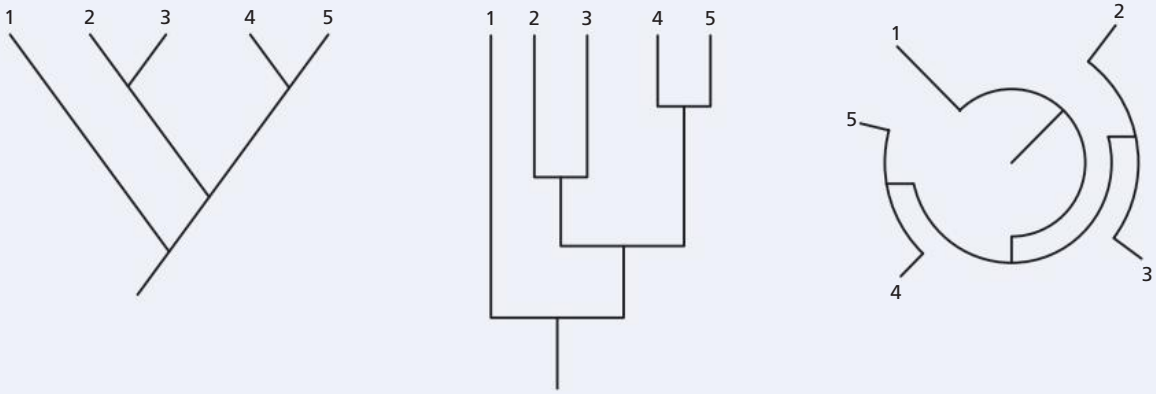
- Help to identify organisms
- Choose between two options until an organism is identified

Common ancestor

- A shared ancestor of two species
- An organism that evolved into a different species
- The time at which the common ancestor existed reflects the degree to which the descendent species are related.

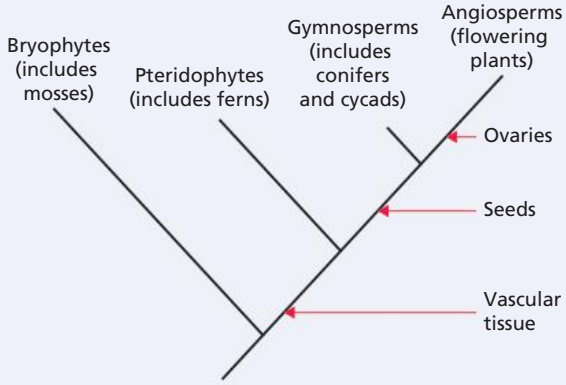
Phylogenetic trees

Represent evolutionary relationships and degrees of relatedness based on common ancestors



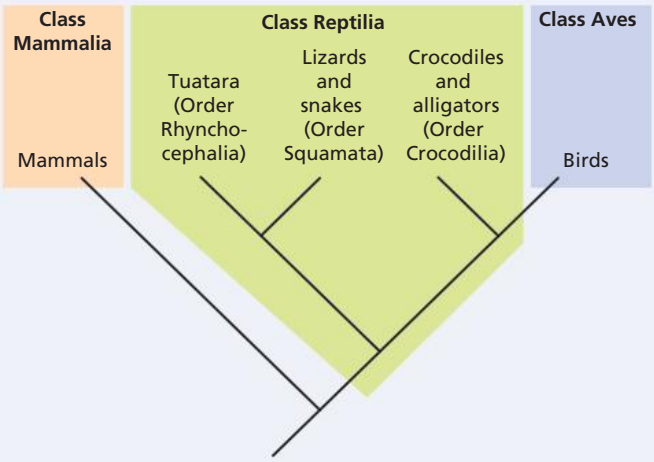
Cladogram

Phylogenetic trees made based on shared characteristics of organisms



Clades

- Branches on a cladogram
- Monophyletic clades: Classes Aves and Mammalia
- Paraphyletic clade: Class Reptilia



New technologies impact classification

DNA sequences provide molecular evidence of the relationships between species.

CHAPTER GLOSSARY

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

binomial system a system of naming organisms using two parts: a generic name and a specific name

character matrix a table that lists the characteristics of organisms and is used to construct cladograms

characteristic a feature or quality of an organism that can be used to classify and identify it

clade a taxonomic group that contains all of the descendants of a common ancestor

cladistics a method of classifying organisms based on the characteristics they share

cladogram a diagram constructed using cladistics that shows the evolutionary relationship between organisms

classification key a tool used to identify organisms based on their characteristics

common ancestor a species from which two different species both evolved

dichotomous describes a classification system where each branch has two options

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

eukaryote a complex type of cell with a nucleus and membrane-bound organelles; a member of Domain Eukarya

field guide a book used to identify organisms using photos and descriptions

monophyletic describes organisms that are grouped together as a clade

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

paraphyletic describes a group that does not contain all of the organisms descended from the most recent common ancestor

phylogenetic tree a system of classification based on common ancestry, often determined through genetic analysis; a diagram that shows the evolutionary relationship between organisms

prokaryote a simple type of cell that lacks a nucleus and membrane-bound organelles; a member of Domain Archaea or Bacteria

subspecies a subdivision of a species

taxa/taxonomic level a group of organisms; the major taxa are known as Domains, Kingdoms, Phyla, Classes, Orders, Families, Genera and Species

taxonomist a scientist who studies organisms and places them into taxa

wildlife corridor a narrow area of wildlife habitat that provides a link between areas of similar wildlife habitat

CHAPTER REVIEW QUESTIONS

Remembering

1 Describe the characteristic that defines members of Domain Eukarya.
2 Name the eight major taxonomic levels.
3 Describe what a common ancestor is.

Understanding

4 Using a specific example, explain what the two parts of the binomial name of an organism represent.
5 Summarise the reasons why biologists classify organisms into groups.
6 Explain why the biological classification system is described as hierarchical.
7 The following questions relate to Figure 5.22. Copy the diagram and answer the questions.
   a State whether the circled group (known as strepsirhines) is monophyletic or paraphyletic.
   b On your diagram, circle the clade that contains macaques and gibbons but not marmosets.
   c State which other primate in Figure 5.22 is also descended from the most recent common ancestor of humans and gibbons.

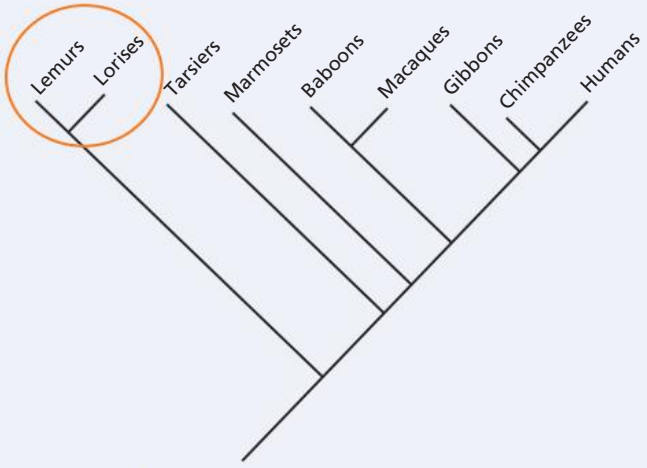


Figure 5.22 ▲
A cladogram showing the relationship between several primates

8 Explain what a cladogram represents.

9 Explain why some organisms that share physical similarities (e.g. the marsupial mole and the African golden mole) are classified separately.

Applying

10 Using the data in Table 5.1 (page 156), construct a cladogram that shows the relationship between the five species listed. (Hint: Consider each amino acid as a characteristic.)

11 Irukandji jellyfish (*Carukia barnesi*) live in the waters around the north of Australia. Even though they are only a couple of centimetres long, the highly venomous sting of this jellyfish can cause symptoms of severe pain, vomiting and blood pressure changes. Rarely, the sting can be fatal.

- **a** List three characteristics of the Irukandji jellyfish that could be used to help classify it.
- **b** Identify what domain, kingdom and genus the Irukandji jellyfish belongs to.
- **c** Using the key on page 157, determine what phylum the Irukandji jellyfish belongs to. You will need to find a photo of the Irukandji jellyfish.

Analysing

12 The Southern Corroboree frog (*Pseudophryne corroboree*) is a critically endangered species of frog that is found in a small region in NSW. Individuals are small (2.5–3 cm long), poisonous and are marked with a bright yellow and black pattern.

- **a** List five characteristics of the Southern Corroboree frog that could be used to classify this species.
- **b** Use the key in Figure 5.8 (page 157) to determine the class to which the Southern Corroboree frog belongs.
- **c** There is a large conservation program, including captive breeding, trying to save the Southern Corroboree frog from extinction. Explain why accurate identification is important for this program.

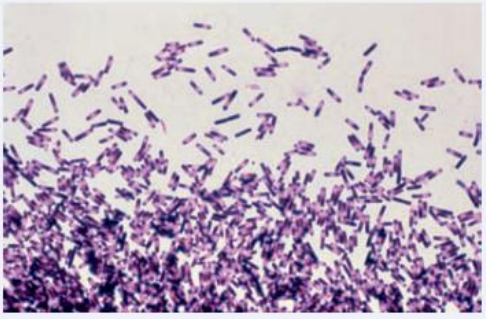
13 Identify two advantages of using the binomial system rather than common names to describe species.

14 Outline how technology has impacted on scientific classification. You may like to present your answer as a flow chart.

15 Shown below is a simplified dichotomous key for identifying several species of bacteria that can cause disease in humans. Using this key involves performing a Gram stain, which is a staining process that divides bacteria into two groups based on characteristics of their cell wall.

1a	Gram positive (stains purple with a Gram stain)	go to 2
1b	Gram negative (stains pink with a Gram stain)	go to 4
2a	Bacteria are cocci (sphere-shaped)	go to 3
2b	Bacteria are bacilli (shaped like rods)	*Clostridium difficile*
3a	Cocci are arranged in chains	*Streptococcus pneumoniae*
3b	Cocci are arranged in bunches	*Staphylococcus aureus*
4a	Bacteria are cocci (sphere-shaped)	*Neisseria* spp.
4b	Bacteria are bacilli (shaped like rods)	*Escherichia coli*

- **a** State which of the species listed in the key are sphere-shaped.
- **b** Using the above key, determine what species of bacterium is shown in Figure 5.23.



Getty Images/CDC/SPL

▲ **Figure 5.23**
A light micrograph of a species of bacterium stained with a Gram stain

- **c** Using this key, not all bacteria can be identified to the species level. Which group are you unable to identify? Provide a reason for your answer.

Evaluating

16 Taxa, dichotomous keys and cladograms are all based on the characteristics of organisms. Create a table that compares these three scientific tools.

17 Distinguish between members of Domain Eukarya and members of Domains Bacteria and Archaea by referring to the specific characteristics of each domain.

18 Do you think that the binomial name, common name or both should be used to describe an organism? Justify your response.

19 Humans use classification systems in many aspects of life, not just in biology.

- **a** List two other situations in which classification systems are used.
- **b** Using what you have learned about why biologists classify, explain why classification systems are used in these situations.
- **c** Describe some limitations of classification systems.
- **d** Do you think that these limitations outweigh the usefulness of these systems? Justify your response.

20 'Dinosaurs are not extinct, because many species of birds exist today.' Do you agree with this statement? Justify your response.

Creating

21 Use the information in the character matrix shown below to create a cladogram, marking in which characteristics evolved at each branch.

Table 5.6 Character matrix showing several groups of aquatic vertebrates

	Lamprey (Order Petromizontiformes)	Shark (Class Chondrichthyes)	Lobe-finned fish (Class Sarcopterygii)	Ray-finned fish (Class Actinopterygii)
Jaw	–	+	+	+
Fins attached to body on a fleshy stalk	–	–	+	–
Skeleton made of bone	–	–	+	+

22 Two initiatives to conserve the unique flora and fauna of eastern Australia are the National Wildlife Corridors Plan and the Great Eastern Ranges Initiative. Devise a possible approach to conserving wilderness areas on the eastern coast of Australia.



CHAPTER 6

RELATIONSHIPS BETWEEN ORGANISMS WITHIN AN ECOSYSTEM

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

KEY KNOWLEDGE

Relationships between organisms within an ecosystem

- the beneficial, harmful and benign relationships between species including amensalism, commensalism, mutualism, parasitism and predation
- interdependencies between species as represented by food webs, including impact of changes to keystone species
- the distribution, density and size of a population of a particular species within an ecosystem and impacts of factors including available resources, predation, competition, disease, chance environmental events, births, deaths and migration.

Investigation of an issue

- the 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 biological concepts specific to the investigation: definitions of key terms; use of appropriate biological terminology, conventions and representations
- the use of data representations, models and theories in organising and explaining observed phenomena and biological concepts, and their limitations

KEY SCIENCE SKILLS

Analyse and evaluate data, methods and scientific models

- process quantitative data using appropriate mathematical relationships and units
- organise, present and interpret data using schematic diagrams and flow charts, tables, bar charts, line graphs, ratios, percentages and calculations of mean

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Corbis/Thomas Marent/Minden Pictures

Figure 6.1 ▲
Lemurs like these Coquerel's sifakas are only found in Madagascar.

Madagascar is classified as one of the biological hotspots of the world. It is home to a large proportion of unique wildlife. In fact, 98% of Madagascar's terrestrial mammals, 92% of its reptiles, 68% of its plants and 4% of its birds are found nowhere else. Biological hotspots are considered extremely important to conserve due to the number of native species found in the area. There are 34 international hotspots worldwide, each with its own unique local species. Hotspots are reservoirs of the most diverse, yet most threatened, of the many different species (**biodiversity**) on the planet.

What factors influence the abundance, range and distribution of diverse organisms from one country to the next or even one region to another? What relationships are there within the community of diverse organisms and with the habitat? This chapter will explore how a diverse group of organisms form a living, interconnected community that is suited to, and utilises, the abiotic resources of its habitat.

Ecosystems, environments and habitats

An **ecosystem** is classified as the interactions between the **environment** and its **community**. Specifically, the community is the sum of all the living organisms in a **habitat** and the environment is the **abiotic** and **biotic** components of the ecosystem. This includes temperature, water availability, nutrient availability and other organisms that make up a part of an individual's environment. The other organisms may compete for food against the individual or prey upon it. They may even change the chemical or physical environment. Ecosystems are relatively self-contained and are able to support themselves by cycling or exchanging materials. For example, in a forest, leaves fall and decompose, and their nutrients are returned to the soil. In turn, the plants remove these nutrients from the soil and use them in growth. Note that this is a very simple explanation of how an ecosystem operates. In reality there are many more organisms interacting with each other in a complex web of relationships.

The world's ecosystems are diverse. They contain species that are directly linked to the abiotic and biotic factors within the ecosystem. An ecosystem can contain many different habitats. A habitat is an area or environment within an ecosystem where an individual of a species lives, feeds and reproduces. Habitats are therefore specific for each **population**. A population is a group of individuals belonging to the same species, living in the same habitat at the same time. For example, a rainforest ecosystem has several habitats. The ground level is home to the cassowary, a flightless bird, while the canopy level is home to the striped possum. The habitat for the cassowary is different from that of the striped possum despite them both living in the same ecosystem.

RECALL

- Ecosystems comprise a number of habitats.
- An ecosystem is considered to be the interaction between the living organisms in the community and their environment.
- The environment is the set of biotic and abiotic factors of a particular area.

RECAP 6.1

1 Explain 'biological hotspot'.
2 Distinguish between:
   a population and community
   b environment and habitat
   c biotic and abiotic.

Relationships and interactions between living things

Ecosystems and habitats have many different relationships and interactions occurring within them. These relationships impact upon the biodiversity of a region. Some of these interactions can be harmful and others may be beneficial. For example, imagine what a necklace of **parasites** could do to a carpet python. Or what would happen to a karri forest if the fungus it depends on for survival died?

Every living thing, as well as its environment, is profoundly affected by the presence or absence of other living and non-living things. Organisms of a soil community, for example, are affected by the texture, mineral content and water content of the medium in which they live. However, the properties of the soil, itself are affected by the activities of burrowing worms and decomposers. The burrows of the worms allow air and water to reach into the soil, and the decomposers increase the fertility of the soils by recycling organic material. A wallaby does not exist on its own. It not only interacts with other wallabies but also with the vegetation it eats, the ticks, mites, flies and other parasites that pester it, and the wedge-tailed eagle or dingo that may attack its young.

Understanding the relationships between organisms and their interactions with each other can help us understand how an ecosystem works. Some interactions can be straightforward but others are extremely complex. It is only by experimentation and careful studies of behaviour that scientists can come close to unravelling these relationships.

Competitor or collaborator?

Communities consist of the complex interactions of different populations and the individuals within them. Many are in **competition** with each other as they require the same resources to fulfil their needs for survival. Competition within and between species is a common feature of all communities. For example, seemingly harmless sea anemones compete for the same food source with others of their species. They can detect slight genetic variations in intruders of the same species. Both rivals discharge a battery of stinging cells, normally used to paralyse and catch **prey**. In the end, one will admit defeat and creep away.



Figure 6.2 ▲
Different sea anemone species compete for food sources. The anemone on the left has discharged stinging cells to ward off the anemone on the right. This is an example of an interspecific relationship.

Members of some species solve the problem of catching their prey by collaborating with each other, for example as wolves do in hunting for their prey and dolphins when herding schools of fish. These are examples of **intraspecific** interactions: relationships between members of the same species. On the other hand, the association that wolves or dolphins have with their respective prey is **interspecific**: a relationship between members of different species.

The way in which one organism competes against or works with another organism to obtain their food helps shape the biodiversity of an ecosystem.

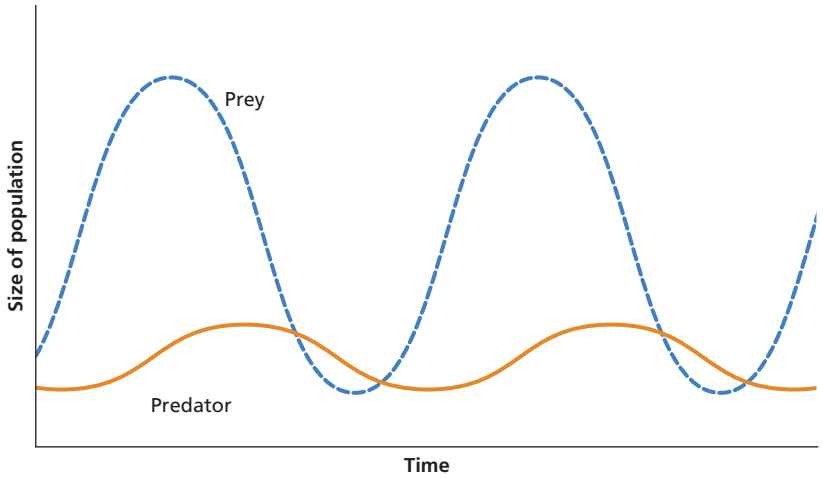
Predator and prey

Food chains are described on page 186.

An obvious interaction within every ecosystem is a predator–prey relationship (Figure 6.3). In this relationship one organism, the **predator**, kills another organism, the prey, or consumes part of it for its food. Although there is usually a preferred prey species, it is unusual for a predator to depend on only one species. It is an advantage for a predator to be a member of a network of **food chains**. If one prey species becomes in short supply, the predator can turn to others.

The dynamic relationship that exists between predator and prey is usually balanced, but sometimes conditions can change and upset this balance. Under favourable conditions, with increasing availability of prey, the number of predators can increase, although it usually still remains less than that of the prey. During a period of adverse conditions, the prey population can decrease. When this occurs, there is increased intraspecific competition in the predator population. Predators turn to alternative prey species and the effect on them can be severe, though it does allow the original prey population to grow again.

Figure 6.3 ▶
The predator–prey relationship



Predation of any sort affects the prey population in an ecosystem. Predation includes animals preying on plants, plants preying on animals, such as the Venus flytrap or pitcher plants, or simply animals preying on other animals. For example, **seed predators** have a large effect on the plant population and their distribution throughout an ecosystem. These animals only feed on the seeds of plants, causing the seeds to become unviable or damaged as they pass through the digestive system of the predator. Another example of the effect of predation on the biodiversity of an ecosystem is the release of nutrients into the soil caused by decomposing animal carcasses left behind by predators, which provides nutrition for micro-organisms in the ecosystem.

The interaction with disease

The interaction between a disease-causing organism and its **host** can affect the biodiversity of an ecosystem. For example, the calicivirus causes a disease that affects rabbits. In Australia, this virus is deliberately used to reduce the rabbit population to allow for native animal populations to increase. In this case, the disease allows the biodiversity of the Australian ecosystem to be higher because without the virus the rabbits become overpopulated and outcompete the native animals for resources. On the other hand, disease can also decrease the biodiversity of an ecosystem. Chlamydia is a disease impacting upon the populations of koalas across Australia. It affects the reproductive tract of the koala, making it unable to produce offspring. This in turn reduces koala numbers, which lowers genetic diversity in particular ecosystems.

RECALL

- Many species are in competition with each other and other species if they require the same resources to fulfil their needs for survival.
- In a predator–prey relationship the predator kills the prey, or consumes part of it for its food.
- The numbers of predators and prey normally fluctuate in a dynamic relationship.
- Disease-causing organisms' relationship with their hosts can reduce biodiversity.

RECAP 6.2

1 Using examples, compare interspecific and intraspecific relationships.
2 Identify and explain the distinctive feature of a predator–prey relationship.
3 Explain how disease affects the biodiversity of a region.

Symbiotic relationships

Symbiosis is the general term used to describe a relationship in which individuals of two or more different species live together and in which at least one of the species benefits or is harmed. There are four main types:

1 **parasitism**: one species benefits at the expense of the other
2 **mutualism**: both species in the relationship benefit and neither is harmed
3 **commensalism**: one species benefits and the other neither benefits nor is harmed
4 **amensalism**: one species is harmed and the other neither benefits nor is harmed.

These relationships help shape the biodiversity of a region.

Parasitism

Most species, including humans, are infected with multiple different parasites. A parasite is an organism (such as a bacterium, virus, fungi, worm or arthropod) that lives on or in another organism, known as the host. The parasites are extraordinarily well adapted, with regards to their life cycle, structure and physiology, to find their host and survive the hazards of being dependent on them. The hosts have **coevolved** strategies for surviving the effects of their unwelcome invaders.

The presence or absence of parasites in an ecosystem is yet another factor that shapes the unique diversity of the region. The ways in which the parasite interacts with the host organism influences the survival of both the host and the parasite. For example, native mistletoe is a parasitic plant that uses eucalypt trees as hosts. The mistletoe plant is transferred from one tree to another by the mistletoe bird, spreading it throughout the eucalypt ecosystem. The mistletoe eventually kills the eucalypt host tree, which also kills the mistletoe attached to that tree, but only after a period of time that allows the mistletoe bird to spread the mistletoe. This means that the survival of the parasite species continues after the host tree has died. The presence of mistletoe can reduce the diversity of the ecosystem by killing numerous varieties of eucalypts.



David M. Watson



Photoshot/NHPA



Alamy/BotanyFocus

Figure 6.4 ▲
The mistletoe plant is spread by mistletoe birds that eat the berries and then defecate the sticky seeds onto branches.

Mutualism

Not all relationships cause harm to a species. There are differing levels of mutualism, from a rather loose association in which the partners seem to gain little from each other to associations that are so intimate that the two partners can be regarded as a single organism. In mutualism, organisms work together and share the same ecosystem and even the same habitat. The relationship between the pistol shrimp and the goby fish is an example of a mutualistic relationship. The shrimp is able to dig a burrow to live in but it is relatively blind and cannot detect approaching predators. The goby fish uses the burrow for protection from predators and, in return, it acts as the 'eyes' for the shrimp. During the day the shrimp maintains continual contact with the goby's tail, which the goby will flick several times if a predator approaches and the two must retreat into the burrow. During the night they rest and share the burrow as partners.

Figure 6.5 ▼
These pygmy possums, while collecting nectar from eucalypt blossom, are also acting as pollinators.



Alamy/Dave Watts

Pollinators are essential for many flowering plants to reproduce. Like grasses, some plants can be pollinated by wind. Flowering plants, however, generally rely on insects, birds, small mammals and even reptiles to transfer pollen from one plant to another. This is another example of mutualism; the pollinator benefits from feeding on the nectar while the plant benefits by being pollinated.

Generalist pollinators pollinate a range of different plant species, while specialists will only pollinate the kind of plant with which they have coevolved. In these partnerships, both members depend on each other so much that if one disappeared, the other would not survive. The plants would be sterile without a pollinator and the pollinator would starve without the plant as its food source.

Seed dispersers are also intrinsic to ecosystem biodiversity. These organisms include mammals and birds that eat fruits and seeds for nutrition. When the animal defecates, it deposits the seeds in a new location where they can germinate and grow. Seed dispersers are distinct from seed predators in that the seeds do not get damaged in the animal's digestive system and therefore remain viable for germination. The symbiotic relationship between the seed disperser and the plant is another example of mutualism because both organisms benefit from the interaction. The cassowary, *Casuarius unappendiculatus*, is a seed disperser that plays a critical role in the Queensland rainforest ecosystem. It feeds on fruits and berries, and can disperse seeds up to a kilometre away from where they were consumed. Studies have shown that the rare rainforest tree, *Ryparosa kurrangii*, found in the Daintree forest, had a better germination rate after it had passed through the gut of the cassowary. The cassowary is one of the only **frugivores** (fruit-eating animals) that can consume the *R. kurrangii's* large fruit and seed. Without this intrinsic relationship, the *R. kurrangii* may struggle to germinate and become even rarer.

If these pivotal relationships become threatened, by hunting or deforestation for example, many species would become threatened or extinct because they cannot survive by themselves. Certain plants would not reproduce without their pollinators and in turn the pollinators would not have a food source. Without seed dispersers, some plants would not germinate and could become extinct. Diverse ecosystems would be lost.

Intimate relationships

The most intimate association is achieved when one organism lives inside the cells or tissues of another. Many coral polyps, jellyfish, clams and sea slugs have algae living in their tissues. The algae need nitrates and phosphates for their metabolism. These are made available in the waste material of their animal partner. The animal partner is careful to ensure that its algae are always adequately exposed to light, because they benefit from the organic compounds produced by algal photosynthesis.

Some sea slugs from the Great Barrier Reef actually stimulate colonies of algae to reproduce. The sea slugs grow out tentacles along their sides and the algae become squatters. The sea slugs come to rely entirely on the food produced by the algal colonies. However, this does not explain how the algae entered the sea slugs in the first place. The algae were present in the coral the slugs fed on, and they passed from the slug's gut into their tentacles.

Commensalism

Commensalism is a one-sided interaction between species. Only one of the two organisms involved, the commensal, benefits from the interaction. The other organism in this case does not benefit, but it is not harmed. Some relationships are easy to identify as commensal, such as the relationship between the remora fish and the shark. The remora gets a free ride, and possibly free leftovers, by attaching the suction pad it has on the back of its head to the shark. The shark is otherwise unaffected.



Alamy/Gallo Images

▼ **Figure 6.6** The commensal relationship between the cattle egret and the zebra

Another example of a commensal relationship occurs between the cattle egret and livestock. This migratory bird is particularly widespread across the world, originating from Africa, Europe and Asia. The cattle egret is generally found foraging for food next to large livestock. The livestock disturb insects in the grass that the egret then feeds upon. The egret will also sit on the back of the beast to have a better vantage point to spot insects (Figure 6.6). The egret has a much higher foraging success rate when feeding near livestock. In this relationship, the bird is the commensal and the livestock are undisturbed and unharmed by the bird feeding near them.

Epiphytes are climbing plants, such as lianas, which use trees to support them as they reach for light. Their seeds germinate on the forest floor and the rapidly growing shoots spread out. If they reach a vertical surface, they take hold of it. Other seeds, such as those of orchids, are carried high up to the branches and take hold there. In both of these instances, the tree provides support without apparently gaining anything in return and without being harmed in any way.

Figure 6.7 ▼
Examples of amensalism. (**a**) The tall tree gains no benefit and the smaller ground plants are harmed. (**b**) *Penicillium* mould does not benefit from the death of surrounding bacteria.



iStock.com/mtreasure



Alamy/dpa picture alliance

Amensalism

Some relationships are not beneficial to either of two species. Amensalism is the relationship where one of the species is inhibited or harmed and the other species is neither harmed nor benefitted. In other words, it is an association which is detrimental to one species and neutral to the other.

Amensalism is a type of competition. In competition, a larger or more powerful organism excludes another organism from its requirements such as a source of shelter or food.

A simple example is the shading out of certain plants under tall trees. The tall trees reduce the available sunshine at ground level, and ground plants such as grasses do not have adequate light to grow in the shade.

'Amensalism' also describes a situation where one organism secretes a chemical that kills another organism, while the one that secreted the chemical is unharmed.

At some point in your life you may have been alerted by a mouldy smell to a sandwich you had forgotten about in the bottom of your bag. Different types of bacteria and fungi could be growing on the sandwich. One of the bread moulds could be *Penicillium*. This mould is capable of producing penicillin, which destroys many types of bacteria that could also grow on the sandwich. The *Penicillium* does not benefit from the death of the other bacteria, making this an example of amensalism.

RECALL

- Symbiotic relationships and interactions include parasitism, mutualism, commensalism and amensalism.
- Different types of relationships between organisms can be summarised in the following table. Types of relationships are described by the effect they have on each partner. '0' is no effect, '−' is detrimental and '+' is beneficial.

Species A	Species B	Type of relationship
+	−	Predation
+	−	Parasitism
+	+	Mutualism
+	0	Commensalism
0	−	Amensalism

RECAP 6.3

1 Define the following terms.
   - a Symbiosis
   - b Predation
   - c Parasitism
   - d Mutualism
   - e Commensalism

2 Using an example, outline why it is essential to have pollinators and seed dispersers in an ecosystem.

3 Explain why amensalism is an example of symbiosis.

Modelling the ecosystem: Interdependencies between species

Scientists study the interactions of complex systems to find out how they are sustained and to predict how they are changed if disruptions occur. A system is a set of interacting components that together form a complex network. A model is an artificial and simplified representation of the system that allows ecologists to understand how changes to individual components of the system will affect other components of the system.

Ecological systems are very complex and include a large number of biotic and abiotic factors. Simplifying the system in a model limits the number of components to those considered relevant or of critical importance to the system. There are many different types of experimental models; however, the aim is to attempt to mimic the real-world situation as closely as possible. This allows scientists to make reliable predictions about the real system if adverse changes were to occur. This predictive power means that ecologists can intervene in a timely manner to prevent an ecological problem leading to catastrophe, such as an animal becoming extinct through loss of habitat or food.

Food chains

Food chains and food webs are examples of qualitative and predictive models that allow ecologists to monitor the sustainability of an ecosystem by investigating feeding relationships. Each link in the chain is referred to as a **trophic level** ('trophic' = feeding). Each organism in the chain feeds on, and therefore obtains its energy and matter from, the preceding one. At the bottom of the food chain are the producers, which are autotrophic species that generate organic matter from chemical matter predominantly through photosynthesis. Above the producers in the food chain are the **consumers**, heterotrophs that ingest their organic matter by consuming other organisms. One consumer is consumed by the next organism in the chain, so energy and matter are transferred progressively from one trophic level to the next.

Animals that feed directly on producers are **herbivores** or **first-order consumers**. **Carnivores** that depend directly on herbivores are second-order (or secondary) consumers, and so on. The **top consumers** are not preyed upon and, like most humans, die of old age, disease or injury. Some organisms are both herbivores and carnivores, and are called **omnivores**. Animals that feed on the dead remains of other animals are **scavengers**. Figure 6.8 shows how a generalised food chain and an ocean food chain can be constructed. Note that larger animals such as sharks, usually higher up in the food chain, must eat large quantities of food to meet their energy requirements.

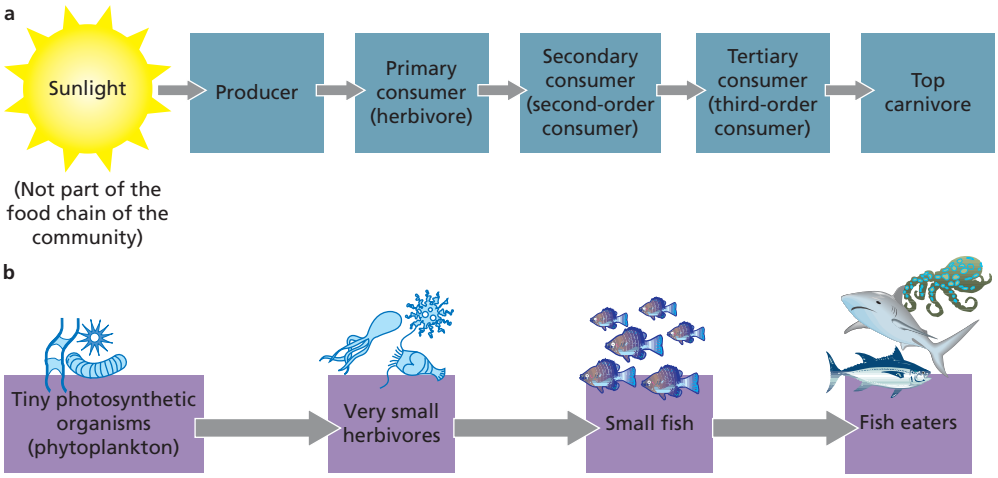


Figure 6.8 ▶
(**a**) A generalised food chain; (**b**) A food chain in the ocean

Energy is lost in food chains

Food chains in an ecosystem depend upon the Sun as a continuous source of energy. A food chain can be thought of as an energy chain. At each trophic level or link in the chain, a proportion of the available energy is lost due to inefficiencies during transfer and the remaining energy is transferred to the next level. Some energy is lost from the chain as heat energy released in cellular respiration, and some is lost as chemical energy in organic wastes of dead plant and animal tissues, collectively called **detritus**.

This loss of energy means that from one link to the next along the chain, progressively less energy is available for successive levels. The percentage of the energy at one trophic level that ends up in the next trophic level is referred to as **trophic efficiency**.

Food chain models often have discrepancies between what is predicted from the model and what is actually observed in the field. Accounting for such discrepancies increases how accurately the model food chain describes the real situation in nature. For example, the oceans are home to our great producers. Some of the highest trophic efficiencies are found there. The trophic efficiencies of **zooplankton** feeding on **phytoplankton** can be more than 40%. So it is important to monitor what is happening to populations of these and other organisms that form the links in the food chains.

A useful general rule in ecology is that about 10% of the energy at one trophic level is passed on to the next level. The remaining 90% is lost to the surroundings as heat energy and chemical energy in wastes.

Table 6.1 A who's who of consumers in ecosystems

Type of consumer	Description of role	Examples	
Primary consumers (herbivores)	Feed directly on producers	Wombat, kangaroo, sheep, many insects, honeyeater, some whales	 Shutterstock.com/Mike Charles
Secondary consumers (carnivores)	Feed on primary consumers	Dingo, kookaburra, fur seals, platypus	 Shutterstock.com/Johan Larson
Top consumers	Feed on secondary consumers	Australian wedge-tailed eagle, shark	 Shutterstock.com/ Stubblefield Photography
Omnivores	Feed on both plants and animals	Foxes, humans	 Shutterstock.com/Tom Wang
Scavengers	Feed on dead organisms	Foxes, crows	 Shutterstock.com/Czesznak Zsolt
Detritivores	Feed on dead or decaying organic remains and wastes	Dung beetles, earthworms, yabbies	 Shutterstock.com/john michael evan potter
Decomposers	Decompose (break down) complex molecules of the organic material in or on which they live	Fungi, some bacteria	 Shutterstock.com/Steve Bower

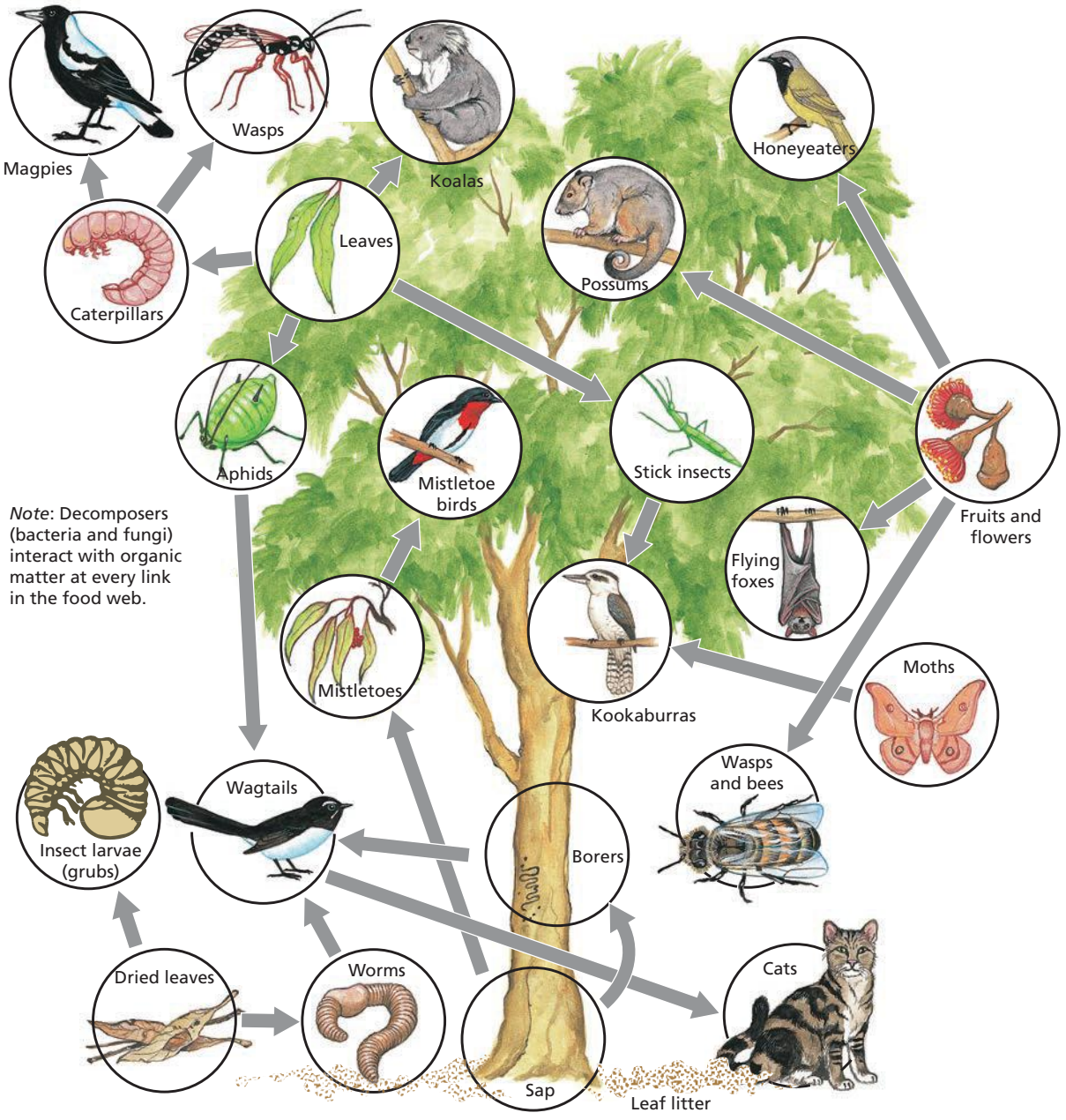
Food webs are integrated food chains

We have seen that energy and matter are transferred along a food chain and energy is lost along the way. What happens when the food runs out? Simple food chains are rare. Most species depend on more than one kind of organism for their food. Ecologists recognise that a herbivore as a primary consumer will feed on a number of species of plants and, in turn, will be eaten by several different kinds of carnivores. These secondary consumers are eaten, in turn, by other carnivores. Such networks of energy and matter form a food web. The feature that distinguishes a food chain from a food web is that an organism in one food chain can occupy a different trophic level from one that it occupies in another food chain. It can be a second-order consumer or a third-order consumer (Figure 6.9).

In other words, food webs are dynamic interactions between organisms in an ecosystem.

Omnivore consumers, including humans, can occupy more than one trophic level in the food chain. As primary consumers, humans can obtain more of the available energy from plants directly without losses that occur by eating foods higher up the food chain.

Figure 6.9 ▼
A food web in a forest ecosystem



Consumption of livestock means that humans can only benefit from 1% of the total available energy from producers. If it is more energy efficient for omnivores to eat plants, why is it necessary for them to consume meats and animal products?

Members of populations of different species move in and out of different ecosystems, so an organism may be part of one food chain or web at one time but not at another time. For example, insects, birds and seeds commonly move between ecosystems wherever their needs are met. On a larger scale, migration of whole populations of animals such as albatross, mutton-birds, salmon or moths results in great changes to the pathways of energy and matter. Phytoplankton is a producer and a fundamental food source for marine animals. Phytoplankton can be carried great distances in ocean currents. Organisms in the next trophic level, such as whales, migrate along with this food source.

Models can be used to predict the impact of changes

Models are often used to better understand how ecosystems function and change. The development of models that describe interactions between components of ecosystems has advanced rapidly over the last few decades. Ecosystem models are useful representations of components within the ecosystem, the relationship between the components and the relationship with surrounding ecosystems.

Ecosystem models are very useful for simulating and analysing the long-term dynamics and properties of complex ecosystems. They allow the use of information from different disciplines as well as the analysis, interpretation and understanding of field observations. This provides a basis for predictions of the impacts of changes in real ecosystems, the development of tools for management support and policy advice.

Models, such as those demonstrating ecosystem interactions, are built using data gathered from studying the ecosystem. The most accurate and comprehensive data set would entail examining every part of the ecosystem, such as in a census collection. However, this is highly impractical for most ecosystems. A more practical approach is to examine parts of the ecosystem through random sampling. Simple random selection ensures that the sample is representative if all members of the population have an equal chance of being selected. The reliability of the model is determined by how well the sample represents the ecosystem overall.

Food chain and food web models can be used to predict how changes in the numbers of one species at a trophic level affect other species in the ecosystem. If populations of lower-order consumers are reduced, the small population of top consumers is at risk of being adversely affected or even wiped out. For example, the population of eagles in an ecosystem is much smaller than the populations of rabbits and small native animals on which they feed. Reduction in numbers of these populations would have a significant impact on the eagle's ability to meet its energy requirements.

RECALL

- Scientists represent the types of relationships that occur within communities and the ecosystem by constructing simplified models such as food chains and food webs.
- Energy from producers can support whole communities of different animals. The size of the food chain is limited by how efficiently energy is transferred to each trophic level.
- The 10% rule in ecology states that only about 10% of the energy at one trophic level is passed on to the next level. The remaining 90% is lost to the surroundings as heat energy and chemical energy in wastes.
- Food chains interconnect to form food webs.
- An organism can occupy one trophic level in one food chain and a different trophic level in another.

RECAP 6.4

1 Distinguish between:
   - a food chain and food web
   - b herbivore and carnivore
   - c second-order consumer and third-order consumer.

2 Describe the relationship between a food chain and trophic levels.

3 Describe how models can be used to predict changes in an ecosystem.

4 Match the terms on the left with the definitions on the right.

a producers	i herbivores, carnivores, omnivores
b consumers	ii break down organic remains and products
c decomposers	iii photosynthetic autotrophs that support the entire food web

ACTIVITY 6.1

COMMUNITY INTERRELATIONSHIPS

In a small chamber of a cave in north-eastern New South Wales there is a heap of bat dung. This material (called guano) has been built up over many thousands of years by the seasonal visits of a single species of bent-winged bat (*Miniopterus schreibersii*). Each year from October to June, between 1000 and 3000 of these insectivorous bats roost in the chamber. From their roost on the roof of the chamber the bats drop faeces and urine to form a heap on the floor. The resulting mass of guano supports a permanent natural community of organisms – a guano community.

An ecologist, John Harris, collected samples of the bat guano at regular intervals over a period of four years. From these samples he extracted 13 species of arthropods (insects). The major organisms in the community were the guano mite (*Uroobovella coprophila*) and the guano fly (*Cypselosoma australis*).

From December until June, Harris observed the organisms and recorded notes on their feeding habits (Table 6.2).

Aim

To explore the relationships that exist between the organisms found in the cave by organising primary data into food webs.

Procedure

Part A: Feeding relationships from December to June

The feeding relationships found in the guano community from December to June can be represented as a food web.

Using the information in Table 6.2, pencil in arrows on a copy of Figure 6.10 to represent the food web of relationship between guano organisms. The direction of each arrow should indicate the direction in which the energy flows.

Table 6.2 Observations of cave organisms (December to June)

	Organism	Observations
1	Bent-winged bat (*Miniopterus schreibersii*)	In October–June roost during the day on the ceiling of the cave chamber, at night leave the cave and feed on moths in the tall open forest nearby. In December and January roost only intermittently in the chamber.
2	Fungi (filamentous forms and yeasts)	Found in and on the freshest part of the guano pile, some of which is broken down and absorbed.
3	Bacteria	Similar to fungi.
4	Protozoans, inc. flagellates	Feed on bacteria.
5	Nematodes	Feed on protozoa and bacteria.

	Organism	Observations
6	Mite 1 (*Histiostoma* sp.)	Feed on the bacteria close to the surface of the pile.
7	Predatory mites (*Hypoaspis* sp. and *Proctolaelaps* sp.)	Feed on the larval and nymph (immature) stages of the guano mite and on the Uropedid mites both close to the surface and inside the guano pile.
8	Guano mite (*Uroobovella* sp.)	Live on the surface of the pile where they feed on fungus. Mate and moult below the surface.
9	Mite 2 (Family Uropodidae)	Source of food is the same as for guano mite.
10	Guano fly (*Cypselosoma* sp.)	Feed on bacterial colonies.
11	Case moth (*Monopis* sp.)	Larvae feed on fungi found low down on the drier parts of the pile.
12	Spiders (*Achaearanea* sp. and *Pholcus* sp.)	Feed on the guano fly adults, case moths and hysterid beetles; are found on both the heap surface and the chamber walls.
13	Hysterid beetle (*Grathoncus* sp.)	Feed on fungi.
14	Beetle 1 (*Atomeria* sp.)	Adult and larval stages feed on guano fly larva.
15	Japanese rove beetle (*Philonthus* sp.)	Adult feeds on guano fly pupa.
16	Beetle 2 (*Sarothrias* sp.)	Feed on fungi.

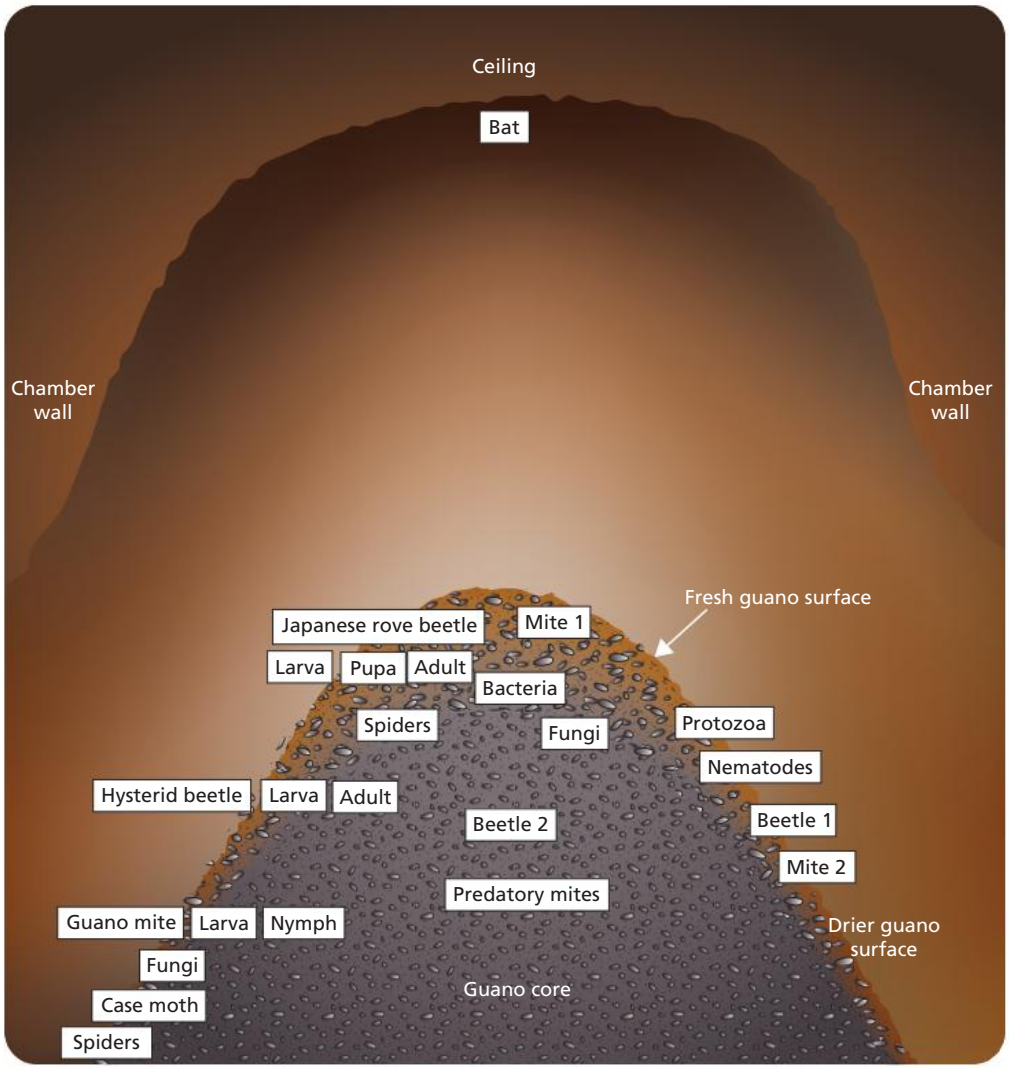


Figure 6.10
Relationships between guano organisms

What did you discover?

1. Does the cave community contain any producer organisms? If so, name them. If not, name the species that is the source of matter and energy on which the rest of the guano community depends.
2. Identify the original source of energy for this community. Explain your answer.
3. Name the organisms that are consumers in this community.
4. Name the consumers that bring about decomposition in the system.
5. Name the highest-order consumers.

Part B: Feeding relationships from July to September

From July to September, the bats were absent from the caves and so no fresh guano was being added to the heap. Harris made the following observations.

- Far fewer individuals of all species were present at this time.
- Bacteria and fungi were found almost exclusively in the form of resistant spores.
- Large larvae of hysterid beetles and several species of mite were found at depths of 25 cm.
- Both the nymph and adult stages of the guano mite became inactive.
- Japanese rove beetles disappeared from the heap and presumably migrated to another part of the cave.
- The number of guano flies dropped dramatically. There were very few larvae and only a few adults. The two species of spider were inactive during this period.

Construct a food web depicting the relationships between the organisms of the guano heap during August.

What did you discover?

1. Describe how the changes in the cave during July to September affect the food web as you described it earlier for the periods between December and June.

Part C: Feeding relationships from October to November

The arrival of the bats in the chamber in October and the deposition of their faeces and urine on the guano heap leads to a spectacular change in the activity of the community.

- Microorganisms (bacterial protozoa and fungi) immediately become active, as do the nematodes soon after.
- Previously inactive mites (*Histiostoma* sp) become active and feed as before.
- Nymphs of the guano mite grow rapidly and moult. Previously inactive adult females begin laying eggs.
- Mature larvae of the hysterid beetle pupate and the new adults emerge and make their way to the surface from 30 cm down inside the heap.
- The density of mites builds up quickly with the hatching of larvae and the emergence of adults, which begin to breed.
- The temperature of the heap rises and a few adult guano flies lay eggs in the fresh guano.
- The guano fly population takes longer to increase because of its initially low numbers. The fly larvae feed directly on the fresh guano.

Construct a food web depicting the relationships between the organisms of the guano heap during October to November.

Discussion

1. Using the information, identify the organisms in the cave that occur in large numbers very soon after the return of the bats.
2. Compare the December to June food web with that for October to November. Identify which organisms (if any) are found in one food web and not the other. Account for this.
3. On looking at this cave community, Harris remarked: 'The bats are to the guano community what the trees are to a woodland'. Briefly explain the analogy.

Coexistence: The power of a keystone species

In some cases predation can affect the **coexistence** of a number of other species. The purple sea star, *Pisaster ochraceus*, is a natural predator of mussels in the intertidal zones of Pacific Ocean seashores. When researcher Robert Paine removed purple sea stars from this environment, it resulted in the expansion of the population of resident mussels. The mussels displaced the other sessile organisms, such as barnacles and limpets, as they spread. The diversity of species in the area decreased from 15–20 invertebrates and algae to below five over the period of three years. When the sea stars were returned, the mussels were again preyed upon and the barnacles, limpets and other species were able to re-occupy the space. The predator, *P. ochraceus*, allowed the coexistence of other species with the same requirements for food and space.

The purple sea star species is known as a **keystone species**. These species are seen to have a large influence over lower trophic levels. A keystone species prevents any one of the organisms in the lower trophic levels from monopolising food resources and space. Instead, they allow for richer biodiversity within a restricted area.

The idea of a keystone species was developed by Robert Paine based on his removal experiments in the intertidal areas of western North America. Since this initial study, many scientist have collected data to help support Paine's theory. Many ecologists believe that keystone species should be specific recipients of the efforts to amplify biodiversity. Over time, policy recommendations have been made in the bid for biodiversity conservation. Conservation of a single keystone species should be the central point for the management strategies of an entire community. Scientists have also put forward arguments that keystone species are essential in the re-establishment of ecological structure and sustainability. However, it is the opinion of some that the definition of a keystone species is not yet refined enough to form the basis of conservation efforts. They also speculate that this process could be detrimental to species that are not considered key to species richness, yet are indicators of habitat health.



Alamy/William Ragosta

◀ **Figure 6.11**
Pisaster ochraceus, the purple sea star

RECALL

- A keystone species is a species of relatively low abundance in a higher trophic level that allows the coexistence of a number of lower trophic level organisms in a particular area.
- Biodiversity can be affected in a negative way if a keystone species is removed.

RECAP 6.5

1 Define:
   a coexistence
   b keystone species.

2 Explain how a keystone species increases an ecosystem's biodiversity.



Corbis/Paul Hobson/Design Pics

Figure 6.12 ▲
The grey-headed flying fox, *Pteropus poliocephalus*

Population dynamics

In 1981, grey-headed flying foxes (*Pteropus poliocephalus*) established a permanent colony at Melbourne's Royal Botanic Gardens. Up until that time, the population had been seasonal with very few individuals present during the cooler months. The population then exploded over the next 20 years, reaching a total of 30 000 individuals in the summer of 2001. Though the population size continued to vary seasonally, a very large population was in permanent residence at the site. The size of any such colony is dependent on available food and roosting sites. The flying foxes' diet of nectar, pollen and fruit, specifically from eucalypts, banksias and melaleucas, also included occasional rainforest fruit and flowers. All these were readily available within or near the Botanic Gardens. This established population grew until it could not be sustained within the confines of the Botanic Gardens. Why did these individuals immigrate to the Melbourne site? Why do populations change?

What is a population?

Ecologists describe the total number of a particular species in a particular place at a particular time as the population. Examples are the number of manna gums (*Eucalyptus viminalis*) in a heathland community, the number of straw-necked ibises (*Threskiornis spinicollis*) in a wetland in a particular month, or even the number of possums in an urban area. Populations in an ecosystem are dynamic. Maybe you have noticed changes in the number and kind of plants or insects in your neighbourhood from one season to another or from year to year.

Size of populations

The black swan (*Cygnus atratus*) is a nomadic species of waterbird native to the waterways of Australia, including fresh water, brackish (briny) water and sea water. In times of plentiful rain, adult swans will migrate to areas that have received the heaviest rain and will reproduce there. These areas often have a small resident population, which will quickly increase in number due to migration. When the environmental conditions return to their previous levels, most of the swans will emigrate, leading to a decrease in the local population size to a level that the environment can support at that time.

This is an example of an open ecosystem, where migration between populations of animals (and occasionally plants) can occur. This migration will affect overall numbers in the ecosystems involved, their distribution and, in the longer term, birth and death rates.

In the Queensland rainforests, located between Townsville and Cooktown, a small number of bird species exist that are not found in any other areas. All of their survival and reproductive needs must be met within this rainforest habitat. The Victoria's riflebird (*Ptiloris victoriae*) is one such species. The population is in decline as its growth rate depends only on birth and death rates. There is no migration as other members of the species will not move into an area where their species is under threat. The decline is also a reflection of habitat loss and hunting pressures. However, the species is abundant throughout its range. This is an example of a closed ecosystem, where migration does not impact on population size. A population therefore increases if the birth rate and/or immigration rate exceeds the death rate and/or emigration rate. 'Rate' refers to the number of individuals migrating, born or dying per hundred, per thousand or whatever unit is appropriate.

Conversely, a population decreases when the death and emigration rates exceed birth and immigration rates. The decline in the numbers of the common sparrow in Indian urban settings is one such example. As the wetland habitat of these birds is reduced due to increased urbanisation, emigration may occur in the first instance, but at their destination the maximum population size that can be supported, called the **carrying capacity**, is reached and therefore the birds just die. The reduction in abiotic and biotic factors in its habitat impacts on many aspects of the sparrow's needs, including availability of nesting sites, food, water and shelter, which together lead to a reduced birth rate. Interestingly, the sparrow is also an indicator of urban ecosystem health. Urban ecosystems are defined as ecosystems of towns and cities – essentially those constructed by humans. They can impact on the surrounding ecosystems of the natural world both positively and negatively. After initial establishment issues, some species of wildlife have been able to adapt and thrive in these environments. How well they integrate into the setting helps determine the general health and growth of this human-made ecosystem. Therefore, the decrease in sparrow numbers does not bode well for the future of this specific ecosystem.

Population growth rate
= (birth rate + immigration rate) − (death rate + emigration rate)
= (br + ir) − (dr + er)



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▲ **Figure 6.13**
The house sparrow at a bird feeder

WORKED EXAMPLE 6.1

Calculate the growth rate of a population of 1000 individuals, where, every year, 100 individuals are born, 65 individuals immigrate into the population, 37 individuals die and 25 individuals emigrate to another population. (4 marks)

Answer

growth rate = $(br + ir) - (dr + er)$

growth rate = (100 per 1000 + 65 per 1000) − (37 per 1000 + 25 per 1000)

= 103 per 1000

Therefore, the population has grown by 103 individuals per 1000. Growth rates can also be expressed as a percentage: +10.3% if there is an increase or −10.3% if there is a decrease.

Logic

State formula	1 mark
Substitute	2 marks
Calculate answer	1 mark

Try these yourself

1 Calculate the growth rate of a population if, for every 1000 individuals, there are 59 born, 105 immigrants, 86 deaths and 40 emigrants. (4 marks)

2 Calculate the growth rate of a population if for every 1000 individuals there are 150 born, 59 immigrants, 29 deaths and 30 emigrants. (4 marks)

Determining growth

Information that is provided by population studies is useful for monitoring ecosystems. Knowing the age structure of a population is important in predicting future growth trends.

A population with individuals predominantly below reproductive age will limit the ability of that species to reproduce and maintain its numbers in challenging situations, as well as in favourable conditions. Similarly, populations with individuals too old to reproduce will impact on the rate of replacement following death or emigration. A useful method of representing collected data is the construction of **population pyramids**. Figure 6.14 shows population pyramids for two different human populations. You can see that the pyramid for population A is wider at the bottom, indicating a healthy future reproduction rate because the number of children is quite high. Population A has a greater proportion of children than does population B. What is the significance of this?

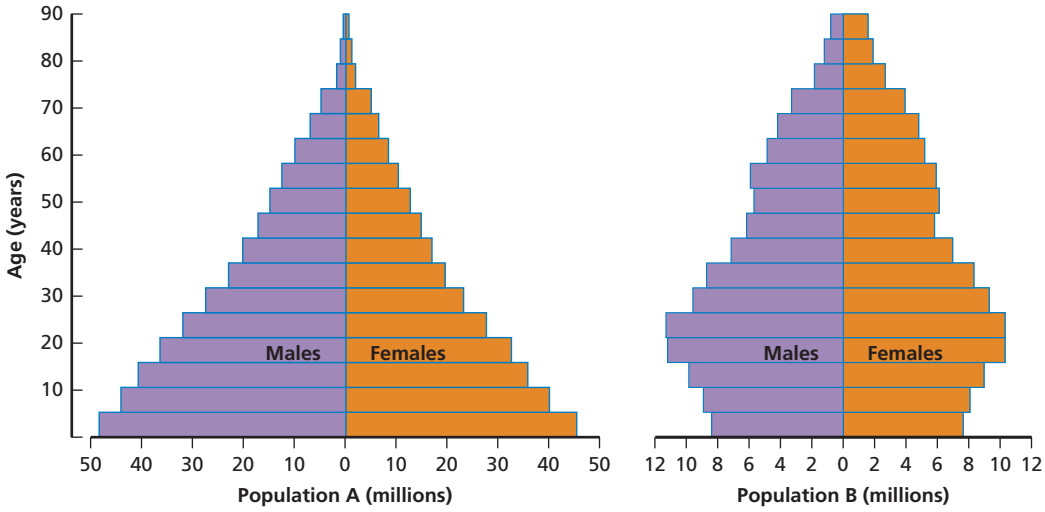


Figure 6.14 ▶
Population pyramids

Scientific data about age distribution and sex ratios can assist in the management of populations. When referring to human populations, this data is called demographics, but it is also important information for understanding the population structures of other species. Each year, federal, state and local governments collect and collate information on the state of wild fish stocks. This information is used to determine the sustainable level of both recreational and commercial fishing. Sustainable fishing ensures that overfishing does not drain the stocks, and that young (smaller) fish are able to contribute to the populations in the future. This information can be used to plan how to ensure sufficient numbers of young live to reach reproductive age, how to develop strategies for protecting endangered species and maintaining ecosystems, and how to restore degraded ones.

RECALL

- Population size is determined by the increases resulting from birth and immigration rates, and decreases resulting from death and emigration rates.
  Population growth rate = (birth rate + immigration rate) − (death rate + emigration rate).
- Carrying capacity indicates the maximum population that can be supported in an environment, and is determined by biotic and abiotic factors.
- Population pyramids represent age structure data.

RECAP 6.6

1 Define 'population'.
2 Ecosystems can be open or closed to particular species. Explain the effect this has on the growth of a population.
3 A particular population of kangaroos has 1000 births during the year; 72 individuals also join the population while 108 leave. There are 345 deaths. Work out the growth rate for this population of kangaroos for the year.
4 Describe one use of a population pyramid.

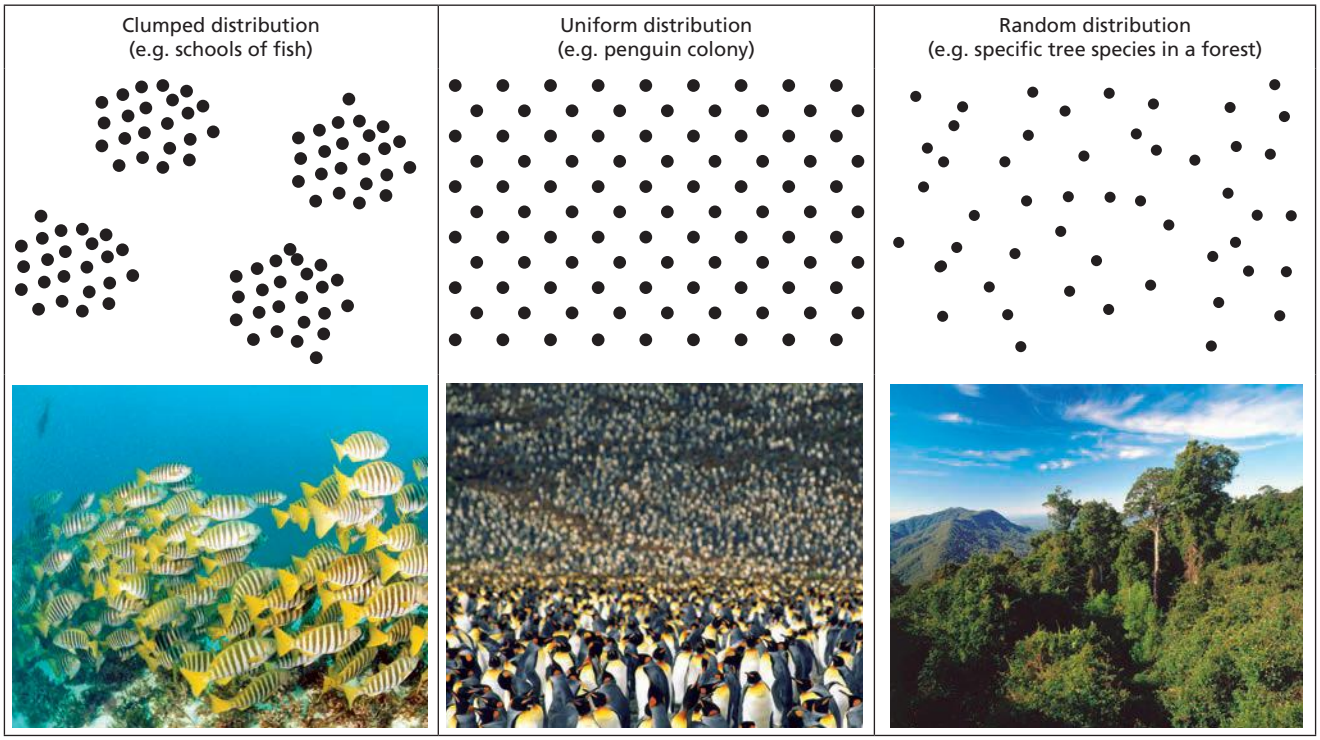
Distribution of populations

Understanding how populations operate takes more than knowing what kinds of species are a part of the system or how they relate to each other. It is also important to know their distribution: exactly where in the physical space members of the different species are found.

Members of a population are seldom spread evenly throughout the entire ecosystem. There are patterns in the way populations are distributed (Figure 6.15, page 198).

- **Random distribution**: organisms are spaced irregularly; the location of an organism does not affect the location of another (more common for plants than for animals).
- **Uniform (continuous) distribution**: organisms are evenly spaced; the presence of one organism determines how close or distant another will be. It is common in relatively high-density populations of some animals that set up breeding territories.
- **Clumped (grouped) distribution**: a number of individuals are grouped together and the groups make up the population as a whole. This can be social behaviour as in schools of fish, or clumping of vegetation in mini-habitats where biotic and/or abiotic factors are favourable.

Knowing the distribution and **abundance** (how many) of a species can help keep track of populations of significance. Knowledge of particular plant species can give clues about the distribution and abundance of animals that depend on them. The forestry industry needs to know about the distribution and abundance of valuable tree species, and the fishing industry needs to know about fish stocks. Keeping track of pest and plague species, such as mice and locusts, gives forewarning of potential outbreaks that would require management.



Getty Images/OSF/Mike Hill; Getty Images/Lonely Planet/Richard I'Anson

Figure 6.15 ▲
Distribution patterns: clumped, uniform and random

Population density

Studying the density of populations in an ecosystem is useful in certain situations. Density refers to the number of individuals in a given area, such as the number of kangaroos per hectare. Sometimes it is difficult to distinguish individual plants, as with grass. In that case, density can be measured as the amount of biomass (dry) per unit area (for example, 0.6 kg of grass per m^2). In the case of diatoms in a pond, density is the number per unit volume (for example, 300 per mL).

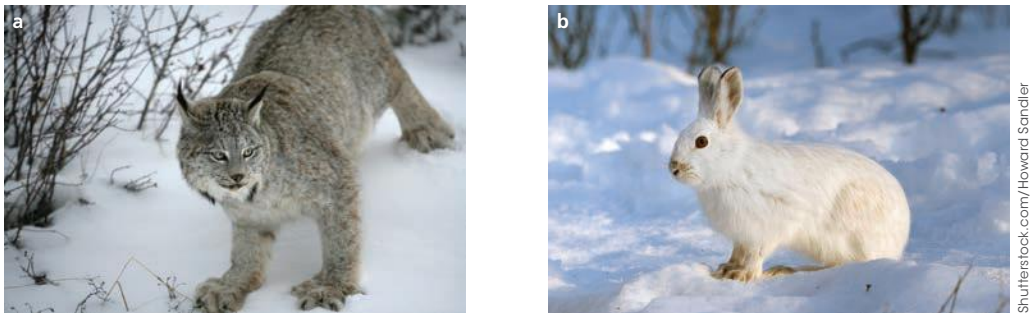
Knowing the density of populations can help ecologists assess an ecosystem's ability to provide sufficient resources to support its populations. This is the carrying capacity of the ecosystem and it can change from time to time as environmental conditions change.

For example, it has been estimated that 100 km^2 of moist tall eucalypt forest is the minimum area possible to support 10 000 sugar gliders as a viable population. Information such as this acts as a guide to the minimum size a park or any closed ecosystem needs to be to conserve animals. Critically, the area needs to be sufficient for a significant number of top carnivores to survive. While this may be a less important consideration for Australian ecosystems where there are few large carnivores, it is still a valid point when considering how much continuous land must remain undisturbed.

Factors impacting populations

When a few members of a species colonise a new and favourable habitat, its population can increase rapidly. However, this rate of population growth cannot be sustained; resources are used and the population begins to level off as the carrying capacity is reached. Despite minor fluctuations in populations, there tends to be upper and lower limits. For a given species in a particular habitat, there is a certain equilibrium population that the ecosystem can support.

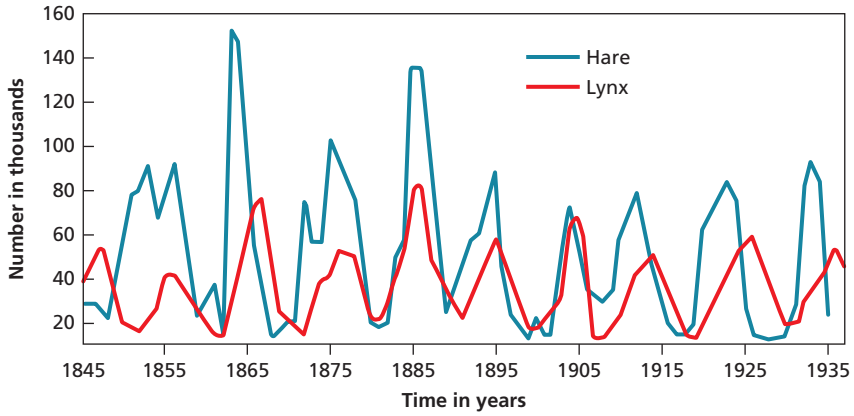
The population numbers of the Canada lynx and the snowshoe hare of northern Canada each depend on the population sizes of the other species. Every 8–10 years the number of hares increases exponentially. The lynx hunts the hare and because there are so many hares, the lynx population also increases. This then puts pressure on the hare population and a slump in numbers follows. This then impacts on the lynx population, even though the lynx is able to hunt and feed on other small animals such as squirrels,



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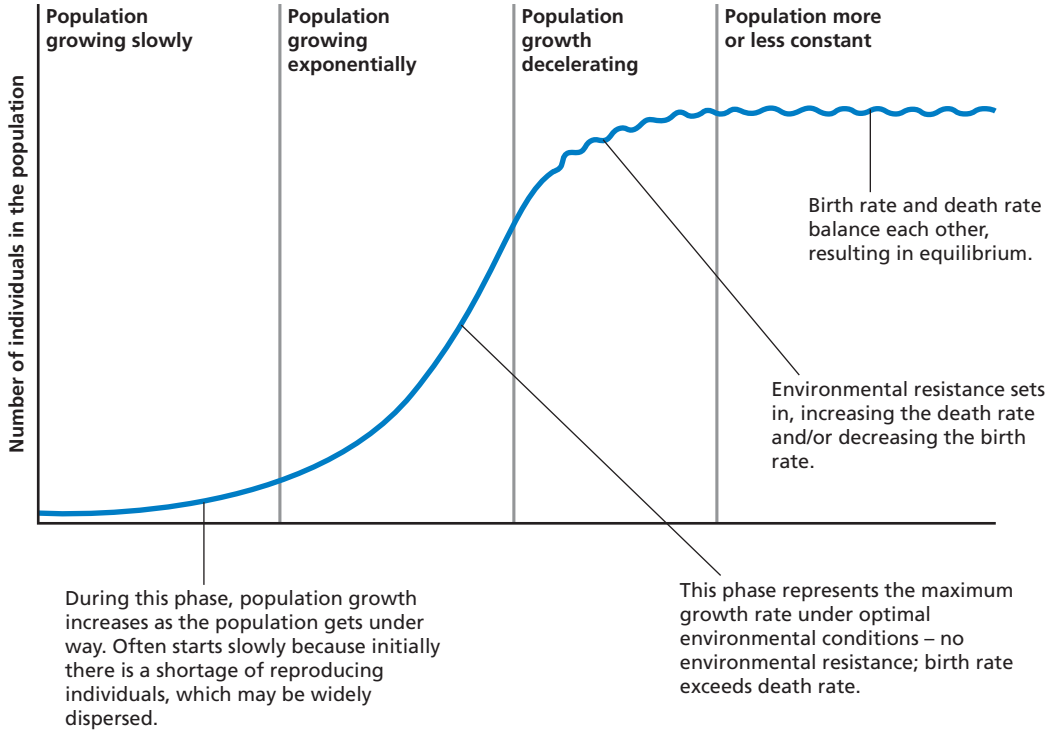
◀ Figure 6.16
(**a**) A Canada lynx; (**b**) A snowshoe hare. Their population increases and decreases are cyclic.



◀ Figure 6.17
Changes in the abundance of the lynx and the snowshoe hare as indicated by the number of pelts received by the Hudson's Bay Company. This is a classic case of oscillation in population density.

grouse and white-tailed deer. For the lynx, the reduction in this important prey source takes its toll and its numbers decrease.

Factors in the environment act on a population in a manner similar to homeostasis. If the population rises above the equilibrium or set point, competition for resources such as food and space begins to take effect. The increased ability of disease-causing organisms and parasites to spread also increases deaths and possibly reduces breeding. This could be to such an extent that the population falls. If it falls below the set point, there is less competition and the population begins to rise again. This kind of negative feedback process, or homeostatic control, keeps the population more or less constant (Figure 6.18).



◀ Figure 6.18
The S-curve: Generalised graph of population growth

The factors mentioned above are **density-dependent factors**. The greater the density of a population, the more individuals die or fail to reproduce. **Density-independent factors**, such as severe weather conditions, volcanic activity or habitat destruction by clearing or fire, are those that affect all individuals in a population regardless of age or stage. These factors are seen vividly following a catastrophic event such as a bushfire or flooding. Populations of all living things usually decrease quite drastically due to either death or emigration to a habitat that is better able to meet their needs and therefore has a greater carrying capacity. Many human communities were devastated by the floods of Brisbane and south-east Queensland from December 2010 to January 2011. Floods and fires, however, are part of nature's cycle and even

Figure 6.19 ▶
Homeostatic mechanism of population control

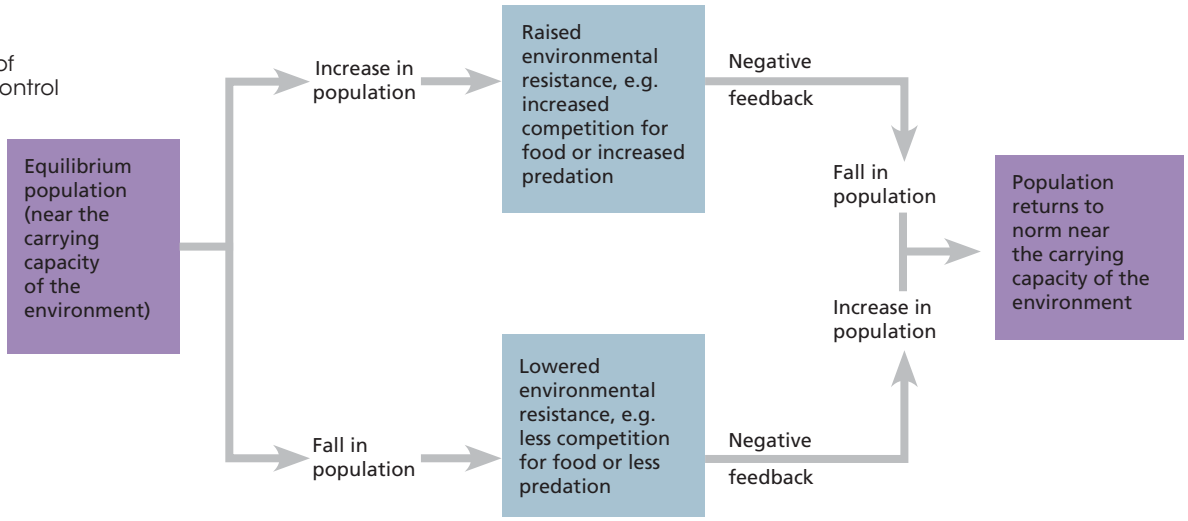
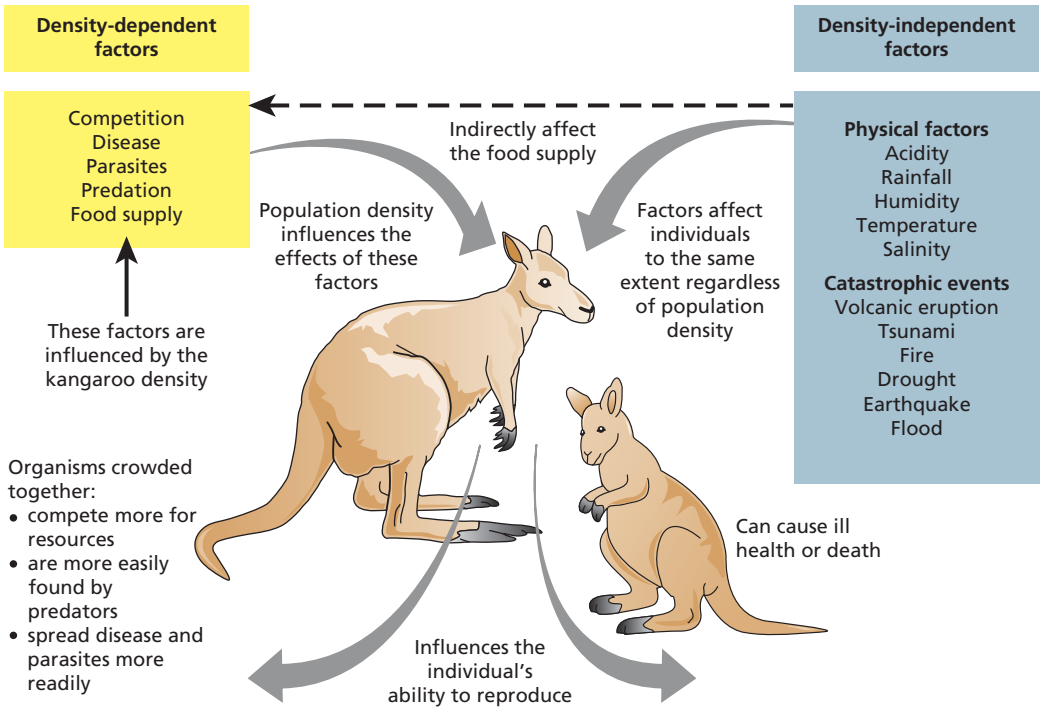


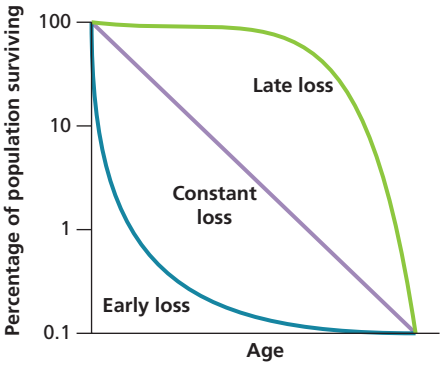
Figure 6.20 ▶
Populations are regulated by density-dependent and density-independent factors.



though the immediate effects on the environment and all communities within them are drastic, in the long term they redistribute sediment, seeds and animals to new areas.

In some cases, populations of species are not able to recover from such extreme environmental resistance and disappear from that ecosystem. This may eventually result in widespread extinction if numbers are continually reduced with little chance of viable population growth.

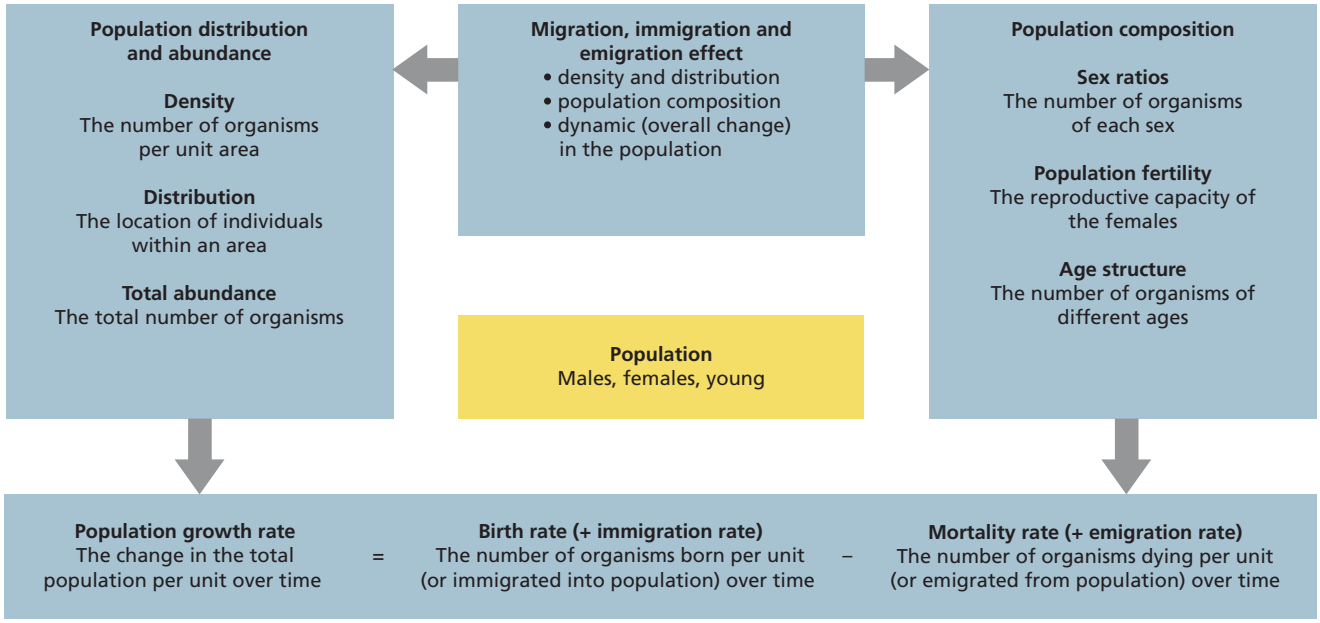
A combination of factors working together determines the survival of populations. If we examine survivorship of various species, patterns emerge. Species can be classified according to their probability of survival. This can be represented in a graph (Figure 6.21).



▲ Figure 6.21
Survivorship curves

Table 6.3 Probability of survival of species

Classification	Description	Examples
Early loss	Species that produce many offspring. Many, even thousands, of young are produced but the probability of survival is low in early life. Probability increases with age.	Fish, frogs and many plants
Constant loss	Species whose probability of survival of individuals does not change with age. There is a fairly constant loss at all ages.	Many bird species
Late loss	Survival of individuals decreases with age.	Humans, elephants



▲ Figure 6.22
Features of populations

RECALL

- Members of populations are not normally spread evenly throughout their ecosystem. Patterns of distribution are described as random, uniform and clumped.
- Density of population refers to the number of individuals in a certain area.
- Populations are regulated by density-dependent and density-independent factors.

RECAP 6.7

1 Describe three basic patterns of distribution of populations of organisms.
2 Using examples, explain the differences between abundance, density and carrying capacity.
3 List two density-dependent and two density-independent factors that affect populations.
4 Explain what survivorship curves show about the survival of populations.

Investigation of an issue: Eradicating invasive species from Macquarie Island

Refer to Chapter 11 for more information on the investigation of an issue.

Macquarie Island is a World Heritage listed nature reserve. It is the only piece of land located between Australia and Antarctica, making it an important refuge and breeding ground for many seal and bird species. In 1810, sealers arrived on the island and in 10 years, fur seals were almost hunted to extinction. From 1870 until 1919, elephant seals and king penguins were harvested for their oil. This harvesting of native animals was not the only terrible legacy left by humans; they also introduced wekas (also known as the Maori hen or woodhen), cats, rabbits, rats, mice and invasive plants.

Millions of seabirds from 23 different species breed on Macquarie Island. Thirteen species are listed as threatened, including species of albatross and giant petrel. These birds breed on land in tussock vegetation or in burrows, exposing them to threats from invasive species through predation and loss of nesting habitat (Figure 6.23). The change in biodiversity on Macquarie Island since humans first arrived has been substantial.



Auscape/Fred Olivier

Nature Picture Library/Fred Olivier

Figure 6.23 ▲
Grazing by rabbits (**a**) causes loss of breeding habitat for nesting seabirds (**b**).

To monitor the biodiversity of island ecosystems, scientists survey the abundance and distribution of species. Data relating to abiotic factors such as weather patterns, and air, soil and water quality are often collected at the same time. This provides a record of what species are living in particular locations at a given time and the conditions they are living in. The survey data can be compared to archived material to monitor changes in populations over time and to study how these changes correlate with other factors in the ecosystem. Models can be constructed to predict why species numbers have changed or to determine how species might be impacted in the future. These models are valuable in environmental impact studies.

Eradication of invasive species is a key approach in island restoration and recovery of native species. Impact studies are used to inform decisions on island eradications. In the 1980s an impact study found that cats were having a negative effect on seabird populations through predation of adults, chicks and eggs. In 1985 a decision was made to eradicate cats. After 15 years of trapping, success was achieved in 2000.

However, eradication of a single species when multiple pest species are present can have unpredicted detrimental effects if other invasive species are also on the island. Bergstrom et al. (2009) believe that an explosion in rabbit populations that occurred from 2000 to 2006 was caused solely by the eradication of cats, having a catastrophic effect on native flora and fauna. Dowding et al. (2009) argue that the rise in rabbit numbers was *correlated* with the eradication of cats, but it was not directly *caused* by the eradication. They believe the modelling used by Bergstrom et al. was flawed as it did not take into account other factors at play, including a drop in the spread of deadly *Myxoma* virus, access to lush vegetation after 20 years of vegetation recovery programs, warmer weather allowing for higher survival rate of rabbit offspring, and less predation by cats.

In 2006, the federal minister of environment approved an eradication plan for removal of all rabbits, rats and mice from the island, at a cost of $25 million. In 2011, helicopters dropped poison baits across the island and dogs were then used to locate and kill any remaining rabbits (Figure 6.24). Following two years of monitoring without seeing evidence of the target species, the project was declared a success in 2014.



Tasmania Parks and Wildlife Service



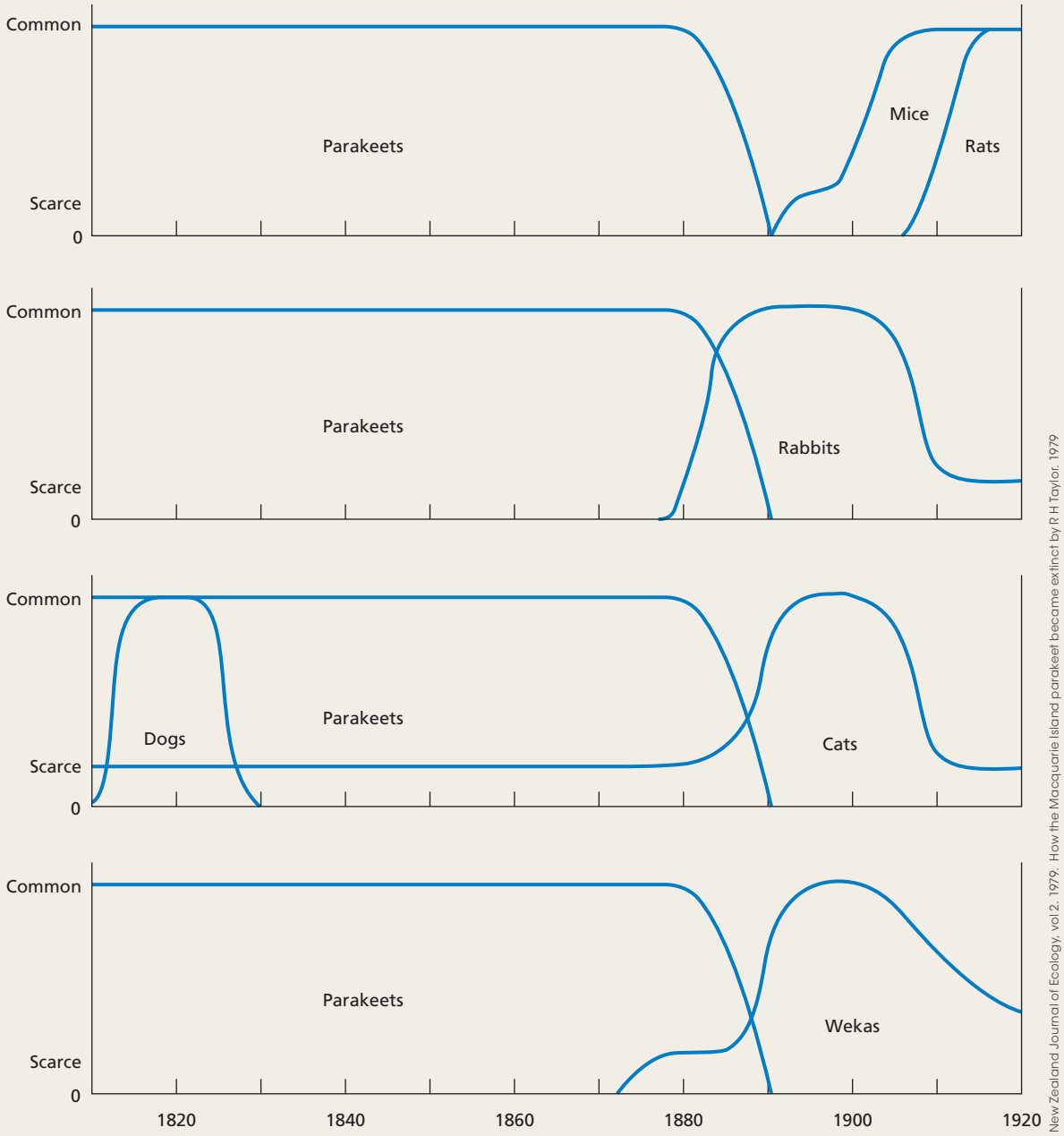
Picture Media/Reuters

▲ **Figure 6.24**
(**a**) Aerial baiting and (**b**) use of dogs to locate surviving rabbits led to the success of the rabbit eradication program on Macquarie Island.

Your turn: Using population models to make predictions

Task 1: In 1891 the Macquarie Island parakeet became extinct. This parakeet nested under tussocks of vegetation on the treeless island. On reading a variety of accounts describing abundance of introduced and native fauna on the island from 1810 to 1920, naturalists constructed a model to compare the relative abundance of introduced species against the parakeet (Figure 6.25).

Use Figure 6.25 to predict why the Macquarie Island parakeet became extinct. This model has limitations. While it provides possible correlations between species, does it provide enough information to prove the cause of parakeets becoming extinct? What further information might be required?

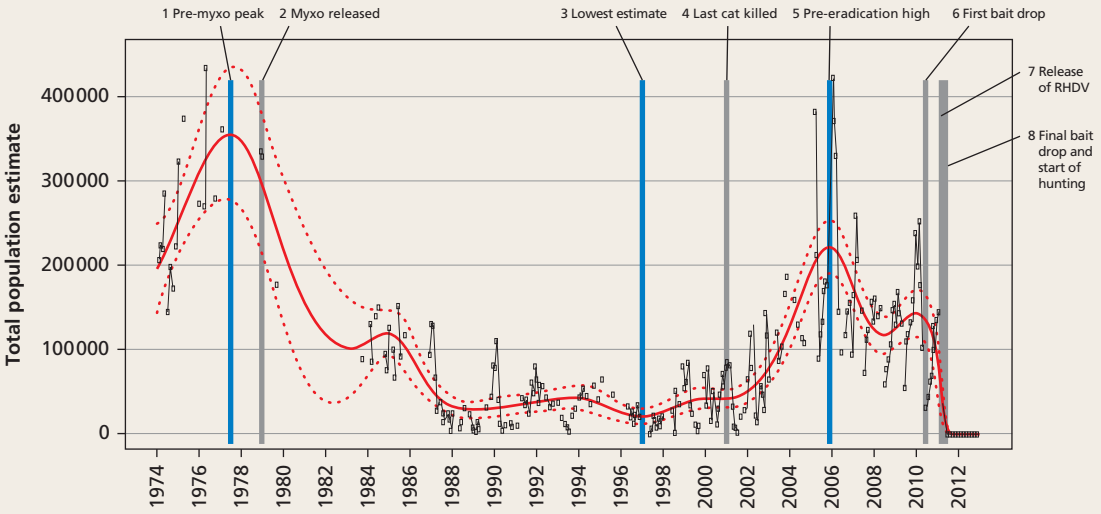


New Zealand Journal of Ecology, vol 2, 1979. How the Macquarie Island parakeet became extinct by R H Taylor. 1979
http://newzealandecology.org/nzje/1448.pdf

Figure 6.25 ▲
A diagram constructed using early accounts of fauna on Macquarie Island to indicate relative abundance of parakeets and introduced species from 1810 to 1920. Not to scale. (Taylor, 1979)

Task 2: Rabbits negatively impact vegetation and cause land erosion through grazing and the construction of warrens. Use Figure 6.26 to describe trends in the rabbit population on Macquarie Island from 1974 to 2012. What factors correlate with a population increase? What factors correlate with a population decrease?

Models of population size are limited to the data that has been collected in scientific studies. This model of rabbit populations over time has limitations. It does not show the effect of all factors that can affect population size that are independent of the density of the rabbit population. List three density-independent factors that could contribute to changes in the size of rabbit populations.



▲ **Figure 6.26**
Long-term rabbit population trends on Macquarie Island from 1974 to 2012. Rabbit population trends are shown by the solid red line. Large fluctuations in the population levels of rabbits over the past 40 years are linked to the history of feral animal management interventions such as introducing the *Myxoma* virus (myxo) and calicivirus (RHDV), using poison baits and dogs trained to hunt rabbits (Terauds et al. 2014).

Task 3: Both native and invasive species of flora are found on Macquarie Island. Describe possible effects that the removal of rabbits might have on the island's flora and fauna.

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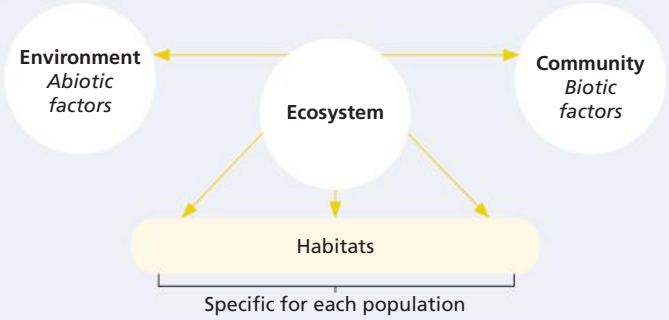
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CONCEPT SUMMARY

Relationships between organisms



Intraspecific
Relationships between organisms within the same species

Interspecific
Relationships between organisms of different species

Predation
(such as seed predators)



Parasitism
(such as mistletoe)



Mutualism
(such as pollinators)



Commensalism
(such as cattle egret)



Amenalism
(such as shady tree)



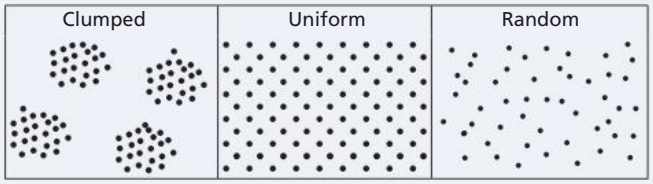
Population dynamics

Population growth rate = (birth rate + immigration rate) – (death rate + emigration rate)

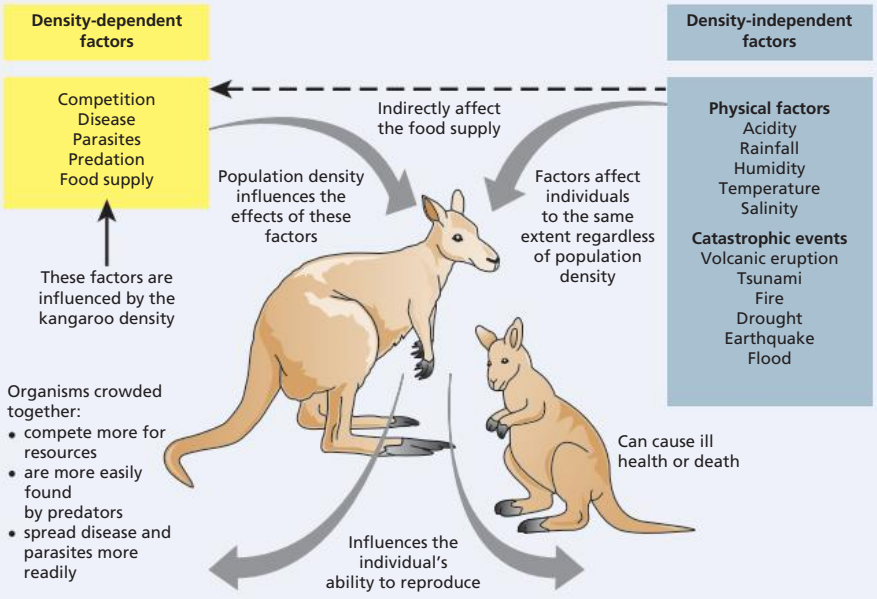
Carrying capacity
The maximum population size that can be supported in a particular environment

Population pyramids
Allow visualisation of age of data of populations

Distribution of populations

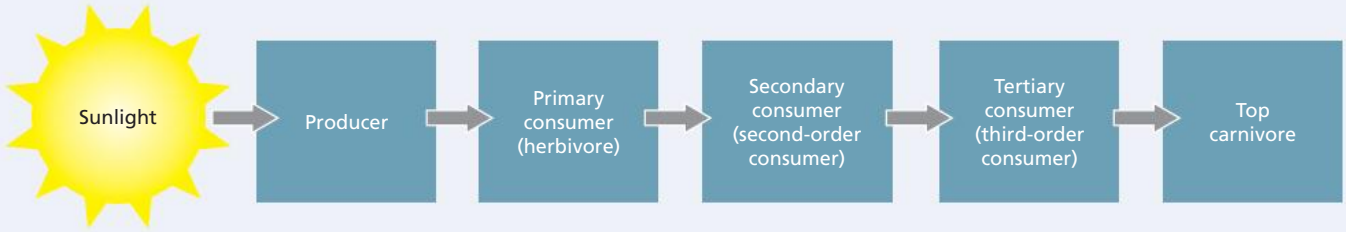


Population regulation



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Food chains

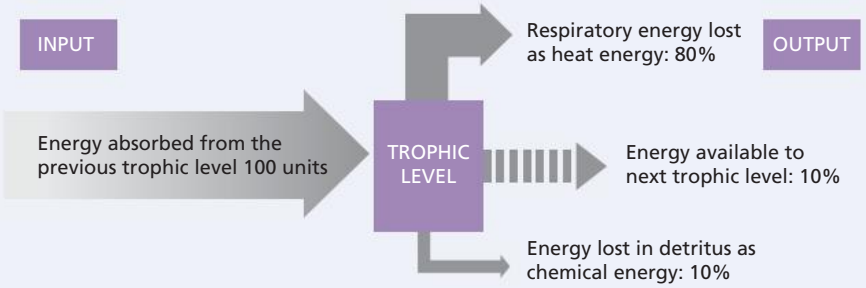


(Not part of the food chain of the community)

Other types of consumers

- Omnivores
- Scavengers
- Detritivores
- Decomposers

Trophic efficiency



Food webs

Integrated food chains

Models

Food chains and food webs are simplified models used by ecologists to predict the effect of various factors on ecosystems

Keystone species

Predator species that keeps prey species in check, allowing the existence of multiple prey species and thereby promoting biodiversity

CHAPTER GLOSSARY

abiotic the non-living components of an ecosystem

abundance how many; the number of a species in a population

amensalism a symbiotic relationship whereby one species is inhibited or destroyed while the other remains unaffected

biodiversity the full range of different living things in a particular area or region; it can be described at various levels, including the range of different species, genetic diversity, or the diversity of ecosystems present in a larger area

biotic the living components of an ecosystem

carnivore an organism that feeds on other animals

carrying capacity the maximum population size of a species that can be supported in a given environment

clumped (grouped) distribution a pattern of distribution in which individuals in a population are grouped together where biotic and/or abiotic factors are favourable

coevolve the evolution of adaptive features in two different species that have placed selective pressures on each other

coexistence different species living together peacefully

commensalism a symbiotic relationship whereby one species benefits and the other is unaffected

community the sum of the different species inhabiting a particular habitat at one time

competition the struggle between two or more species for resources to fulfil their need for survival

consumer any organism that cannot manufacture its own food, but depends on others for food

density-dependent factor a factor that affects a population more as the population increases, e.g. disease-causing organisms or parasites; the greater the density of a population, the more individuals die or fail to reproduce

density-independent factor a factor that affects all individuals and usually leads to a drastic decline in population due to death or emigration; e.g. severe weather conditions, volcanic activity and habitat destruction by clearing or fire

detritus organic wastes, including faeces and dead tissues

ecosystem a self-sustaining unit consisting of the interactions between the community and the environment

environment abiotic and biotic factors of an area

epiphyte a type of climbing plant, such as lianas, which uses trees as support as they reach for light

first-order consumer a consumer that feeds directly on producers; also known as a herbivore

food chain one organism occupying a trophic level is consumed by an organism in a higher trophic level, creating a chain whereby energy and matter are passed to progressively higher levels

frugivore a fruit-eating animal

habitat an area or environment where an individual or species lives within an ecosystem

herbivore a first-order consumer that feeds on plants

host an organism that another organism lives on or in

interspecific interactions or relationships between members of different species

intraspecific interactions or relationships between members of the same species

keystone species a species of relatively low abundance that has a large influence over lower trophic levels by allowing the coexistence of these species in a particular area

mutualism a symbiotic relationship whereby both species in the relationship benefit from each other

omnivore an organism that feeds on a range of foods, including plant and animal matter

parasite an organism, such as a bacterium, virus, fungi, worm or arthropod, that lives on or in another organism

parasitism a symbiotic relationship whereby one species benefits to the detriment of the other

phytoplankton the collective term for the tiny photosynthetic organisms present in bodies of water

pollinator an organism that is able to transfer pollen from one flower to another

population a group of individuals belonging to the same species living in a particular area at the same time

population pyramid a graphical illustration that shows the distribution of various age groups in a population

predator an organism that hunts another organism for its food

prey an organism that is hunted by another organism for food

random distribution a pattern of distribution in which organisms are spaced irregularly; the location of an organism does not affect the location of another

scavenger a consumer that feeds on dead and decaying flesh or remains

seed disperser an organism that feeds on fruits and seeds for nutrition; when the animal defecates, it deposits the seeds in a new location where they can germinate and grow

seed predator an organism that feeds on seeds and generally acts as a seed disperser

symbiosis the relationship between individuals of two or more species that interact together whereby at least one organism benefits from the relationship

top consumer the last link in the food chain

trophic efficiency relates to the percentage of energy at one trophic level that ends up in the next trophic level

trophic level a feeding level in the food chain of an ecosystem

uniform (continuous) distribution a pattern of distribution in which organisms are evenly spaced; the presence of one organism determines how close or distant another will be

zooplankton a collective term for the tiny heterotrophic organisms present in bodies of water

CHAPTER REVIEW QUESTIONS

Remembering

1 Explain the role of a keystone species in an ecosystem.

2 State each of the links in a general food chain and describe how they relate to one another.

3 Describe the differences between density-dependent and density-independent factors.

Understanding

4 Explain 'dynamic relationship' with regards to predator and prey.

5 Is it possible for a carnivore to occupy more than one trophic level in a food web? Give an example to support your answer.

6 Why does a herbivore depend on producers for its energy requirements?

Applying

7 The Yellowstone cutthroat trout is a keystone species in Yellowstone National Park, in Wyoming in the United States. Apply your understanding of a keystone species to explain Figure 6.27 and why it is essential to conserve population numbers of the Yellowstone cutthroat trout.

8 Copy and complete the table below, which summarises the relationships and interactions between living species.



▲ **Figure 6.27**
Yellowstone cutthroat trout is a keystone species

Relationship or interaction	Description	Example
	Different species living together and sharing the same resources	
Commensalism		
	Rivalry between species for particular resources	
Mutualism		
	Transfers pollen between flowers	
	An animal that kills for food	
Keystone species		
Seed disperser		

9 Explain the advantages of being an omnivore such as a fox.

10 Explain, using examples, why it is often difficult to assign trophic levels to organisms.

11 In the following examples, determine the resource that probably has the greatest impact on population distribution.

- **a** Heath plants in clumps in a field
- **b** Penguins distributed evenly across an ice sheet
- **c** Alpine grasses randomly spread along the side of a hill

12 List as many factors as you can think of that might affect the population size of daisies on a lawn.

Analysing

13 Explain why there is a limit to the number of trophic levels in a food chain.

14 Refer to Figure 6.9 (page 188), which shows a forest ecosystem.

- **a** Draw two food chains, using an arrow between each link.
- **b** Identify an organism that is a second-order consumer in one chain but a third-order consumer in another. The chains do not have to be those of your answer to part **a**.

15 The Galapagos Rift, which receives no light, is a deep-sea boundary between oceanic plates. Sulfate in the sea water is converted into hydrogen sulfide at high temperatures. Chemosynthetic bacteria obtain energy from the hydrogen sulfide; they use this energy to convert carbon dioxide dissolved in the water into organic molecules. In the same area, clams that feed on the chemosynthetic bacteria are an energy source for crabs and octopus. Chemoheterotrophic bacteria return resources to the community. Choose which one of the combinations in the table below correctly identifies the producer, the first-order consumer, the second-order consumer and the decomposer for the community described above.

	Producer	First-order consumer	Second-order consumer	Decomposer
A	Photosynthetic bacteria	Clams	Octopus	Chemosynthetic bacteria
B	Chemosynthetic bacteria	Clams	Crabs	Chemoheterotrophic bacteria
C	Photosynthetic bacteria	Octopus	Crabs	Chemosynthetic bacteria
D	Chemosynthetic bacteria	Crabs	Octopus	Chemoheterotrophic bacteria

16 **a** Draw a graph to show what would happen to a population of rabbits if there were no predators in the areas where the rabbits lived.

- **b** Introduce a predator such as a fox into your population and show on your graph what may be expected to happen to the rabbit population.

17 Describe the attributes that would indicate that a population is increasing in size.

18 Two populations of different species within an area are measured at 3-year intervals. Over that time, the numbers of the two species vary as shown in the following table.

Table 6.4 Numbers of individuals

Time	Number of species 1	Number of species 2
Year 0	25	85
Year 3	50	50
Year 6	30	75
Year 9	60	70

- **a** Graph the results on one set of axes.
- **b** Describe the trend you see with the two species.
- **c** One species preys on the other. Explain which species you think is the predator and why.

19 A black rhinoceros often has birds on its back that remove ticks from its skin. Suggest how a person might determine whether the relationship is an example of mutualism, commensalism, parasitism or amensalism.

Evaluating

20 Discuss whether you think the age structure of a population indicates future growth patterns. Predict what age group would need to show a steady growth to indicate a healthy overall population growth.

21 Population fluctuations seem to be far more extreme in the Arctic than in tropical regions. Suggest reasons for this.

22 Justify this statement: 'The world is a more diverse place because of the relationships found within ecosystems'.

23 'Ecosystem models are useful representations of elements within the ecosystem, the relationship between the elements and the relationship with surrounding ecosystems.' Identify the elements, the types of relationships between species and the types of relationships with the environment using the food web in Figure 6.9.

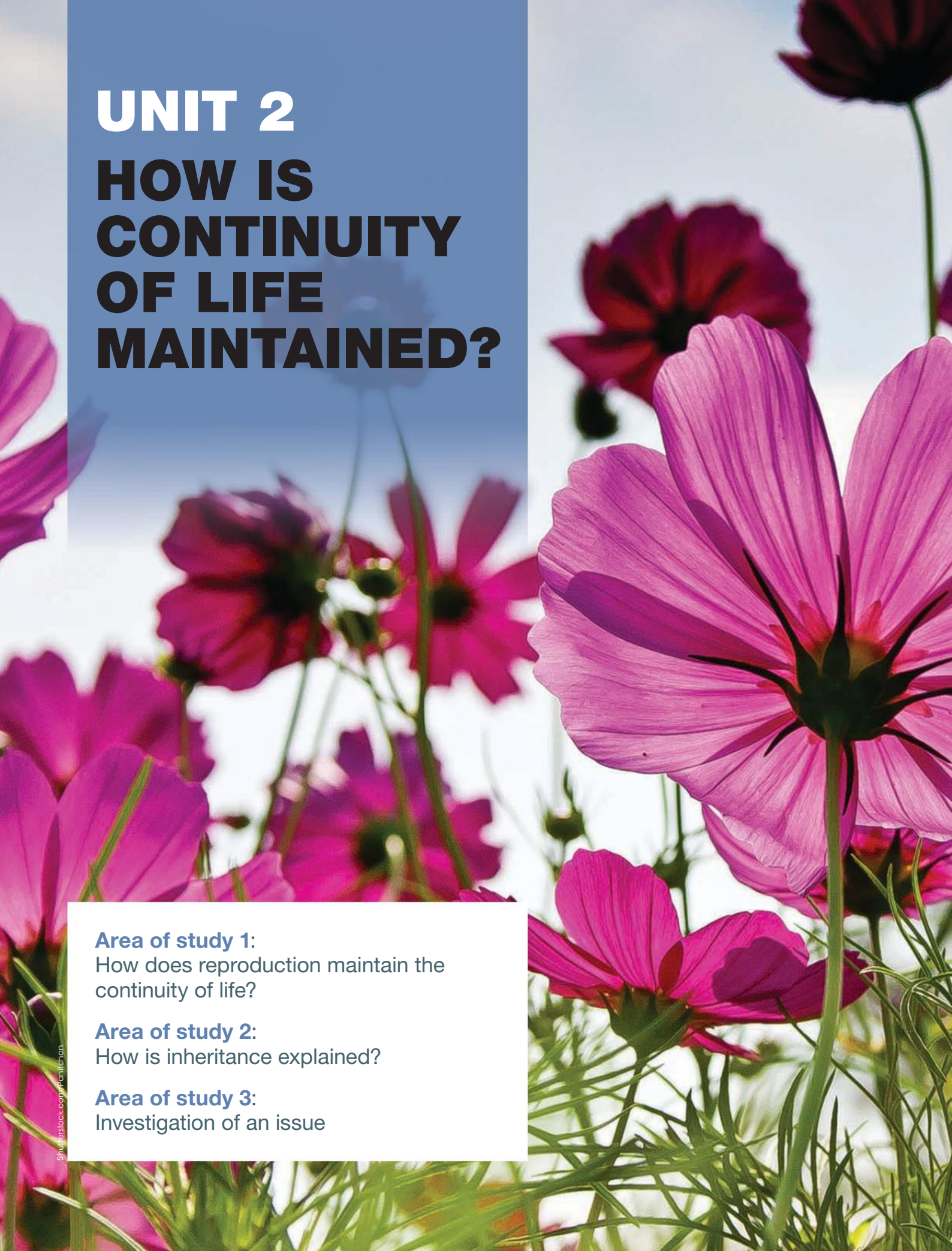
Creating

24 Draw a simple annotated diagram that summarises homeostatic control of populations.

25 Work in a group of about four. Each person is to choose a different category of relationship or interaction between living things (e.g. mutualism) and then find two Australian examples to investigate. Identify the components of the relationship or interaction and include which organism is harmed/benefitted/not affected. Decide how your group will collate and present its findings.

26 Different species of ants have an amazing range of relationships and interactions with their own kind and with other organisms. They 'milk' caterpillars, store honeydew and nectar in specialised workers and use their own grubs to weave threads to bind their nests, to give just a few examples. Analyse some ant interactions, and prepare and present your findings.

UNIT 2
HOW IS CONTINUITY OF LIFE MAINTAINED?



Area of study 1:
How does reproduction maintain the continuity of life?

Area of study 2:
How is inheritance explained?

Area of study 3:
Investigation of an issue

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CHAPTER 7

THE CELL CYCLE, AND CELL GROWTH AND DIFFERENTIATION

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

KEY KNOWLEDGE

The cell cycle

- derivation of all cells from pre-existing cells through completion of the cell cycle
- the rapid procession of prokaryotic cells through their cell cycle by binary fission
- the key events in the phases (G1, S, G2, M and C) of the eukaryotic cell cycle, including the characteristics of the sub-phases of mitosis (prophase, metaphase, anaphase and telophase) and cytokinesis in plant and animal cells.

Cell growth and differentiation

- the types and function of stem cells in human development, including the distinction between embryonic and adult stem cells and their potential use in the development of medical therapies
- the consequences of stem cell differentiation in human prenatal development including the development of germ layers, types of tissues formed from germ layers and the distinction between embryo and foetus
- the disruption of the regulation of the cell cycle through genetic predisposition or the action of mutagens that gives rise to uncontrolled cell division including cancer and abnormal embryonic development.

Investigation of an issue

- the 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 biological concepts specific to the investigation: definitions of key terms; use of appropriate biological terminology, conventions and representations
- the use of data representations, models and theories in organising and explaining observed phenomena and biological concepts, and their limitations
- the influence of social, economic, legal and ethical factors relevant to the selected biological issue.

KEY SCIENCE SKILLS

Analyse and evaluate data, methods and scientific models:

- explain how models are used to organise and understand observed phenomena and concepts related to biology, identifying limitations of the models

Draw evidence-based conclusions:

- critically evaluate various types of information related to biology from journal articles, mass media and opinions presented in the public domain
- discuss the implications of research findings and proposals.

Communicate and explain scientific ideas:

- use appropriate biological terminology, representations and conventions, including standard abbreviations, graphing conventions and units of measurement
- discuss relevant biological information, ideas, concepts, theories and models and the connections between them.

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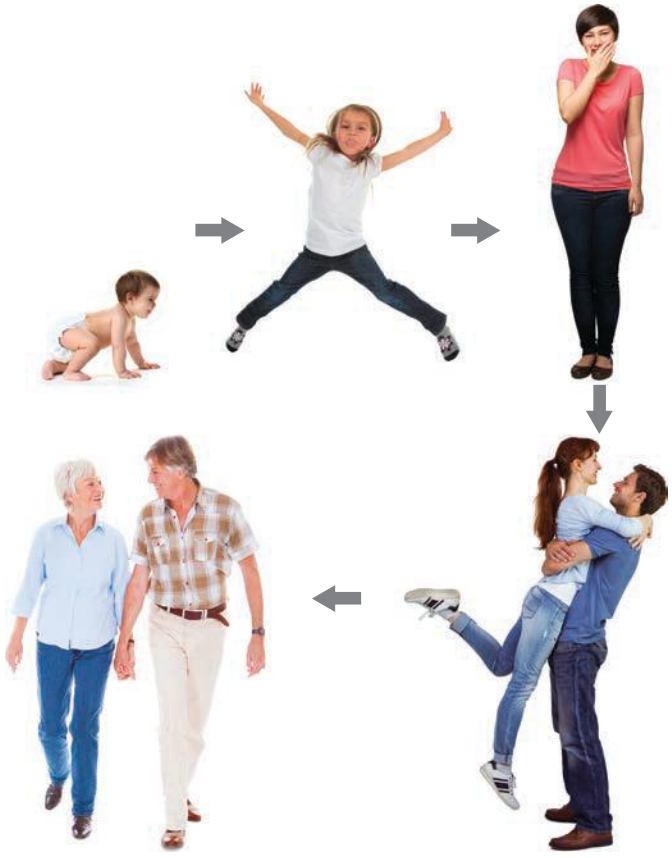


Figure 7.1 ▲
Organisms grow and develop.

Table 7.1 Average life span of human cells

Cell type	Average life span (days)
Intestinal lining	1.3
Stomach lining	2.9
Tongue surface	3.5
Cervix (neck of the uterus)	5.7
Cornea of the eye	7.0
Outer skin of the abdomen	7.0
Inside of the cheek	10.0
Alveolus (air sac in the lung)	21.0
White blood cell	Depending on type and activity, from minutes to years
Red blood cell	120.0
Kidney	170.0
Bladder lining	330.0
Liver	450.0
Nerve cell in brain	29200+ (80+ years)

When a baby is born, most parents receive a book to record their child's health, growth, development and immunisation. When they visit a Maternal and Child Health Centre, the nurse will review the baby's health, growth and development, comparing the baby's height and weight to other babies using percentile growth charts to assess their development. The length, weight and head circumference of the baby are measured. This is important because a steady progression in growth is expected. Babies develop at different rates but when the growth rate is too fast or too slow, further investigation is required.

You have increased in size a lot since you were born. This growth was not caused by your cells increasing in size, but was a result of an increase in the number of your cells.

Cell division

In the previous chapters the focus has been on the life-sustaining processes of the whole organism, whether it is in the form of a single cell, a colony of cells, a multicellular flowering plant or an animal. Our focus now turns to life-continuing processes of the whole organism and, as such, we look at the replacement of individual parts of the organism and reproduction of the whole organism.

Reproduction is the creation of a new generation of single cells, single-celled organisms or multicellular organisms. The production of new cells and new organisms always begins with the division of a single cell.

Cells reproduce so that tissues and organs can grow larger, but even in a mature person, cells are constantly reproducing. Cells that are damaged, worn out or diseased must be replaced. Some human cells have a very short life span. Table 7.1 shows the life span of different types of human cells.

For cells to begin life as separate individuals, a eukaryotic parent cell must provide its **daughter cells** with the necessary genetic material (DNA) and cytoplasmic organelles. The DNA molecules are located within the nucleus of the cell and contain the instructions for making the proteins that are necessary for normal cell functioning. The daughter cells must receive the full set of instructions or they may fail to function correctly, resulting in cells or organisms that are unfit.

Eukaryotic cells pass on their instructions for growth and development from one generation of cells to the next by division of the nucleus, known as **mitosis**. Mitosis ensures that each body cell receives exactly the same genetic material (DNA) as that possessed by its parent cell. Division of

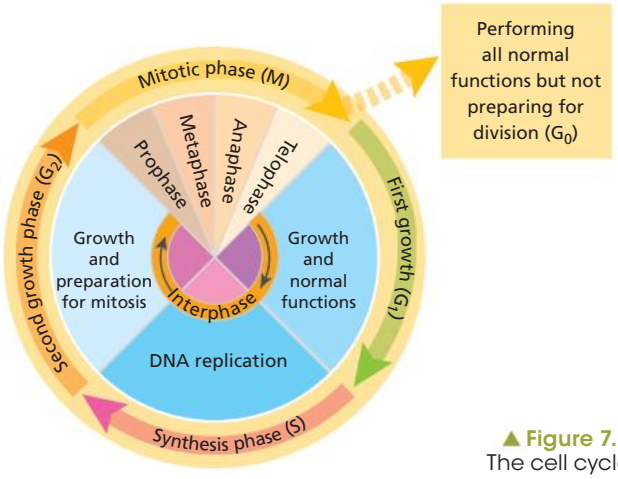
the nucleus is followed by cytoplasmic division (**cytokinesis**). Under normal circumstances cell division takes place in an orderly progression. Mitosis and cytokinesis result in the formation of two daughter cells, which each contain identical sets of **chromosomes**.

DNA in a cell is present as a set of molecules arranged as chromosomes. Each chromosome is made up of a single very long piece of DNA. The DNA is a double helix molecule, with two strands 'zipped' together by chemical bonds. Just before cell division begins, the DNA in each chromosome stretches out, 'unzips' the double helix and makes a copy of each strand. This results in two identical DNA molecules (chromosomes). These stay together until the end of cell division. While they remain together, they are called sister **chromatids** of the chromosome. DNA replication is necessary so that the daughter cells produced by cell division have full sets of chromosomes and, therefore, DNA.

DNA and chromosome structure are studied in more detail in Chapter 9.

The cell cycle

The sequence of events that take place from one cell division to another is called the **cell cycle** (Figure 7.2). It is called a cycle because the events repeat each time the cell divides. Even though we describe this cycle as taking place in phases, in reality it is usually a continuous process. The stage of actual nuclear division (M) is a small part of the cycle. The stage between nuclear divisions is called **interphase**, and is a period of active growth (G_1 phase), synthesis of DNA (S phase) and preparation for the next division (G_2 phase).



▲ **Figure 7.2** The cell cycle

- G_1 phase: the cell produces new proteins, grows and carries out its normal tasks for the body; this phase ends when the cell's DNA begins to replicate.
- S phase: exact duplicates of DNA molecules are formed.
- G_2 phase: preparation for cell division.
- M phase: the cell divides into two daughter cells (M stands for mitosis).

In addition to these four phases, another phase exists. The G_0 phase indicates the non-proliferating state, in which cells are undergoing an extended G_1 but are not preparing to replicate DNA and divide. These **quiescent** cells have withdrawn from the active cell cycle. **Terminally differentiated cells** (that is, the most specialised cells), such as nerve cells, are described as being in G_0 phase. Cells in G_0 can re-enter the cell cycle under certain circumstances. The cell cycle is controlled by a specific set of genes and gene products and has multiple checkpoints that allow the cell cycle to be stalled while mistakes are fixed, reducing the chance of error in the formation of daughter cells.

The length of the cell cycle varies in different cells. Phases in the cell cycle can be identified by measuring the changes in cell volume or in the amount of nuclear DNA, which vary depending on whether the cell is in a phase of growth or DNA synthesis (Figure 7.3, page 216). But not all cells divide. Specialised cells tend not to divide (they are usually in G_0 phase), but other cells in areas of high growth or wear, such as skin cells and lining cells of the mouth and gut, tend to divide frequently to replace worn tissues. Dead cells in these organs 'slough off' as a result of mechanical disturbance or replacement from new cells growing below. New cells not only replace old cells but can also divide to create new organs or tissues. Cells of a growing root tip may divide every 20–24 hours.

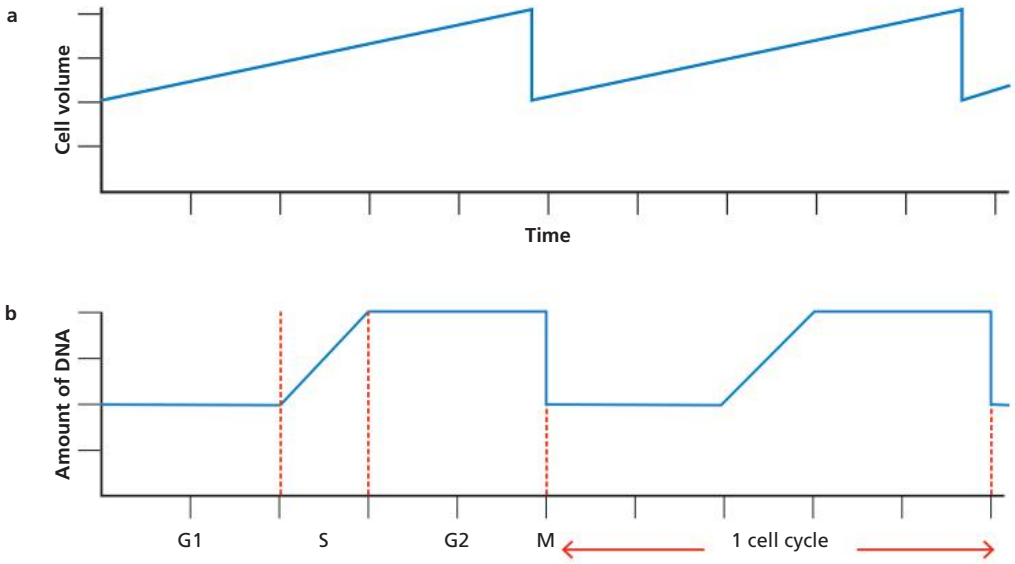


Figure 7.3 The (**a**) cell volume and (**b**) amount of nuclear DNA change during a cell cycle, reflecting the different phases of the cycle.

RECALL

- Reproduction of a cell or organism starts with the division of a single cell.
- The sequence of events in cell division is called the cell cycle.
- Specialised cells have withdrawn from the cell cycle.

RECAP 7.1

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

2 Explain why cell division is called a cycle.

3 Name the four phases of the cell cycle.

The phases of mitosis in eukaryote cells

For convenience, biologists describe mitosis in four stages: prophase, metaphase, anaphase and telophase. However, the process is continuous; it does not occur in steps.

Interphase

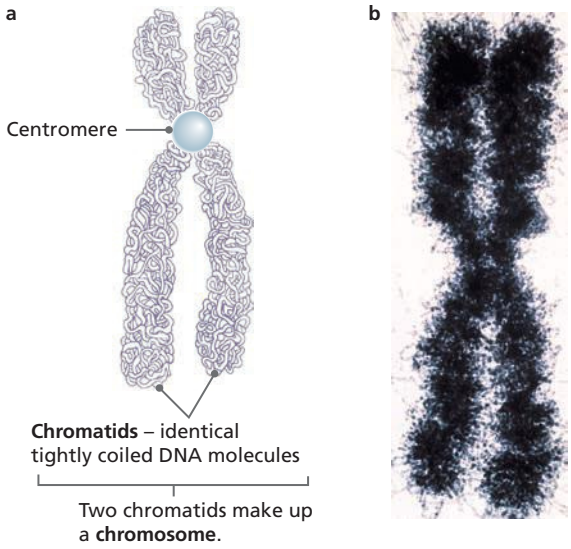
During interphase, the stage between nuclear divisions described earlier, the chromosomes are not visible and cannot be clearly distinguished under a light microscope or an electron microscope. This is because the DNA strands are loose and the chromosomes are long and unwound. Immediately before mitosis begins, **centrioles** are visible in many animal cells. Centrioles will later help to form a structure within the cell that allows the separation of the chromosomes into the

Centrioles are introduced in Chapter 1, page 15.

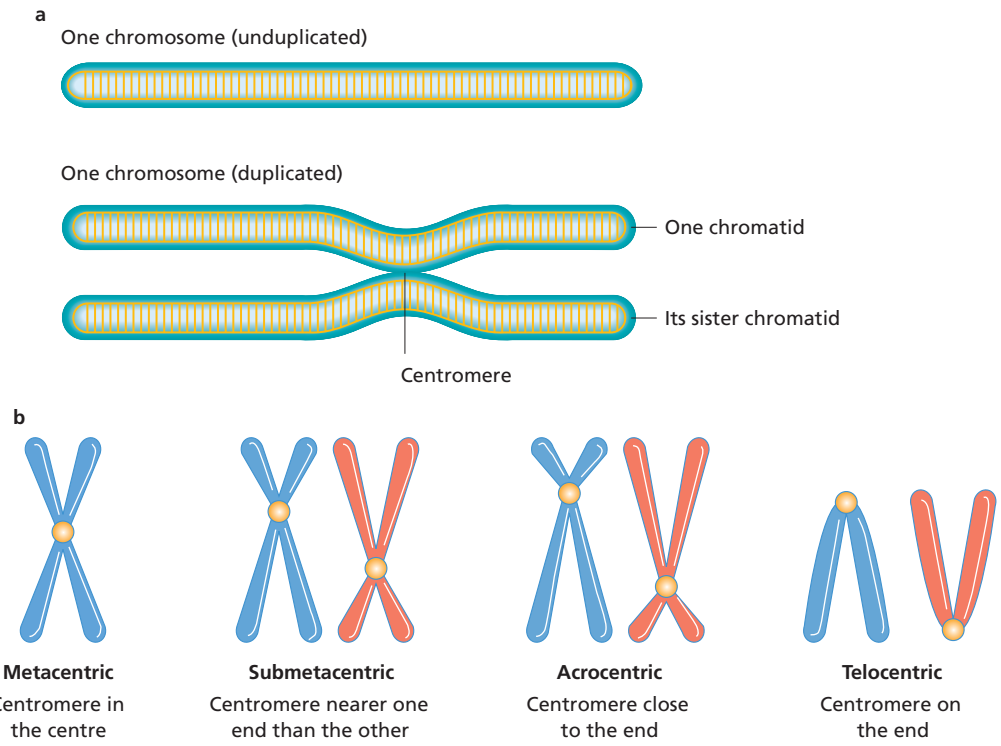
daughter cells. As the cell leaves interphase and begins mitosis, the threads of **chromatin** (a loose mass of DNA and associated proteins) become shorter and thicker, forming chromosomes that are visible under a light microscope.

Prophase

During prophase, the chromatin threads condense and become visible as pairs of chromatids, held together at a **centromere**. Centrioles move to opposite ends (or poles) of the cell and **microtubules** begin to radiate from them. Some of these microtubules join to form a framework of fibres called a **spindle**. The **nucleolus** disappears from view. The nuclear membrane breaks down.



▲ **Figure 7.4**
(**a**) During prophase, chromosomes become visible as pairs of chromatids. (**b**) Scanning electron micrograph of a chromosome



◀ **Figure 7.5**
(**a**) An unduplicated chromosome and a duplicated chromosome, showing the position of the centromere (bottom) (**b**) The position of the centromere can vary in different chromosomes, and descriptive names are given according to their position.

Metaphase

During the next stage, termed metaphase, the chromatid pairs move to the centre of the cell and line up along the equator (sometimes called the metaphase plate). The centromere of each pair is attached to a spindle fibre.

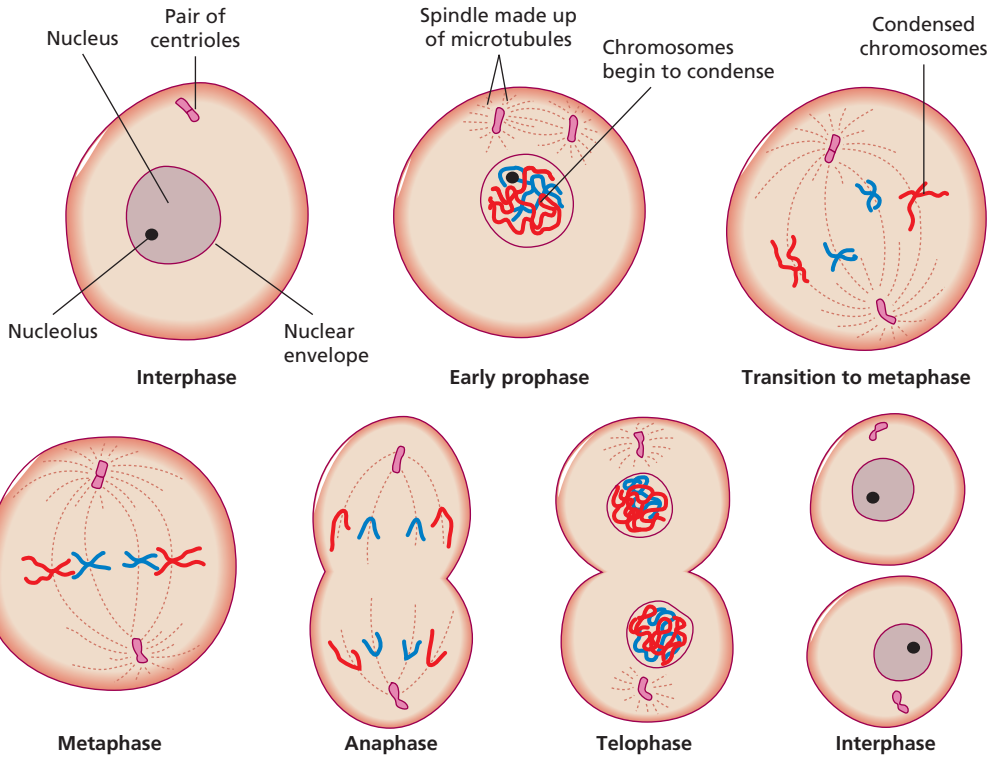
Anaphase

The next phase is called anaphase. Spindle fibres attached to the chromatids help to pull them apart. Chromatids separate at the centromere and move to opposite poles of the spindle as the spindle fibres contract. As the chromatids have become independent of each other they are now called chromosomes.

Telophase

During telophase, the two sets of chromosomes form tight clusters at each pole of the cell. The chromosomes de-condense as the chromatin unwinds and becomes less visible. A new nuclear envelope forms, nucleoli reform and the spindle disassembles.

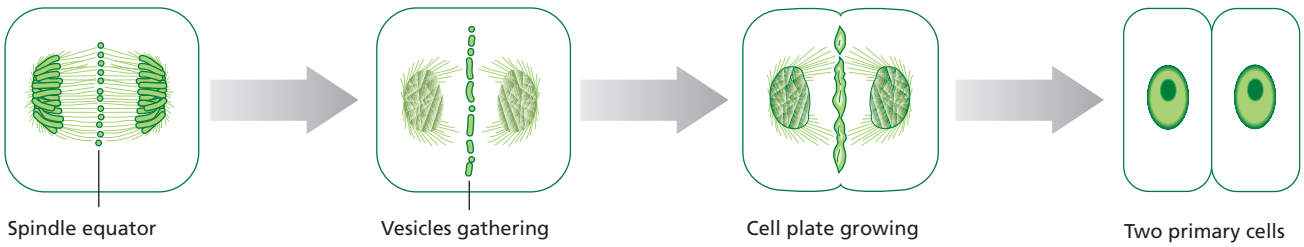
Figure 7.6 ▶
The stages of mitosis in animal cells

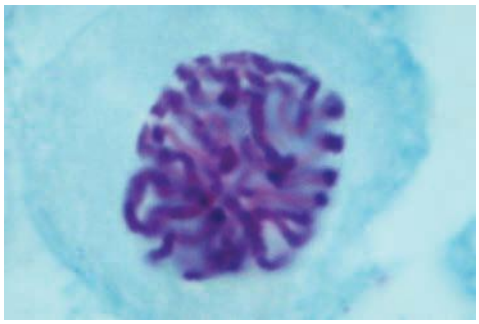


Cytokinesis in eukaryote cells

Following mitosis, cytoplasmic division (called cytokinesis) occurs. In plant cells, a new cell wall must form around each daughter cell and so cytokinesis of plant cells involves the formation of a structure called a **cell plate**. Figure 7.7 shows how parts of the cell wall fuse with parts of the spindle, forming the cell plate. Cellulose is deposited at this site, forming a wall that divides the parent cell into two daughter cells, each one with a plasma membrane.

Figure 7.7 ▼
Cytokinesis in a plant cell results from the formation of a cell plate, on which cellulose is deposited to form a cell wall around the two new daughter cells.

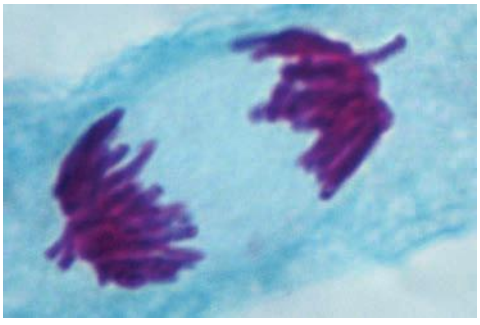




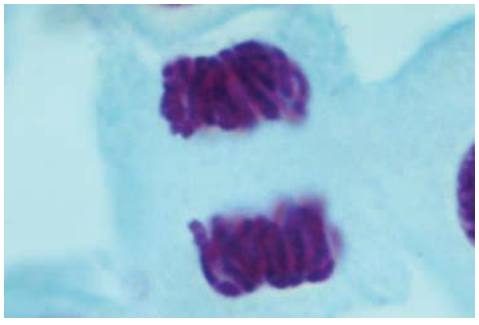
Prophase



Metaphase



Anaphase

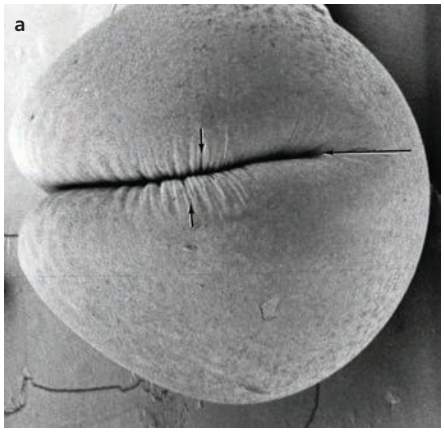


Telophase

Getty Images/Ed Reschke

◀ Figure 7.8
The micrographs show prophase, metaphase, anaphase and telophase in onion root tip cells.

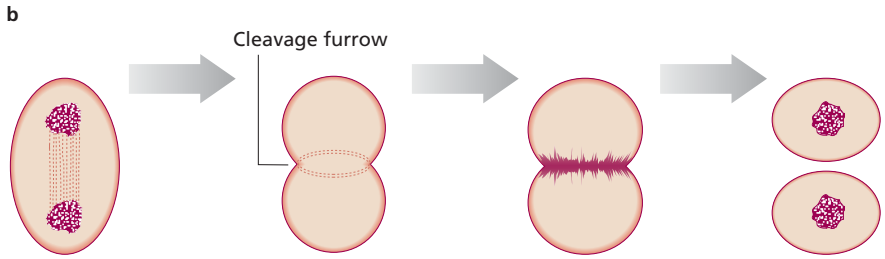
Animal cells do not have a cell wall, so division of the parent cell is less involved. In this case, the cytoplasm divides by a process known as **cleavage**. The plasma membrane around the middle of the cell draws together to form a **cleavage furrow**. The cleavage furrow continues to develop until it eventually meets and the cell is then cleaved, or split, with two new daughter cells resulting (Figure 7.9). Unequal distribution of proteins into the two daughter cells may result in the daughter cells having different fates; this normal process is termed asymmetrical cell division.



Visuals Unlimited/Dr Richard Kessel & Dr Gene Shih

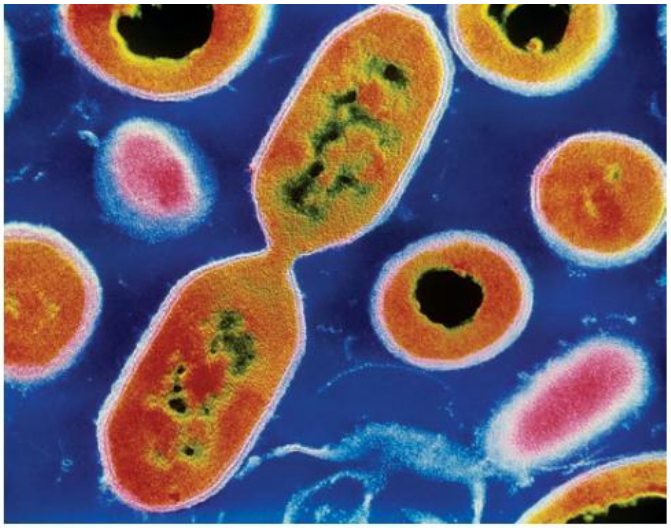


Science Source/David M. Phillips



◀ Figure 7.9
(**a**) Micrographs of an animal cell during cytokinesis; (**b**) Cytokinesis in an animal cell results in the formation of a cleavage furrow, where the cell eventually divides to produce two new daughter cells.

Mitosis and cytoplasmic division thus result in the formation of two daughter cells, which now enter interphase. Because each chromosome has been duplicated, and because the duplicates have separated into daughter cells, each daughter cell has exactly the same number and type of chromosomes as the parent cell. The genetic information is therefore passed on completely and without change, from parent cell to daughter cells.



Science Photo Library/CNRI

Figure 7.10 ▲
Transmission electron micrograph of *Listeria* dividing in two by binary fission (magnification × 9800)

Binary fission

Cell reproduction is more complex in eukaryotes than in prokaryotic cells. As prokaryotes lack a nucleus and have only a single chromosome with no centromere, they do not need to undergo the complex events of mitosis in order to accurately pass on their DNA. They reproduce instead by **binary fission**, a process that includes DNA replication, chromosome segregation and cytokinesis (Figure 7.10). As with mitosis, binary fission also leads to the production of two daughter cells with the same number of chromosomes (just one) as the parental cell.

Prokaryotic bacterial cells simply replicate their single DNA strand. Following replication, each copy attaches to a different part of the cell membrane. When the cell begins to pull apart, the original and replicated chromosomes are separated. A wall forms across the cell and divides it into two cells of identical genetic composition.

Because of the relative simplicity of prokaryotes, completion of the cell cycle, through binary fission, is a less complicated and much more rapid process than cell division in eukaryotes.

A similar process of binary fission occurs in eukaryotic cells when mitochondria and chloroplasts divide to form new organelles. They divide independently of nuclear DNA and segregate evenly into two daughter cells during cytokinesis.

RECALL

- Eukaryotic cell division involves a number of phases resulting in nuclear division (mitosis) and cytoplasmic division (cytokinesis).
- Cells formed by mitosis have the same genetic material as their parent cells.
- Prokaryotic cells reproduce by binary fission.

RECAP 7.2

1 Distinguish between mitosis and cytokinesis.
2 Draw an annotated graphic that summarises the cell cycle.
3 Suggest why it is important for DNA to replicate before cell division.

ACTIVITY 7.1

IDENTIFYING STAGES OF THE CELL CYCLE

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

What to do

Part A

In the middle of an A3 piece of paper or other surface, draw a graphic depicting the cell cycle of a cell. You may wish to use a graphic similar to Figure 7.2. Alternatively you could create an infographic or digital presentation.

Create four chromosomes from items such as beads, string, pipe cleaners or any other material you decide on. Start at the G_1 phase of the cell cycle. Model the events that happen at each phase, including all phases of the M (mitosis) phase, with your model chromosomes.

As you work through each of the phases, record an image and detailed description on the outside of your cell cycle graphic.

Part B

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

What did you discover?

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

Disruption of cell cycle regulation

Cells do not live forever; they age and die at a given life span. For example, some skin cells, known as keratinocytes, live for approximately three weeks. The dead cells form a surface layer that is continually shed. Keratinocytes self-destruct in an orderly and programmed manner called **apoptosis**, also known as programmed cell death.

Apoptosis

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

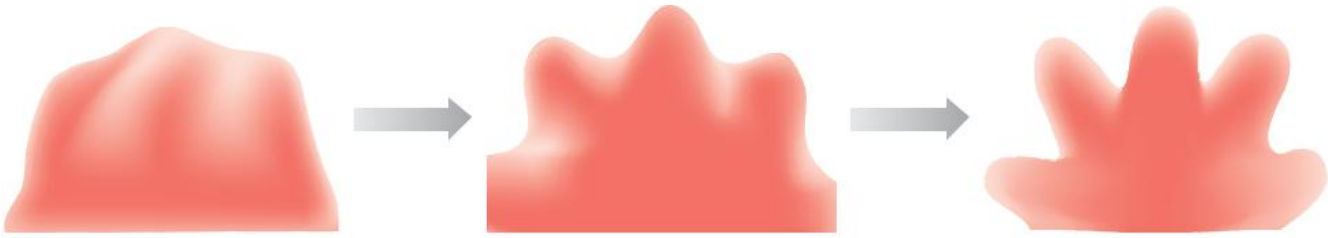


Figure 7.11 ▲
During mouse embryonic development, programmed cell death (apoptosis) leads to loss of cells in the webbing, or interdigital tissue, between fingers to help form a paw. Hand formation in human embryos is also assisted by apoptosis.

Unit 3 Biology goes into more detail about the role of phagocytes, including macrophages.

The demise of these cells is genetically programmed and, when their time comes, death is orchestrated by the regulated expression of dozens of genes. Apoptotic cells are destroyed through a series of active, orderly events that start with enzymes shredding a dying cell's DNA into thousands of fragments. The nucleus is gradually dismantled and the membrane begins to form **blebs**. Blebs are balloon-like outgrowths of the plasma membrane. They occur when the plasma membrane detaches from the underlying cytoskeleton. The membrane inflates rapidly and stops abruptly. Eventually, apoptotic bodies, containing the contents of the dead cell encased by plasma membrane, are formed and are cleared by scavenging cells called phagocytes, particularly macrophages.

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

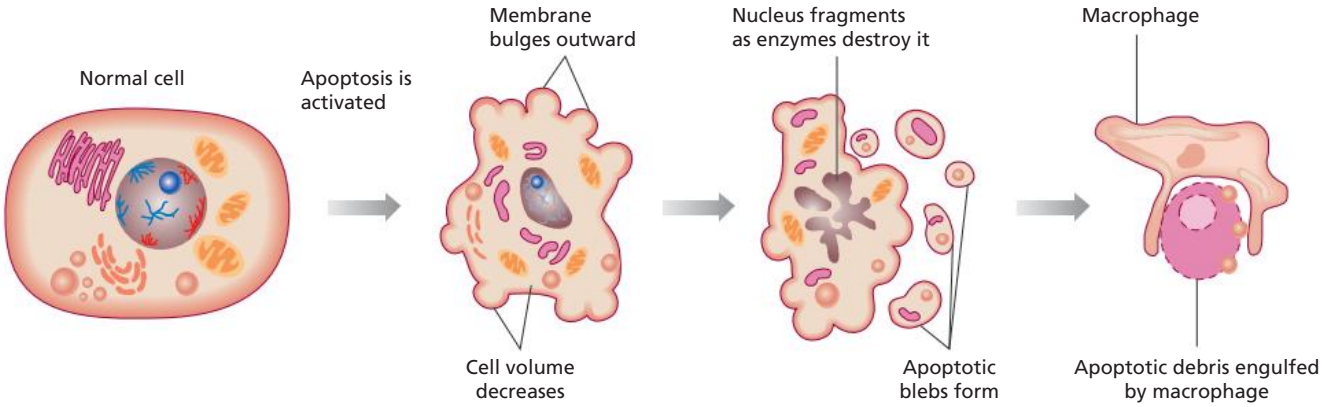
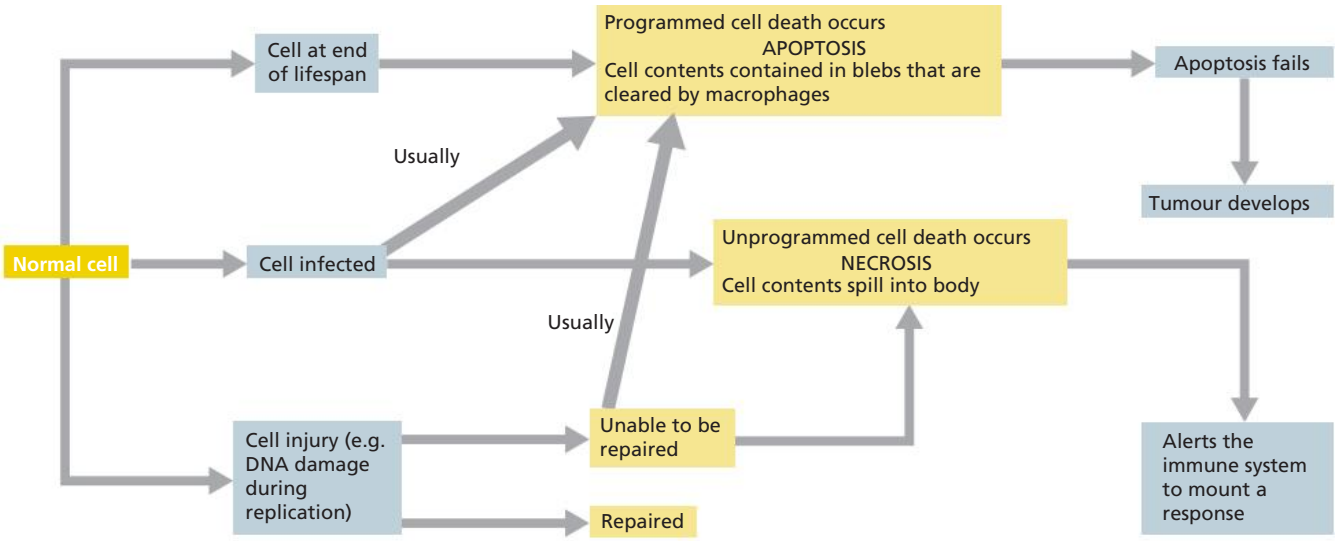


Figure 7.12 ▲
Apoptosis pathway

Failure in apoptosis can result in many problems, ranging from developmental defects to cancer. An important stage in the formation of cancer occurs when apoptosis is avoided and cells do not die as they should. Some tumour cells have changes to their apoptosis genes that make them unable to activate the apoptosis program, or become unresponsive to pro-apoptotic stimuli. Cancer is normally controlled by keeping a tight rein on cell division, particularly by preventing division when damage has occurred to DNA. When this damage cannot be repaired, apoptosis is initiated and the cell is disposed of. It is much safer to remove an individual cell, replacing it later, than to allow the cell to persist if it carries changes in its DNA that may result in cancer.

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



▲ **Figure 7.13** Summary of potential cell fates

RECALL

- Apoptosis is important for development, removing unwanted cells and protecting an organism from ill health.
- Cancer can result if apoptosis fails.

RECAP 7.3

1 Name two types of cells that would be destroyed by apoptosis.
2 Outline the sequence of events in apoptosis.
3 Explain why apoptosis is important for maintaining life.

Cell cycle checkpoints

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

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

There are a number of checkpoints in the cell cycle. After cell division the cell either goes into quiescence and no longer divides – the G_0 phase – or proceeds into the G_1 phase of the cell cycle.

G_1 checkpoint

The cell cycle progresses during the early G_1 phase only if certain growth factors are present. At a critical point of this phase the cell cycle will continue even if growth factors are absent.

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

G_2 checkpoint

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

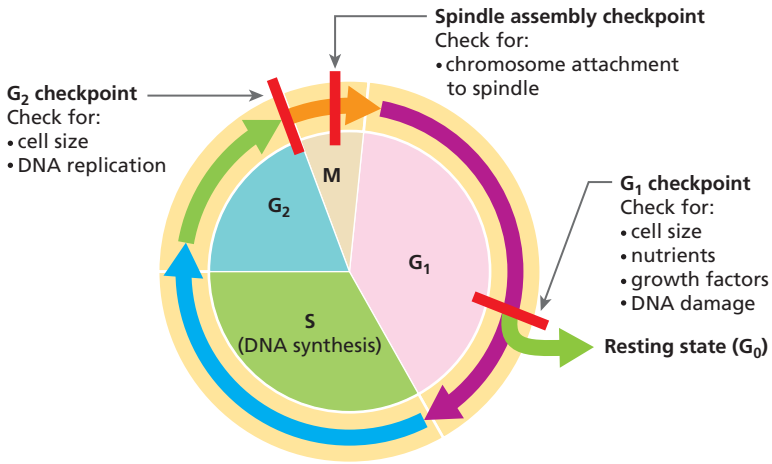


Figure 7.14 ▲
Cell cycle checkpoints

Mitosis checkpoint

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

Genetic control of the cell cycle

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

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

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



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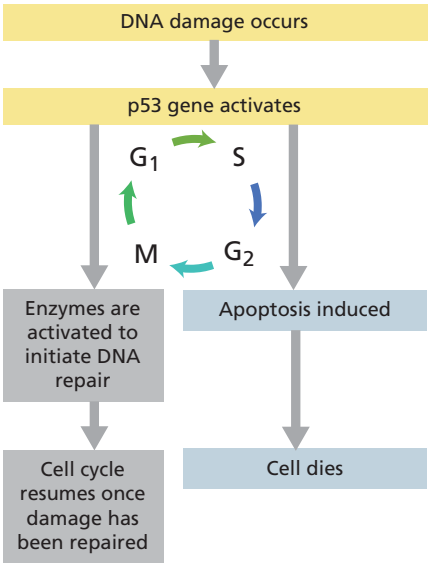
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◀ **Figure 7.15**
(**a**) Proto-oncogenes act like the accelerator on a car. (**b**) Tumour suppressor genes act like the brakes on a car.

A very important means of controlling the cell cycle is via the **p53 gene**. This gene activates when DNA damage is detected or cell injury occurs. When the levels of p53 increase in response to DNA damage, one of two possible pathways is triggered, depending on the the stage of the cell cycle. During the early stage of the cell cycle, progress is halted to allow damaged DNA to be repaired. During the later stages of the cell cycle apoptosis is initiated to prevent the damaged cell from replicating (Figure 7.16).

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

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



▲ **Figure 7.16**
The p53 gene is activated when DNA damage is detected.

If mutated, another gene called RB1 results in **retinoblastoma**, a cancer of the retina in the eye. RB normally inhibits progression of the cell cycle. Like the BRCA genes, it is a tumour suppressor gene. Normally, by the time an embryo has developed, immature cells in the retina have stopped growing and dividing. The immature retinoblasts become differentiated, resulting in distinct photoreceptor and nerve cells within the retina. In children with the mutated gene, the cell cycle continues and differentiation does not occur. Retinal tumours develop. While genes such as the BRCA1/2 and RB1 genes are named according to particular cancers in which they have been implicated, these genes, like p53, are important in controlling the cell cycle in most cell types and are found to be mutated in many different cancers.

Genetic predisposition to cancer

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

RECALL

- There are a number of checkpoints in the cell cycle. They occur towards the end of the G_1 phase, at the end of the G_2 phase and during the M phase.
- The balance between the activities of proto-oncogenes and tumour suppressor genes keeps normal cells dividing at a rate that is appropriate for their position and role in the body.
- Some genetic mutations can lead to a predisposition to develop cancer.

RECAP 7.4

1. Name the checkpoints in the cell cycle.
2. List three reasons why it is important to regulate the cell cycle.
3. Describe what would happen if the p53 surveillance system did not work properly.
4. Define 'genetic predisposition'.

Action of mutagens on the cell cycle

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

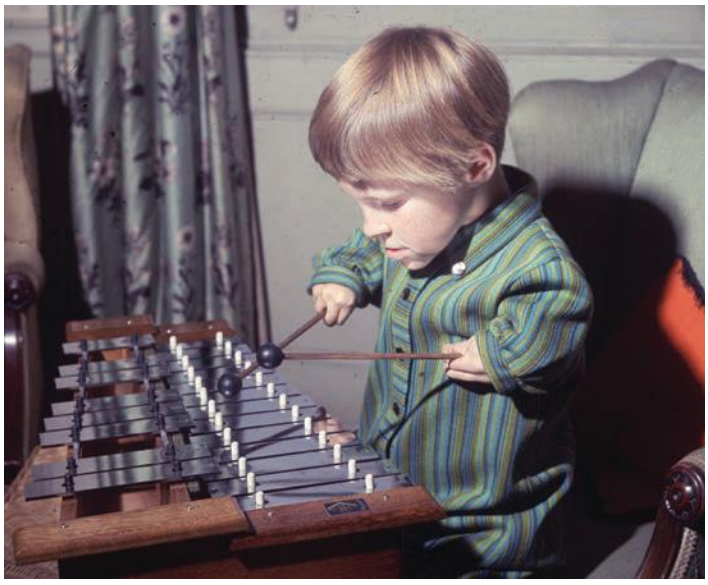
When mutated, proto-oncogenes can become **oncogenes** – genes that stimulate excessive cell division. The gene can become permanently turned on or activated when it is not supposed to be. The production of oncogenic proteins can lead to unregulated cell division, a slower rate of cell differentiation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

Chemical mutagens

There are many types of chemical mutagens, with one thing in common: their ability to interfere with DNA, by interrupting its structure, sequence or replication. Mutagens can introduce mutations in DNA that can change the function of proteins in the cell and impair normal cellular processes, which is especially dangerous when the mutations affect tumour suppressor genes or proto-oncogenes. If the mutation causes the tumour suppressor to become inactive, the result is impaired regulation of

cell cycle checkpoints and loss of inhibition of cell growth, allowing the cell to keep dividing in an uncontrolled manner. If a mutation affects a proto-oncogene, boosting its activity, a similar effect on cell growth may occur.

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



Getty Images

▲ **Figure 7.17** Many children of women who took the drug thalidomide during pregnancy in the 1950s were born with malformed limbs.

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

Physical mutagens

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

▼ **Figure 7.18** Professor Ian Frazer led a team that developed the world's first vaccine against a virus associated with cancer.

Biological mutagens

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



Getty Images/Jonathan Wood

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

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

RECALL

- Disruption of cell cycle regulation can be caused by the action of chemical, physical or biological mutagens. Mutagens that lead to cancer are called carcinogens.
- Mutagens can cause mutations in DNA that may affect proto-oncogenes or tumour suppressor genes, leading to uncontrolled cell division and potentially cancer.

RECAP 7.5

1. Define 'mutagen'. Provide three examples of mutagens.
2. Explain why smoking cigarettes is harmful.
3. Explain how UV rays from the sun may lead to skin cancer.
4. Describe three ways in which viruses can cause cancer.

Stem cells

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

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

Potency of stem cells

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

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

The totipotent cells undergo several rounds of cell division. Approximately five days after fertilisation, they begin to specialise and form a **blastocyst**. The blastocyst is a ball of cells consisting of a hollow outer layer of cells, within which is a cluster of cells called the inner cell mass (Figure 7.20).

The outer layer of cells will eventually form the **placenta**, the organ that supplies nutrients to, and removes wastes from, the **foetus** and other tissues that are needed for the support and development of the foetus. The inner cell mass will form all the tissues of the human body; therefore, these are the cells that develop into the foetus. The cells of the inner cell mass are **pluripotent stem cells**. This means that they are able to give rise to all cell types in a foetus. Pluripotent stem cells are currently under investigation for medical use.

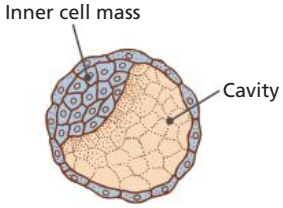
Note that the first two months of pregnancy are referred to as the embryonic period, but after the second month the developing individual is called a foetus.

Each pluripotent cell then undergoes further specialisation into another type of stem cell, a **multipotent stem cell**. Multipotent stem cells give rise to cells that have a particular function; for example, multipotent blood stem cells give rise to red blood cells, white blood cells and platelets, and multipotent skin stem cells give rise to the different types of skin cells. Multipotent stem cells exist in both embryos and adults, the best understood example being the blood stem cell. In each person's bone marrow, blood stem cells constantly replenish the supply of red blood cells, multiple types of white blood cell and platelets.

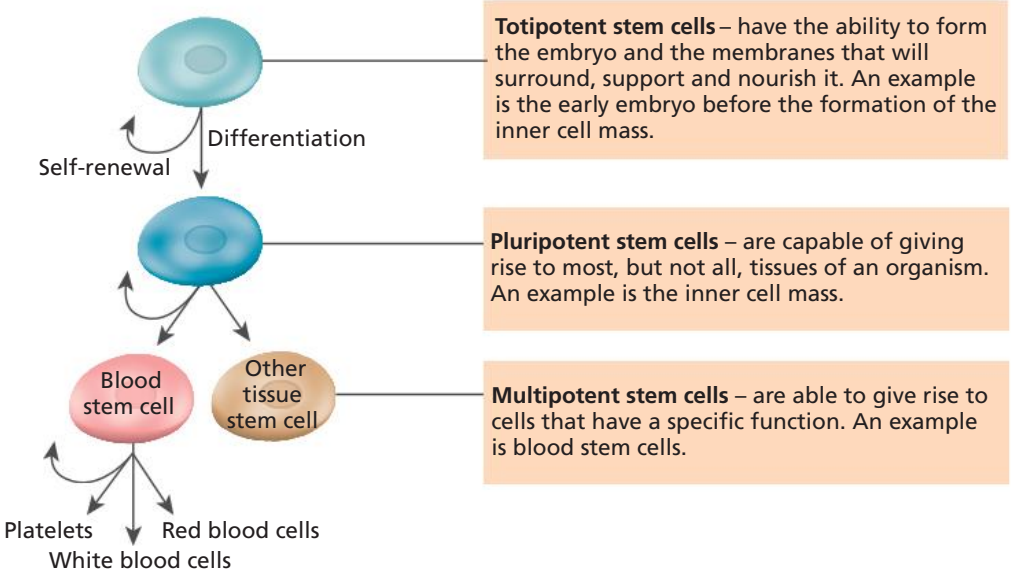


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▲ **Figure 7.19**
A human embryo at the two-cell stage. In this photograph the embryo is still surrounded by the gelatinous covering that was around the egg.



▲ **Figure 7.20**
Blastocyst formation



◀ **Figure 7.21**
The process of cell differentiation

See Chapter 3 for a description of blood cells.

Table 7.2 Potency of stem cells

Totipotent stem cells	Can give rise to all the cell types that make up the human body and all the cell types that make up the membranes that surround the developing embryo (including the placenta)
Pluripotent stem cells	Can give rise to all the cell types that make up the body but *not* the cell types that make up the embryonic membranes
Multipotent stem cells	Can develop into more than one of the cell types that make up the body but *not* all cell types

RECALL

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

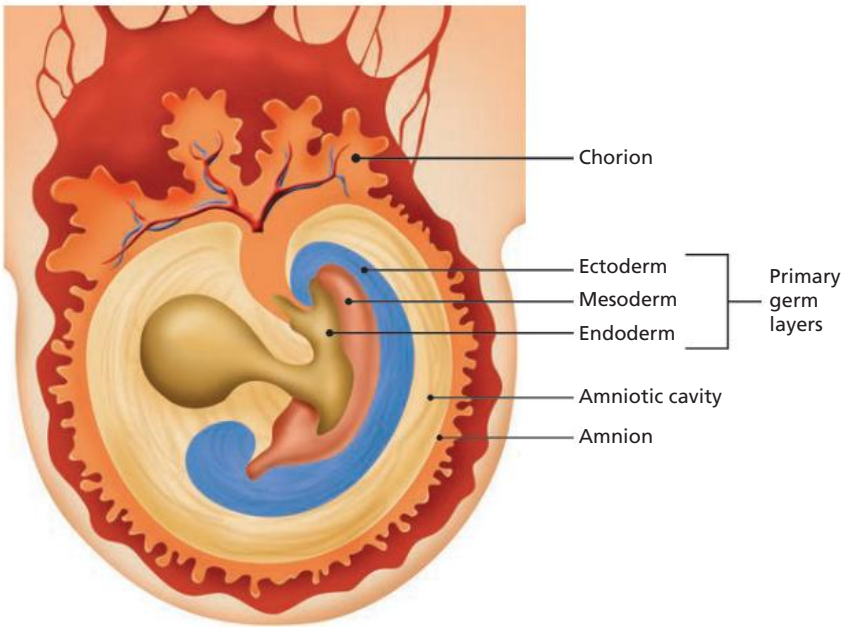
RECAP 7.6

1 Define 'differentiation'.
2 Describe the three different types of stem cells.
3 Explain the importance of stem cells to the body.

Development of germ layers in human prenatal development

While the blastocyst is implanting in the lining of the uterus, the inner cell mass undergoes changes resulting in the formation of three layers of cells, the **primary germ layers** (Figures 7.22). These layers, called the **ectoderm**, **mesoderm** and

Figure 7.22 ▶
Formation of the embryonic germ layers



endoderm, are the embryonic tissues that will differentiate into all the tissues and organs of the body. Table 7.3 lists the structures that are formed by the three primary germ layers.

Table 7.3 Structures formed by the three primary germ layers

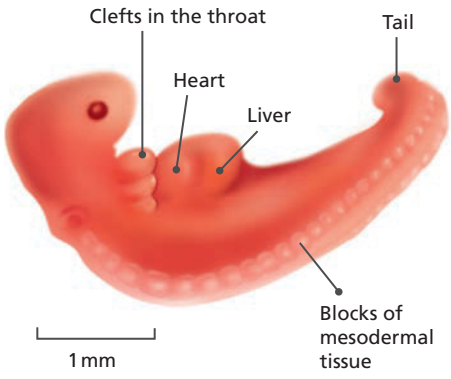
Endoderm	Mesoderm	Ectoderm
Epithelium of alimentary canal and its glands (e.g. liver and pancreas)	Skeletal, smooth and cardiac muscles	Epidermis of skin
Epithelium of urinary bladder, urethra and gall bladder	Cartilage, bone, blood and other connective tissue	Hair, nails, glands of skin
Epithelium of pharynx, auditory canal, larynx, trachea, bronchi and lungs	Lymphoid tissue	Lens, cornea and muscles of the eye
Epithelium of tonsils, thyroid, parathyroid and thymus glands	Endothelium of blood vessels and lymphatics	Receptor cells of the sense organs
Epithelium of vagina and associated glands	Epithelium of the body cavity and joint cavities	Epithelium of mouth, nostrils, sinuses, glands of mouth, and anal canal
	Epithelium of kidneys and ureters	Enamel of the teeth
	Epithelium of ovaries, testes and reproductive tracts	Entire nervous system
	Epithelium of adrenal cortex	Anterior lobe of the pituitary gland
	Dermis of skin	Adrenal medulla

From embryo to foetus

After one month of growth, the human embryo is just under 4 mm long. The most obvious feature at this stage is the development of muscle segments on either side of the tube that is to become the brain and spinal cord. These blocks of mesodermal tissue increase in number over time. By the end of the fourth week there are 30 pairs of them, representing the beginnings of the muscles and the vertebrae of the spinal column. In addition, the brain is beginning to form, a tail is evident, and the heart and liver are beginning to develop (Figure 7.23).

The throat region contains a number of pharyngeal arches with clefts between them. As development proceeds, these arches will form the structural elements of the face and throat, and the pouches that develop in the clefts will give rise to the epithelial linings and glands associated with the throat.

During the fifth week, the arm and leg buds start to appear (Figure 7.24 on page 232). The arm buds are slightly more advanced, but both elongate rapidly from this time on. By the end of the embryonic period (week 8), the embryo has a recognisably human form and all organs are present, although many are not fully functional. It has undergone considerable growth from a microscopic cell to being 3 cm in length from the top of its enlarged head to its buttocks, and weighing approximately 1 g. The head is almost half the size of the embryo (Figure 7.25 on page 232) and the eyes appear like slits, having moved from the sides of the head to be directed forward. The jaws are almost fully developed, as is the nose, and there are small earlobes. The arms and legs are well proportioned, and the hands are formed with distinctly human fingers. Similarly, the toes are well formed, and the external sexual organs are evident, so the embryo is clearly male or female.



▲ **Figure 7.23** Embryo at the end of the fourth week

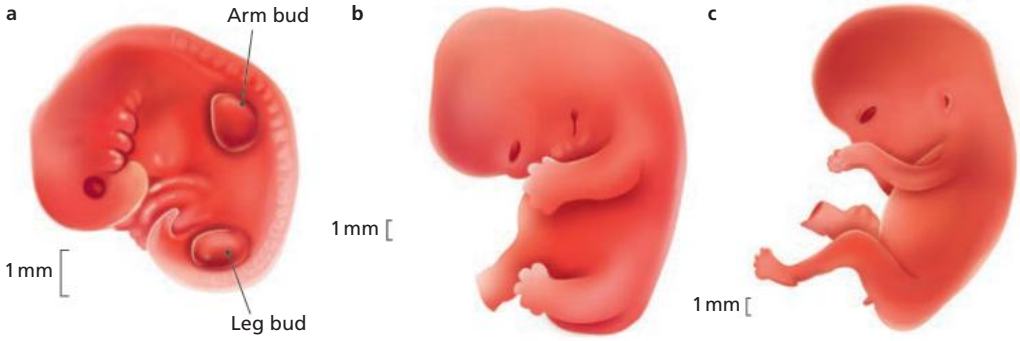


Figure 7.24 ▶
(**a**) Embryo at the beginning of the fifth week; (**b**) Embryo at the middle of the sixth week; (**c**) Embryo at the end of the seventh week



Approximate actual size

Figure 7.25 ▲
An 8-week-old foetus

By the end of the first two months of embryonic life, the general body form of the infant has developed and the basic plan of the organ systems is in place. The developing baby is now known as a foetus.

RECALL

- There are three primary germ layers in a human embryo: the ectoderm is the outer layer of cells, the endoderm is the inner layer of cells and the mesoderm is the middle layer of cells.
- By the end of the 8-week embryonic period, the general body form of a baby has developed and the basic plan of the organ systems is in place. The developing baby is now called a foetus.

RECAP 7.7

1 Name the three primary germ layers.
2 Give two examples of tissues that develop from each of the germ layers.
3 Distinguish between 'embryo' and 'foetus'.

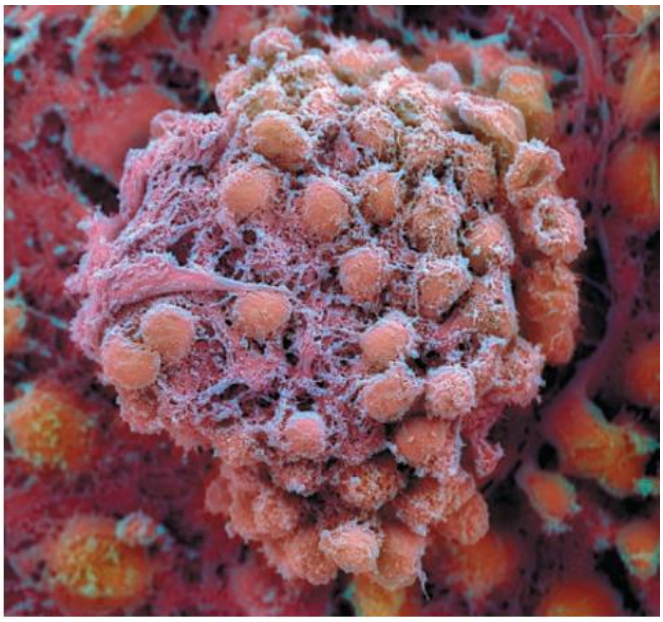
Sources of stem cells for research and therapy

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

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

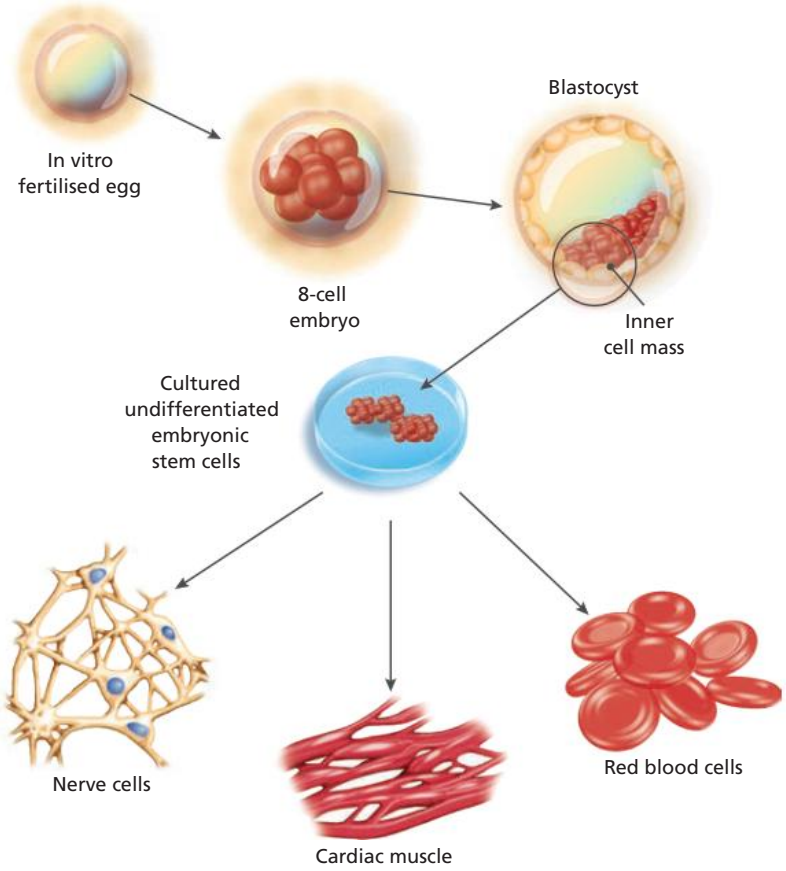
In Australia there is a national network of umbilical cord blood banks called AusCord. Parents can choose to donate their baby's cord blood to one of AusCord's public cord blood banks. The donated blood is then available to any suitable recipient. If parents wish to ensure that the cord blood is available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

2 *Embryonic stem cells:* **Embryonic stem cells** (Figure 7.26) are cultured from frozen embryos (Figure 7.27) that are obtained from in vitro fertilisation clinics. Unused embryos from in vitro fertilisation may be donated to research because the couple no longer desire additional children and do not wish to continue storage. However, there are significant ethical issues related to the use of embryonic stem cells, because obtaining them requires destruction of an embryo, and governments have strict regulations in place for controlling this type of technology. A potential advantage of using embryonic stem cells is that they are pluripotent. They can become any of the cell types of the body and are therefore more versatile than adult stem cells. A disadvantage is that they come from embryos that are not derived from the patient's own cells, and the patient's immune system may therefore reject them.



Science Photo Library/Professor Miodrag Stojkovic

▲ **Figure 7.26**
A scanning electron micrograph of human embryonic stem cells



◀ **Figure 7.27**
Culturing embryonic stem cells may allow scientists to grow replacement tissues and organs for patients.

3 *Adult stem cells:* Multipotent **adult stem cells** can form cells of many kinds of tissue. An important potential advantage of using adult stem cells to treat disease is that a patient's own cells could be used for treatment. Risks are lower because a patient's immune system would not reject its own cells. A disadvantage of most adult stem cells is that they are pre-specialised – for example, blood stem cells make only blood, and brain stem cells make only brain cells. It appears that most organs of the body have stem cells so that they can replace dead or damaged cells. For example, bone marrow contains multipotent stem cells that give rise to all the cells of the blood. Bone marrow is, therefore, a good source of adult stem cells (Figure 7.28).

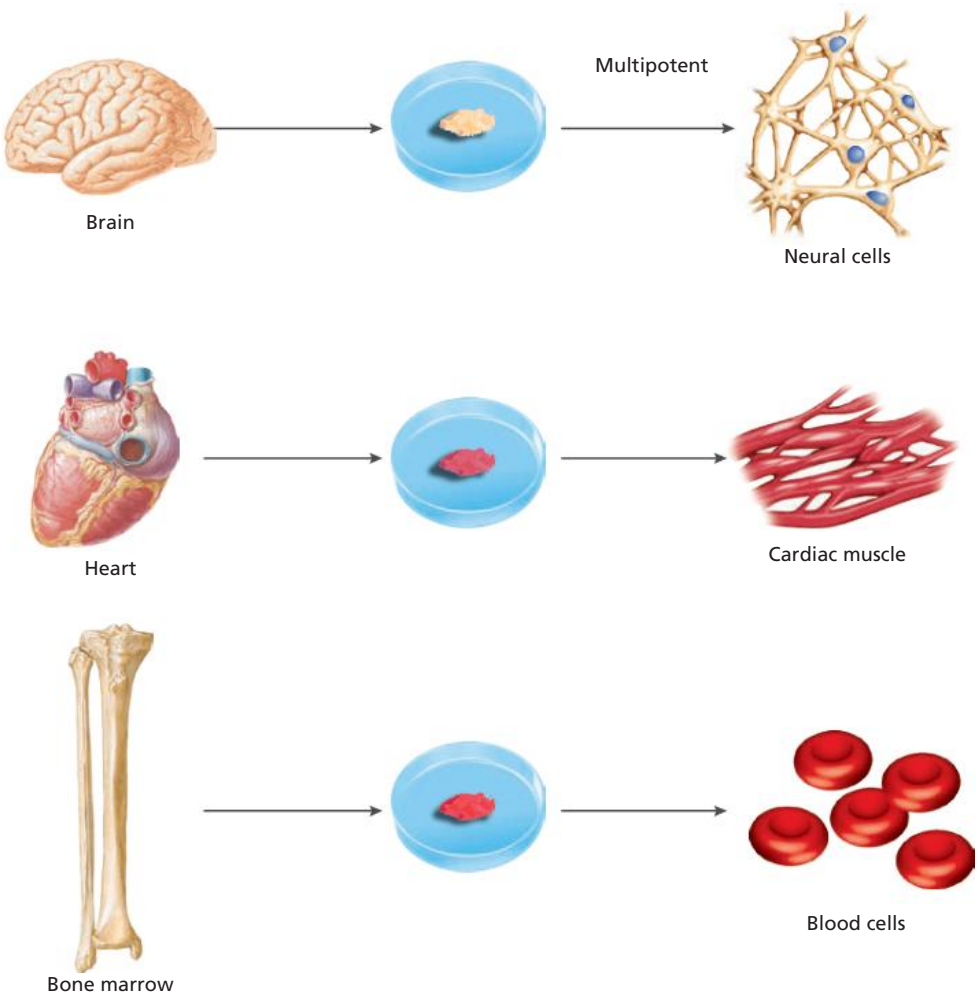


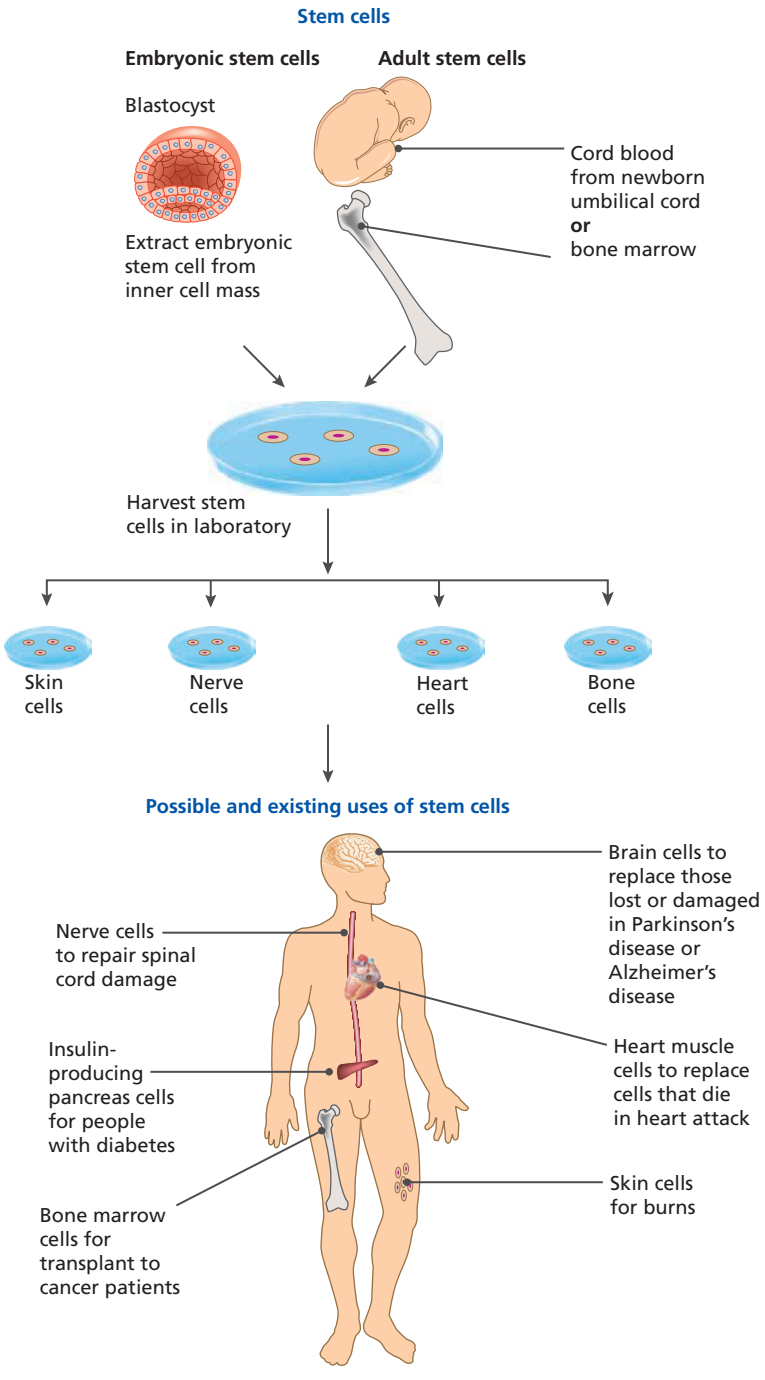
Figure 7.28 ▶
Examples of adult stem cells. Adult stem cells are now thought to be multipotent.

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

Stem cell research

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

Because of their ability to differentiate into cells of many different types, stem cells are the subject of intense scientific research. It is hoped that ways will be found to use stem cells in cell-based therapies to treat disease (Figure 7.29). If stem cells could be made to differentiate into particular cell types, they could provide replacement tissues for treating conditions such as stroke, spinal cord injury, burns, heart disease, diabetes, arthritis, Alzheimer's disease and Parkinson's disease. In addition to being used in cell-based therapies, stem cells could be used for such things as testing new drugs or testing toxins, and for understanding the causes of birth defects.



◀ **Figure 7.29**
The process of culturing stem cells, and their possible uses

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

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

RECALL

- There are three sources of stem cells for research and therapy: umbilical cord blood and placental stem cells (a type of adult stem cell), embryonic stem cells and adult stem cells.
- Embryonic stem cells are obtained from 3–5 day old embryos and give rise to many different types of specialised cells.
- Adult stem cells are obtained from adult tissues. These stem cells give rise to the same type of tissue as where they were taken from.

RECAP 7.8

1 Name the three sources of stem cells.
2 Summarise the differences between embryonic stem cells and adult stem cells.
3 Describe three potential uses of stem cell therapy.

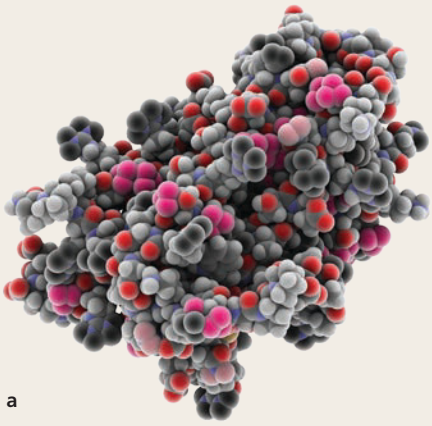
Investigation of an issue: A lifesaving therapeutic drug is abused for power

Refer to Chapter 11 for more information on the investigation of an issue.

Every second over 2 million red blood cells (erythrocytes) are produced in your bone marrow. You produce approximately 200 billion every day. Each erythrocyte lasts approximately 120 days. In its lifetime it will travel through the lungs an average of 170 thousand times, picking up a cargo of oxygen using the millions of haemoglobin molecules inside the cell. It then gets pumped around the body by the heart, through the circulatory system, so it can deliver oxygen to cells along its path. It squeezes through the very narrow passages of capillaries, allowing oxygen to diffuse through the capillary walls into the body tissues.

Over time, erythrocytes become damaged. The spleen monitors red blood cells and targets damaged ones for destruction. Your body makes and destroys approximately the same number of erythrocytes every day, keeping erythrocyte numbers in balance. This balance is important. Too many erythrocytes circulating in the blood make it thick and can lead to thrombosis or stroke. Too few and you become tired and anaemic as not enough oxygen is delivered to cells.

How does your body know how many red blood cells to make? This is regulated by your kidneys. A specific set of cells in the kidney are sensitive to hypoxia – that is, low levels of oxygen. If not enough oxygen is being ferried through the kidneys, these kidney cells release a protein hormone called erythropoietin (EPO). This hormone travels in the blood to target stem cells in the bone marrow. These stem cells have surface receptors that specifically bind EPO. When EPO binds to EPO receptors on stem cells, a message is passed into the cell that initiates a series of changes. Genes are expressed and proteins are made. These proteins commit the stem cell to cell division and they switch off apoptosis pathways. After cell division, other proteins commit the cell to differentiate into



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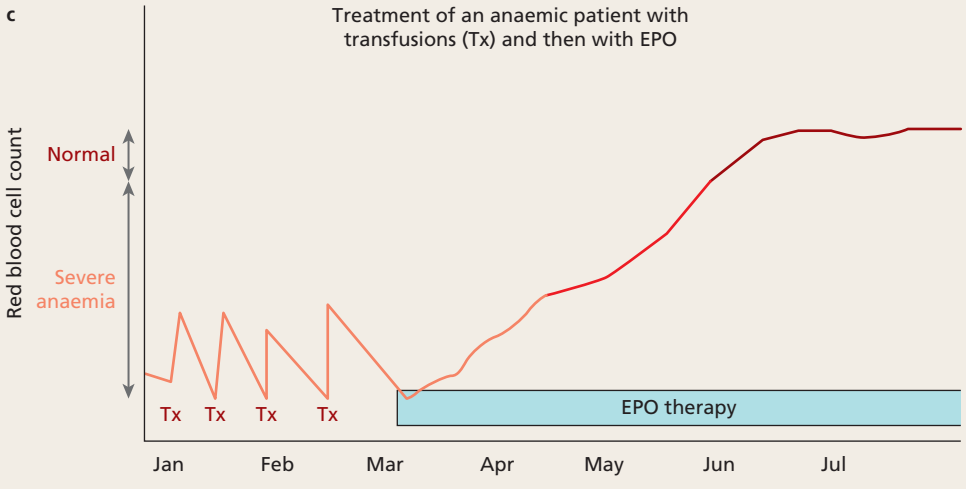
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erythrocytes and produce haemoglobin. These red blood cells exit the cell cycle and can no longer divide. As more red blood cells are produced, oxygen levels in the kidney tissues increase, so the kidney cells slow down production of EPO. EPO only stays in the circulation for a short time but its effects on target cells can last for days.

Sometimes disease can interfere with this regulatory mechanism and people can suffer from anaemia, as not enough erythrocytes are produced. Anaemia is just one of the symptoms of chronic kidney disease, which affects 1 in 10 Australians. Since the 1980s this type of anaemia has been treated with recombinant EPO, produced using genetic engineering technologies. Bacteria transformed with the human EPO gene produce recombinant EPO (rEPO) that is almost identical to natural EPO. The rEPO is injected and enters the bloodstream to stimulate erythrocyte production (Figure 7.30).



Getty Images/Frederic Stevens



◀ Figure 7.30
(**a**) EPO, mass produced in bacteria (**b**) EPO is used as a replacement therapy to treat anaemia. (**c**) A graph of the red blood cell count of an anaemic patient treated first with transfusions, and then with EPO

Over to you: Using models to make predictions and communicate science

Task 1: Helping patients with chronic kidney disease

Models are often used by doctors to explain to patients why a diagnostic test is being carried out, what the results mean, and what is making them experience their particular symptoms. Imagine you are a doctor consulting with a person who has chronic kidney failure. Your patient looks very pale and is describing symptoms of lethargy. Complete the following steps to clearly communicate to your patient the biological concepts underpinning your diagnosis, their illness, and suggested tests and treatments.

Step 1

Construct a model to represent how erythrocyte numbers are controlled through the production of EPO. Be sure to include the following elements in your model: kidney, EPO, stem cells in bone marrow, erythrocytes. As there is a feedback mechanism at play in this system, make sure that your model represents this clearly.

Step 2

Use this model along with the patient history and symptoms to make a preliminary diagnosis. Defend this diagnosis (your prediction) by referring to your model.

Step 3

Recommend a diagnostic assay that could test your preliminary diagnosis. Describe how the test would work, including what a positive and negative result would look like and what this means to the patient.

Step 4

Regulation of cell division can be represented using a cell cycle model. Construct a cell cycle model and use it to indicate the stage of the cycle where EPO would exert its effect on a stem cell in the bone marrow. Also indicate at which stage of the cycle a cell would differentiate into an erythrocyte.

Step 5

Connect the information in these models to suggest a treatment for your patient and to describe how the treatment would work.

Task 2: Detecting the use of rEPO as a performance-enhancing drug

Elite sports are big business and sometimes athletes use illegal methods to enhance their performance. Blood doping is one method used to increase the capacity of blood to supply oxygen to the muscles. This can increase endurance in long-distance events such as cycling. A number of tests for blood doping exist. Critique the following tests to assess their effectiveness in determining whether an athlete has injected rEPO to enhance their performance.

- Comparing an athlete's blood profile (including erythrocyte numbers) at testing time to results collected previously. Is it possible to use methods other than blood doping to increase erythrocyte levels?
- Blood and urine test to detect the presence of rEPO.

Blood doping tests are designed not only to stop cheating, but also to protect athletes. Use the information and statistics in Table 7.4 and your knowledge of the risks associated with higher than normal erythrocyte levels to construct an argument of 400–500 words as to why we should continue to invest in methods of detecting performance-enhancing drugs in sport.

Table 7.4 Factors affecting the drug doping issue

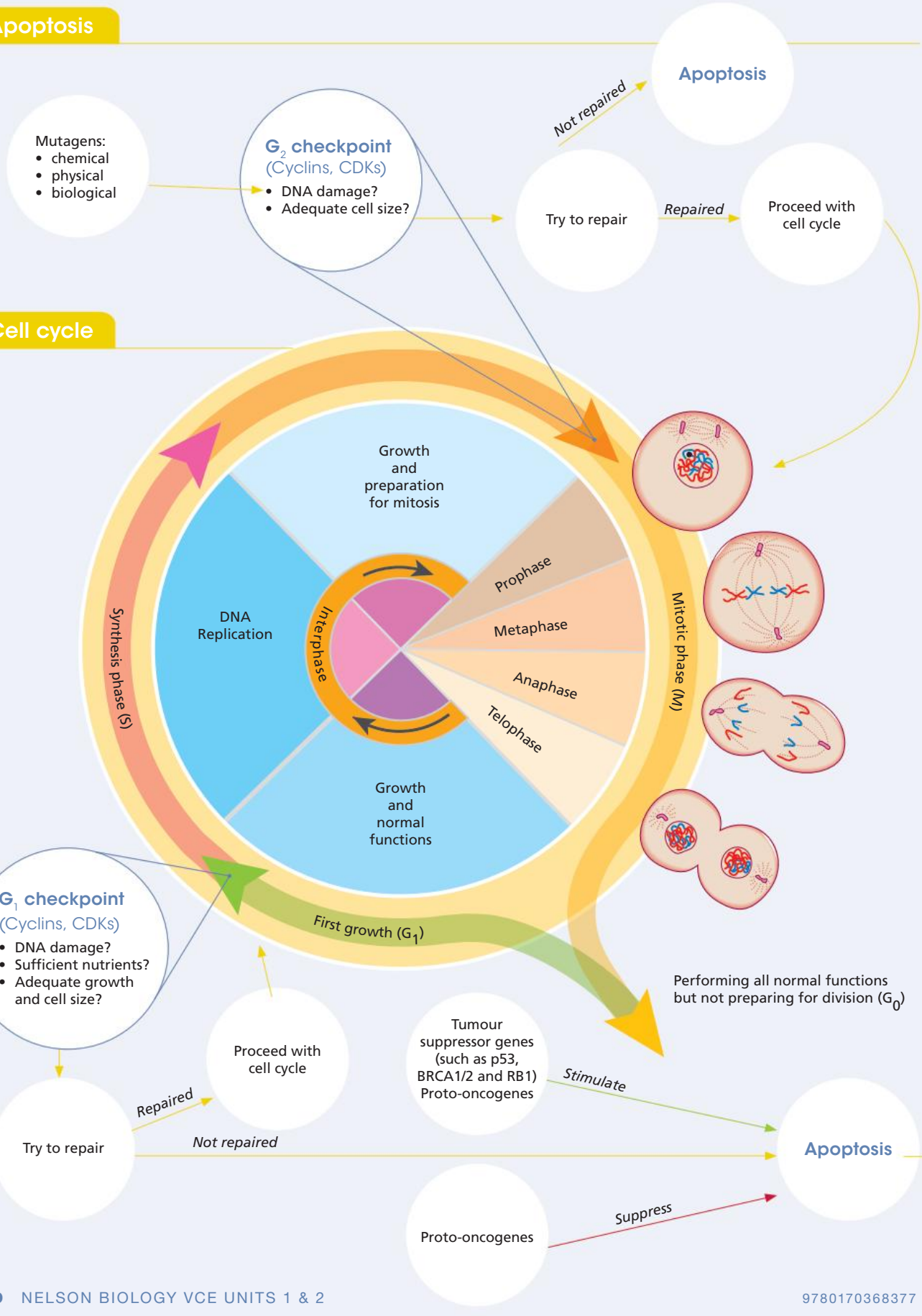
Action	Result
In 1999 the World Anti-Doping Agency (WADA) was established.	The World Anti-Doping Code is produced – this lists banned substances and provides a consistent approach to sanctions. Resources are used more effectively to fund studies aimed at improving drug detection methods.
In 2001 the international governing body for athletics introduced a blood testing program.	It is hoped that less drug doping occurs as a consequence. See study by Sottas et al. (2011) for results.
A study by Sottas et al. (2011) was conducted on 7289 blood samples from 2737 top-level track and field athletes to detect evidence of blood doping. A number of samples were tested for each athlete, to reduce the likelihood of false positives.	A mean score of 14% of athletes were found to be doping. Of these positives, major factors that correlated with positive results include: • endurance sports (79%) • ethnicity (white 63%) • age (66% > 24 years of age) • nationality (in particular countries, up to 43% tested positive) • 92% of positives were training at low altitude leading up to the test.
$310 million was spent by the Australian Institute of Sport (AIS) to prepare athletes for the London Olympics in 2012.	Australia performed poorly in the Olympics (35 medals in total) and media and society questioned whether almost $10 million spent per Olympic medal was money well spent.
In 2012 Cadel Evans, a cyclist trained by the AIS, was listed by *Business Review Weekly* as earning a $4.5 million annual salary.	Opportunities to earn money from commercial sponsorship are increasing.
In the past 47 years of the Tour de France, there have been 28 winners. Half of the winners have either tested positive or confessed to drug doping.	EPO can enhance performance by up to 15%. Translated into minutes this can be the difference between coming first or finishing at the back of the field in the Tour de France.
In 2003 and 2004, eight cyclists at the peak of their career died in their sleep from heart attack.	Autopsy cannot reveal whether these deaths were caused by drug doping, but the correlation requires further study.

Reference

Sottas P., Robinson N., Fischetto G., Dolle G., Alonso J. & Saugy M. (2011) Prevalence of blood doping in samples collected from elite track and field athletes. *Clinical Chemistry* 57(5): 762–9.

CONCEPT SUMMARY

Apoptosis



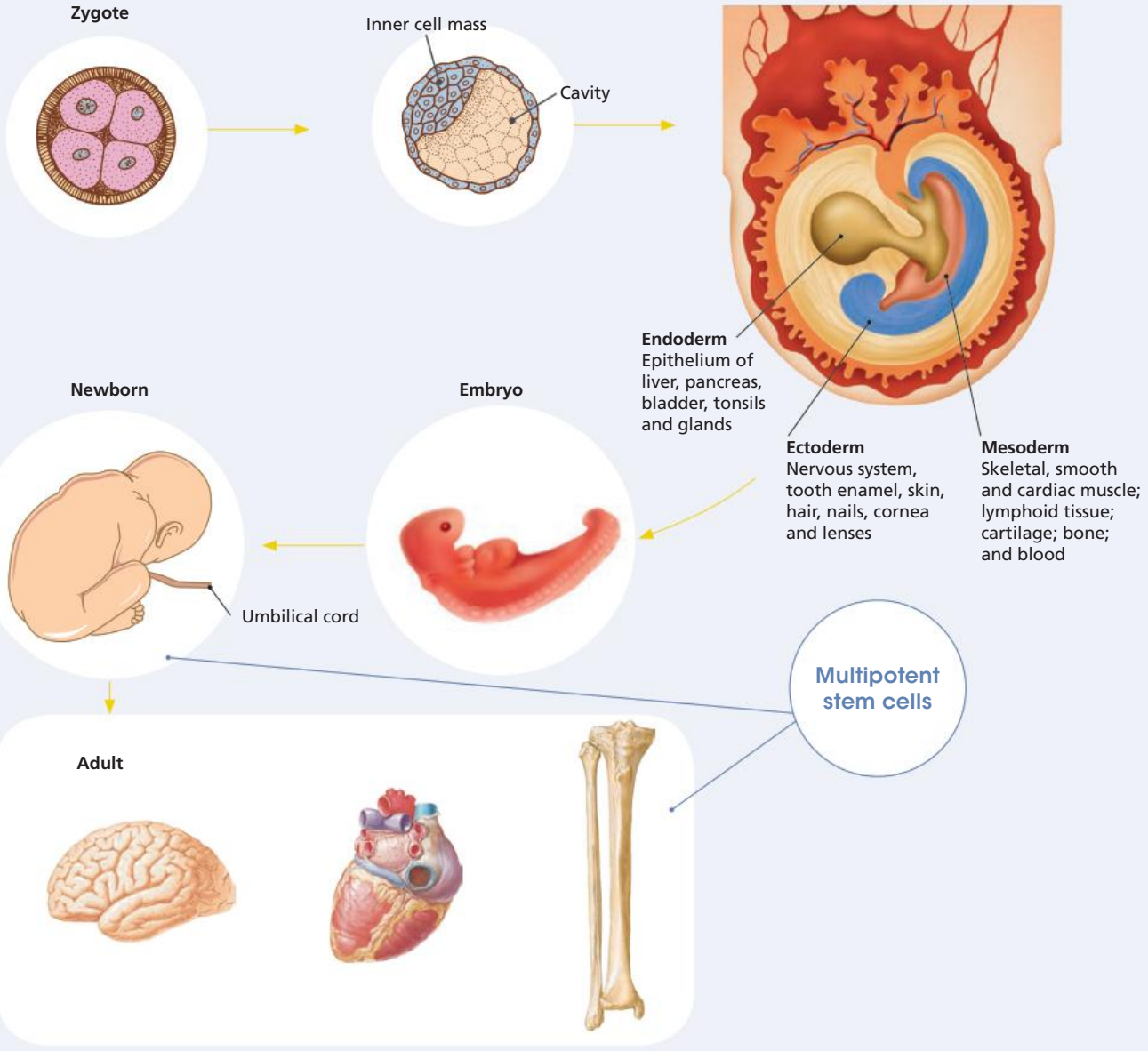
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Stem cells

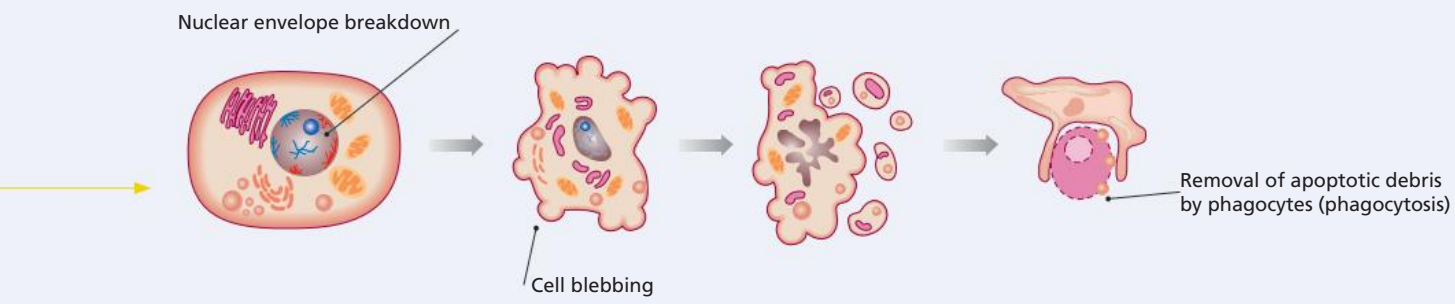
Totipotent stem cells

Pluripotent stem cells

Multipotent stem cells



Apoptosis



CHAPTER GLOSSARY

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

apoptosis a programmed series of events that lead to cell death

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

blastocyst a hollow ball of cells formed during early embryonic development

bleb a balloon-like outgrowth of the plasma membrane

carcinogen a cancer-causing agent

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

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

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

centriole a minute rod-shaped body present in many resting cells just outside the nuclear membrane; it doubles before mitosis, moving apart to form the poles of the spindle; usually absent in plants

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

chromatid daughter strands of a duplicated chromosome

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

chromosome a structure composed of DNA and protein that contains along its length linear arrays of genes carrying genetic information; prokaryotes have one circular chromosome while eukaryotes have a number of linear chromosomes

cleavage division of the cytoplasm in an animal cell

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

cyclin a type of molecule that regulates the cell cycle

cytokinesis division of the cytoplasm

daughter cell one of the cells resulting from the division of a cell

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

ectoderm the outer tissue layer of the embryo; it gives rise to the outer covering of the body

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

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

endoderm the inner tissue layer of the embryo

foetus the developing individual after the second month of pregnancy

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

interphase the stage between nuclear divisions

mesoderm the middle tissue layer of an embryo

microtubules fine tubes that help to maintain the shape of the cell and separate chromosomes during mitosis

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

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

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

nucleolus a structure found within the nucleus of a non-dividing cell; a site in which the protein and RNA subunits of ribosomes are assembled

oncogenes genes that can promote cancer

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

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

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

primary germ layers the embryonic tissues from which all tissues and organs of the body will develop; the ectoderm, endoderm and mesoderm

proto-oncogene a gene that can promote cancer

quiescent inactive

reproduction the creation of a new generation of single cells, single-celled organisms or multicellular organisms

retinoblastoma a cancer of the retina in the eye

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

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

teratogen an agent that causes physical defects in a developing foetus

terminally differentiated cells cells that have lost their ability to replicate

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

tumour suppressor gene a gene that inhibits cell division

umbilical cord the cord that attaches the foetus to the placenta

CHAPTER REVIEW QUESTIONS

Remembering

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

Understanding

6 Distinguish between a chromatid and a chromosome.
7 Compare binary fission to mitosis.
8 Explain why p53 is sometimes called the 'guardian of the genome'.
9 Explain the role of tumour suppressor genes and oncogenes in cancer development.

Applying

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

Evaluating

20 An umbilical cord blood bank was established in Australia in 1995. Parents can voluntarily have a sample of their baby's cord blood stored for later use. Discuss the advantages of such a bank.
21 A group of cells being studied were never observed to undergo division. Predict whether this means the cells were dead. Justify your answer.
22 Interphase is sometimes referred to as the 'resting phase'. Evaluate this statement, giving reasons why this description is or isn't accurate.

Creating

23 Paclitaxel is a drug that stops microtubules such as spindle fibres from disassembling.
   a Predict what effect this fault would have on mitosis.
   b Describe the checkpoint of the cell cycle that would normally detect this fault.
   c Write a press release of no more than 300 words for paclitaxel to communicate its benefits for treating cancer.
24 Create a concept map showing how cancer develops, using your understanding of how proto-oncogenes, oncogenes and tumour suppressor genes contribute to the process.

25 Stem cells have caused great excitement in medical research. They have also caused much ethical and scientific debate. Key reasons for such excitement and debate relate to how stem cells differ from other body cells, their source, how they are being used in research, and why they are being used. Investigate these reasons and construct a PMI chart (Plus, Minus, Interesting) on the use of stem cells in medical research.

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

- If these technologies are not safe for humans, how can they be tested?
- How can the study of their potential be continued?
- Who or what should they be tested on?
- What kinds of guidelines should scientists follow in this type of research?

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

27 Reflect on your lifestyle. Discuss whether your understanding of the concepts in this chapter has made you more aware of ways to reduce your risks of developing cancer later in life.



CHAPTER 8

ASEXUAL AND SEXUAL REPRODUCTION

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

KEY KNOWLEDGE

Asexual reproduction

- the types of asexual reproduction including fission, budding, vegetative propagation and spore formation
- the biological advantages and disadvantages of asexual reproduction
- emerging issues associated with cloning, including applications in agriculture and horticulture.

Sexual reproduction

- how an offspring of two parents has a unique genetic identity
- the key events in meiosis that result in the production of gametes from somatic cells including the significance of crossing over of chromatids between homologous chromosomes in Prophase 1 and the non-dividing of the centromere in Metaphase 1
- the biological advantage of sexual reproduction, specifically the genetic diversity in offspring.

Investigation of an issue

- the 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 nature of evidence and information: distinction between opinion, anecdote and evidence, weak and strong evidence, and scientific and non-scientific ideas; and validity, reliability and authority of data including sources of possible errors or bias
- the influence of social, economic, legal and ethical factors relevant to the biological issue.

KEY SCIENCE SKILLS

Draw evidence-based conclusions

- determine to what extent evidence from an investigation supports the purpose of the investigation, and make recommendations, as appropriate, for modifying or extending the investigation
- identify, describe and explain the limitations of conclusions, including identification of further evidence required
- discuss the implications of research findings and proposals

Communicate and explain scientific ideas

- identify and explain formal biological terminology about investigations and concepts
- use clear, coherent and concise expression

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Figure 8.1 ▲
Strawberry fields in the Yarra Valley area of Victoria

There are many tourist destinations in Victoria. The Yarra Valley in the outer eastern area of Melbourne is particularly attractive to tourists interested in fine food and wine. If you drive through the area, you will find roadside stalls selling different fruits and berries, including locally grown strawberries.

If you were to grow strawberries in your garden, you would observe 'runners' coming from the plants. These are offshoots of the parent plant. At intervals along the runner, nodes appear. From each node, a daughter plant or 'plantlet' can develop, complete with roots and leaves. Each of these plantlets forms a new individual plant with the same genetic make-up as all the others. In this way, one strawberry plant can cover a large area with genetically identical offspring.

The strawberry plant also produces flowers that are pollinated by insects. Strawberries will only develop when the flowers are pollinated. These strawberries contain seeds that are all genetically different from the parent plants. These seeds are then dispersed by animals that eat the strawberries.

Strawberry plants are unusual in that they reproduce both asexually (producing offspring with the same DNA as their parents) in the plantlets that form from runners, and sexually (combining DNA from two different parents) in plants that arise from the seeds of strawberries.

Asexual reproduction

When strawberry plants send out runners, new cells are produced by the process of **mitosis**. Mitosis ensures that the two cells formed have exactly the same DNA as the dividing parent cell. When organisms reproduce by mitosis, this is known as **asexual reproduction**. Organisms produced by asexual reproduction are exactly the same genetically as their parent.

Asexual reproduction occurs in both prokaryotic and eukaryotic organisms, both unicellular and multicellular. All cells produced by asexual reproduction are genetically identical to the cell or cells of the parent.

Asexual methods of reproduction are divided into a number of types:

- fission
- budding
- vegetative reproduction
- spore formation.

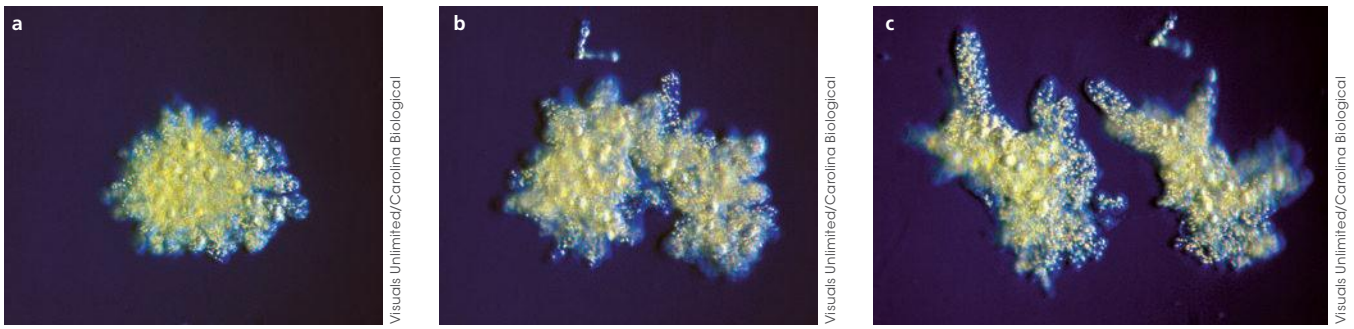
Fission

Further details about mitosis and binary fission are provided in Chapter 7.

Amoebae are single-celled, eukaryotic organisms possessing a nucleus and other membrane-bound organelles. These organisms reproduce by **binary fission**, which is the division of a parent nucleus by mitosis and then division of the cytoplasm to produce two new daughter cells.

The rate of multiplication by fission can be extraordinary. For example, under suitable environmental conditions, cells can divide every 20 minutes. This means that in a 24-hour period a single cell can lead to a population in excess of 4^{21} (or 4 billion trillion) cells. This number of cells is achievable because the increase in cell division is **exponential**. For example, from one amoeba dividing every 20 minutes, only eight

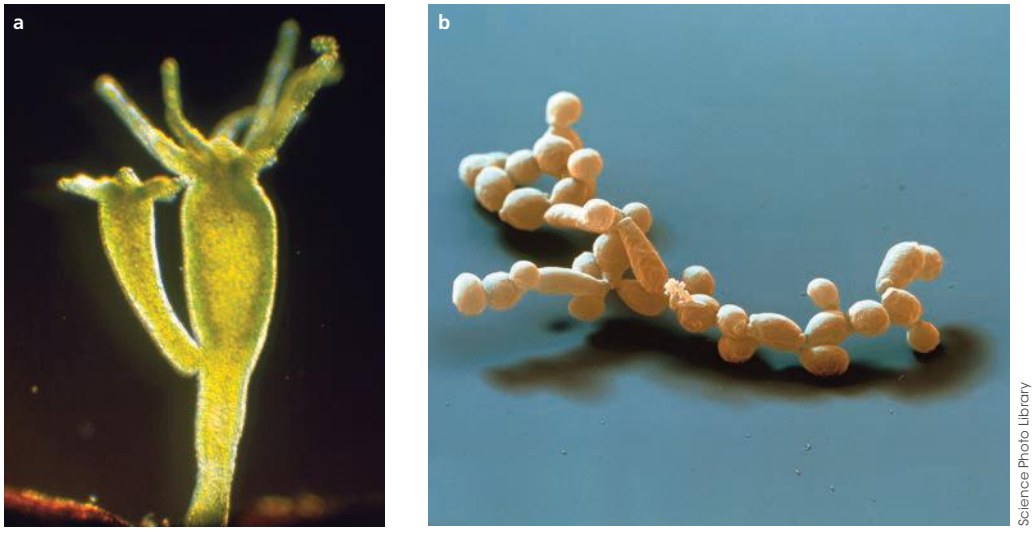
amoeba will be present at the end of the first hour, but 512 amoeba will be present after 3 hours, and by the end of the day the number of amoeba produced is almost overwhelming. This does not actually happen, as there are other population controls on amoeba such as space, food and build-up of toxic wastes.



▲ **Figure 8.2**
(**a**) The parent amoeba (**b**) Cell division begins. (**c**) Two new daughter cells

Budding

Hydra is a multicellular animal in the phylum Cnidaria. It is found in freshwater environments, which are sometimes turbulent. Occasionally, the *Hydra* may experience injuries that seemingly amputate parts of its body. *Hydra* have the unique ability to regenerate parts of their body and give rise to a complete organism. The process *Hydra* undergoes is one of **budding**, which involves the development of a new organism or parts of an organism from an outgrowth of the parent organism. The new organism may detach from the parent and grow to adult size. If the new individual remains attached to the parent, a branching colony is formed. This form of reproduction also occurs in yeast cells, some flatworms and several of the annelid groups.



◀ **Figure 8.3**
(**a**) In *Hydra* a new individual forms from the outgrowths of the parent by producing a bud that branches from the side of the body. (**b**) Budding in yeast, where new individuals remain attached to the parent body

Vegetative propagation

You may have tried cutting the top off a carrot or pineapple and planting it. This is enough to grow a whole new plant. Have you ever walked around your neighbourhood and collected pieces of plants from people's gardens? If you put the piece of plant into water you may find that after a few days, roots begin to sprout. If you then transfer it into the garden, a new plant will grow.

The new plants produced are genetically identical to the parent plant – they are **clones** of the parent plant. This is a form of asexual reproduction known as **vegetative**

propagation and is seen only in plants. Vegetative propagation involves part of a plant body becoming detached and developing into a new individual. Vegetative propagation can be performed artificially and one technique is known as **grafting**.

With this method, a piece of stem of one plant is attached to the stem and roots of another. The actively dividing tissues of the different plants join here and unite, giving rise to normal conducting tissue. The plant to which the part of another plant is attached in grafting is the **stock** and the piece of stem is the **scion**. This method of propagation is commercially important to growers of fruit trees and roses as it enables the reliable production of plants with desirable qualities.

The runners produced in strawberry plants are an example of vegetative propagation. This form of reproduction is also seen in the piggyback plant from the saxifrage family.

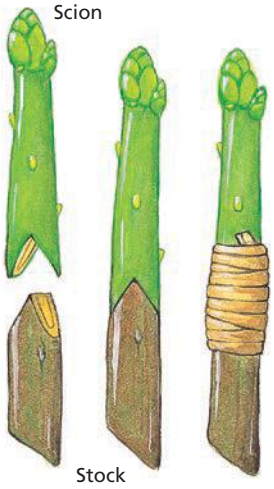
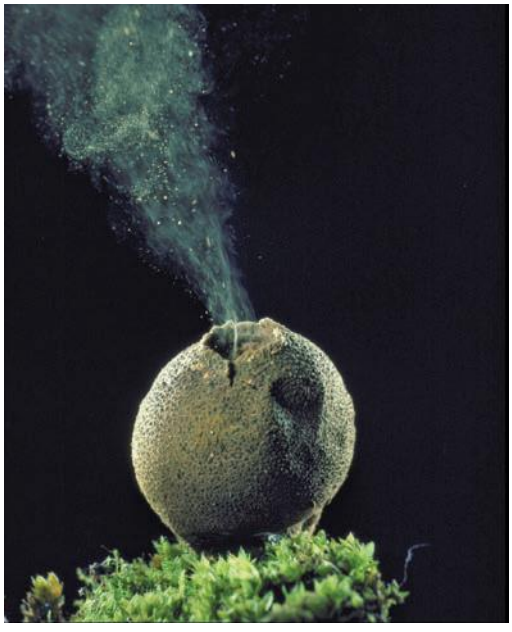


Figure 8.4 ▲
Grafting techniques are used by growers to produce desirable qualities in their plants.



Alamy/Kevin Ebi

Figure 8.5 ▲
New plants arise from the upper side of the old leaves of the piggyback plant, a member of the saxifrage family, a perennial herbaceous plant native to North America.



Getty Images/OSF/Richard Packwood

Figure 8.6 ▲
A puffball releasing a cloud of spores

Spore formation

In desert conditions, survival and reproduction of plants is often difficult and confined to a short period of time. Some plants conserve energy and water by producing **spores** – hardy, self-contained capsules that contain the DNA instructions required to produce a new plant in times of rain.

Spores are single-celled structures formed by cell division in a parent organism. Spores detach from the parent organism and develop into new individuals in suitable environmental conditions. Prokaryotes, protists, fungi and many plants such as ferns and club mosses, can produce spores. Spores are generally mass-produced, small and light, and are easily dispersed by wind, water or animals. Each spore may be surrounded by a thick, resistant wall, which helps it survive unfavourable environmental conditions such as drought, extremes of temperature and time. Spores found in the tombs of the Egyptian pharaohs have been germinated to grow into new plants.

RECALL

- Asexual reproduction occurs when cells or organisms reproduce by mitosis.
- Organisms produced by asexual reproduction are exactly the same genetically as their parent.
- Asexual methods of reproduction include fission, budding, vegetative reproduction and spore formation.

RECAP 8.1

1 Prepare a table describing the four methods of asexual reproduction. Your table will have three columns, headed:
   - Name of method
   - Description of method
   - Example.

2 Explain the benefits of producing spores.

3 Explain why organisms produced by asexual reproduction are referred to as clones.

Asexual reproduction has biological advantages

Asexual reproduction enables the exploitation of an ideal habitat. For example, say a single spore from a fungus lands on a patch of damp soil beneath a pine plantation. The best conditions for growth of the fungus are here, and therefore it is advantageous for the fungus to reproduce quickly and maximise the number of offspring. In plants, a crop with identical features will thrive in a suitable situation.

Considering the characteristics of asexual reproduction, it is possible to understand the biological advantages of this type of reproduction.

- Asexual reproduction involves only one parent; a mate is not required. Consequently, there is no need to spend time and energy searching for a suitable mate. Energy is also saved because there is no need to develop special mechanisms to combine germ cells (e.g. egg and sperm) and allow **fertilisation** (fusion of germ cells). Instead, the available energy can be used to produce numerous offspring. This is important when an organism colonises a *new* area, as suitable mates might not be available in this area. It is also important if organisms are confined to one particular place and are unable to look for a mate – an example is the fungus in the pine plantation mentioned previously.
- All the offspring are genetically identical to the parent. If an individual is well adapted to an area and has a successful genetic make-up, this is reproduced exactly many times to form many new individuals with that particular gene pattern. The offspring are equally well adapted to their environment because of the success of their parents.
- A large number of offspring are reproduced rapidly and efficiently. This enables offspring to spread and colonise an area quickly and to take advantage of favourable environmental conditions. This is particularly advantageous in stable environments with very little change.

Asexual reproduction can be disadvantageous in certain situations

Asexual reproduction has short-term benefits, with rapid growth of the population in a stable environment. However, asexual reproduction does not produce variation between organisms, which can leave populations susceptible to extinction when the environment changes or when an infection kills all the individuals in the population.

- Offspring are genetically identical. If environmental conditions change, there is very little variation, other than mutations, to allow for adaptation to the changed conditions. Whole communities of genetically identical individuals may not survive these changes. An asexual species runs the risk of suddenly disappearing because of a catastrophe that affects all organisms of the species that are genetically identical. If there is a genetic mutation in the parent cell, it may cause harmful effects on the survival ability of the offspring. This could be deadly to all these individuals.
- A large number of offspring are reproduced rapidly. This may be disadvantageous if the offspring are close together and have to compete for limited resources.

RECALL

- Advantages of reproducing asexually include: not needing to spend time and energy seeking a receptive mate; a large number of offspring being produced quickly; and offspring being genetically identical, allowing them to be well adapted to a favourable environment.
- Disadvantages of reproducing asexually include: very little genetic variation, which leaves the population susceptible to infection or environmental changes; and increased competition for limited resources.

RECAP 8.2

1. List reasons why asexual reproduction is advantageous for some species.
2. Fertilisation is not necessary in asexual reproduction. Explain why.
3. Discuss the conditions under which asexual reproduction may be disadvantageous.
4. Describe an environment where organisms that reproduce asexually are likely to be found.

EXPERIMENT 8.1

ASEXUAL REPRODUCTION IN *HYDRA*

The name *Hydra* commonly refers to cnidarians (jellyfish) in the class Hydrazoa. They are small, multicellular, freshwater animals, usually less than a centimetre long. They have a hollow, cylindrical body with a mouth surrounded by six to ten tentacles. They move either by gliding like a snail, or by somersaulting slowly. *Hydra* can reproduce sexually or asexually, depending on environmental conditions.

Yeast (*Saccharomyces cerevisiae*) is a single-celled member of the kingdom Fungi and reproduces asexually by budding. Yeast has long been used to ferment the sugars of rice, wheat, barley and corn, in producing alcoholic beverages, and in the baking industry to expand, or raise, dough.

Aim

To observe asexual reproduction in *Hydra* and yeast

Materials

Each student will require:

- *Hydra*
- half a teaspoon of fresh yeast mixed in 100 mL of warm water with a teaspoon of molasses (let stand for 15 minutes)
- Pasteur pipettes or eye droppers
- microscope
- microscope slides

What are the risks in doing this experiment?	How can you manage these risks to stay safe?
If you drop the microscope it could damage yourself or the lenses.	Handle the microscope with two hands.
A glass slide could break and cut you.	Clean up any broken glass using protective gloves and put glass into a safety container.

Procedure

Hydra

1. Use a pipette to capture a *Hydra*. Sometimes they stick to the walls of the container. Use the pipette to gently prise one off.
2. Lay out four microscope slides. Place a few drops at each end of each slide until the *Hydra* comes out of the pipette. Do not place a coverslip on top.
3. Choose the slide with the *Hydra* on it and observe under low power. You may find another *Hydra* growing on the parent like a branch on a tree, or that the *Hydra* changes shape.
4. If you need to add water for some reason, use only the water that the *Hydra* came in, as water from the tap may be chemically too different for them to survive.
5. Make a labelled drawing including tentacles, mouth and bud.

Yeast

6. Draw up some yeast solution using a clean pipette.
7. Place it on a clean microscope slide and place a coverslip on top.
8. Observe under low power and then high power of the microscope.
9. Locate some yeast cells that are budding and draw them.

Discussion

1. Explain the advantages for *Hydra* of reproducing asexually.
2. Explain the advantages for *Hydra* of reproducing sexually.
3. Suggest the genetic make-up of the bud compared to its parent and explain why you made this suggestion.
4. When a *Hydra* is cut into pieces, each piece can grow into a complete individual. Describe how the genetic composition of such *Hydra* compare to the original reproducing organism.
5. The *Hydra* is a cnidarian. From your observations of its body structure, hypothesise what method it would use to get its food.
6. Describe how budding in yeast is different from that in *Hydra*. Describe how it is similar.

Extension activities

1. Use a time-lapse camera to capture the process of budding in both *Hydra* and yeast.
2. Some chemicals can make the stinging cells of *Hydra* fire off. Find out what chemicals can do this and examine the stinging cells under high magnification.
3. Make a list of other organisms that reproduce in a similar way to yeast and *Hydra*.
4. Plan and carry out an experiment to determine the best conditions for yeast reproduction. Try varying the amounts of yeast, molasses, temperature or time. Suggest why varying each of these factors alters the rate of reproduction in yeast.

Cloning

Gene cloning is discussed in more detail in Unit 4.

Cloning is the process of making an identical copy of an original. In biology it is used in two contexts. First, cloning a gene involves using recombinant technology: a gene is extracted from one organism and then inserted into a bacterium, where it can be used and studied.

In contrast to **genetic cloning**, which involves making a copy of a gene, **biological cloning** involves cloning an entire organism – that is, reproductive cloning. Cloning can make it possible for cattle or sheep with desirable characteristics, such as high milk production or fine wool growth, to be produced more rapidly than through the normal cycles of reproduction and selection. It is achieved by embryo splitting or by nuclear transfer.

Embryo splitting

See Chapter 7, page 229, for more information on blastocysts and embryonic development.

In embryo splitting, egg cells are removed from the donor female and fertilised *in vitro* (that is, in tissue culture) by sperm from the male. After the fertilised egg has divided, the coat around the two cells that promotes cell division is removed and the two cells are separated. Each cell is then given an artificial coating that promotes cell division. Embryos that have just begun to differentiate, called **blastocysts**, are implanted into surrogate mothers. The individuals are genetically identical; they are like identical twins but in different surrogate mothers.

Nuclear transfer

The process of cloning by nuclear transfer came to prominence in 1996, when Dolly the sheep was cloned. Nuclear transfer involves removing mature donor somatic cells from a mature animal and a recipient egg cell from another mature animal of the same species (Figure 8.7). The donor cells are cultured in a nutrient medium before becoming inactive, and the nucleus of the recipient egg cell is removed.

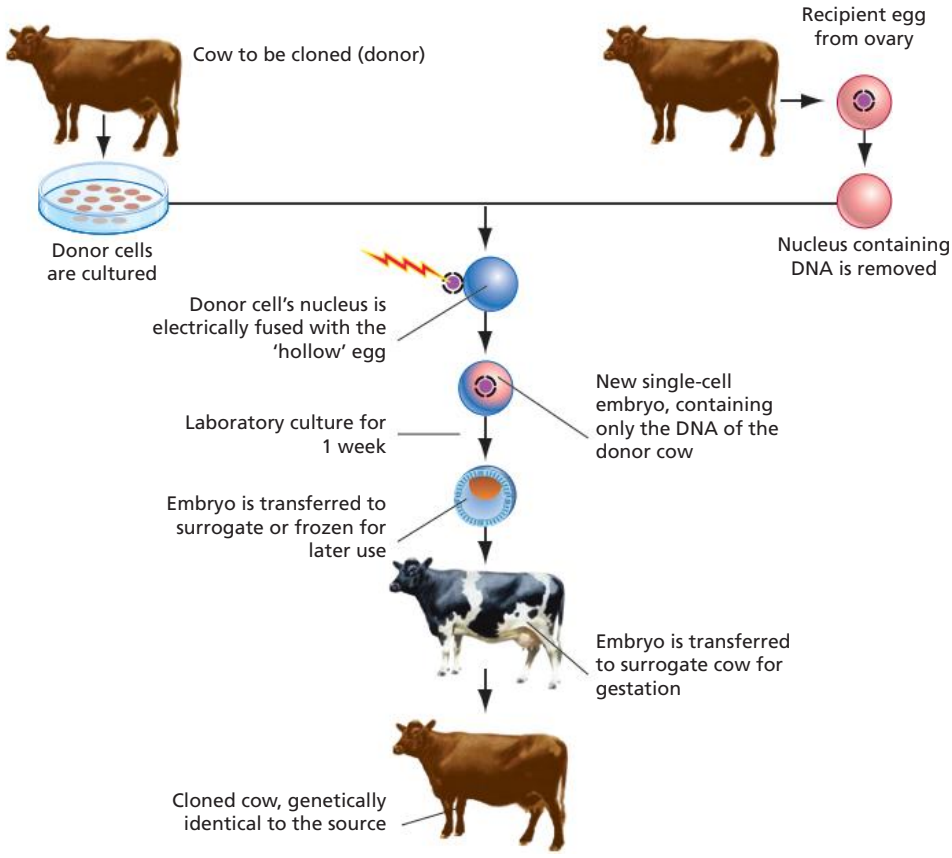


Figure 8.7 ▶ Cloning a calf by nuclear transfer

The donor cell, with the intact nucleus, is fused with the 'hollow' egg by an electrical impulse. The new single-celled embryo is cultured for about a week, then cell division is activated and the developing blastocyst is surgically implanted in the surrogate mother. The offspring is genetically identical to the nucleus donor.

Cloning using nuclear transfer has not proceeded without some controversy. The success rate of live births is low and many of the offspring suffer from deformities. For these reasons, the scientific world is almost universally opposed to experimenting with reproductive cloning for humans.

Application of cloning in agriculture and horticulture

Animal cloning, like other types of cloning, is used to increase the number of breeding animals with naturally occurring desirable traits. This allows for the rapid spread of these characteristics through the herd. The cloning of farm animals for food production is already under way in a number of countries.



AAP/AFP Photo/Juliette Michel

◀ **Figure 8.8**
The four white-haired Shorthorn heifers are clones.

In the European Union (EU), a draft directive on cloning of animals aims to ban temporarily the use of the cloning technique on EU farmed animals. The draft directive allows cloning for purposes such as research and conservation of rare breeds and endangered species, or for use in the production of pharmaceuticals and medical devices, where the technique can be justified.

Keen gardeners are aware of the ability of plant cuttings to regenerate into mature plants with all the many different types of cells needed for the plant to function independently. The brand new plant is a genetic replica of its parent – it is a clone of the parent. Gardeners may consider regenerating plants by cloning rather than using seeds from the parent plant when the parent plant has a desirable characteristic they want to keep. If the new plant was grown from a seed of the parent plant, the genetic material would not be an exact replica and the desirable characteristic may not appear in the offspring.

As far back as the beginnings of agriculture, humans have been 'cloning' plants from cuttings and by other methods. Cultivated olive trees originated about 6000 years ago in Asia Minor. Somewhere between 3000 and 1800 BC, olive trees were introduced to Egypt from Syria. There are many records of clonal propagation of these trees.

Today, many economically important plants are commonly grown using cloning techniques, including vegetable crops such as the potato, fruit crops such as bananas, strawberries and dates, and even woody species such as pines and grapes.



Alamy/blickwinkel

Figure 8.9 ▲
Wollemi Pine

Cloning can be used to conserve rare or endangered plant species. The Wollemi Pine (Figure 8.9), a plant thought to be extinct and only known previously from fossil records, has been saved through cloning. A small number of the pines were discovered in 1994 in the Wollemi National Park in the Blue Mountains in New South Wales. Ancestors of the Wollemi Pine go back to the mid-Cretaceous, and possibly even the early Cretaceous, period some 110 million years ago. All the Wollemi Pine plants currently for sale around the world are clones of the original trees found in the wild.

The cloning of plants by plant tissue culture technologies has had a huge impact on the horticultural industry. Using these techniques, cells are grown in sterile conditions on a culture medium supplying all the nutrients needed. **Micropropagation** is the method used to produce clones of a plant, often scaled up to mass production.

The advantages of plant cell, tissue and organ culture technologies include more rapid production of plants, taking weeks instead of months or years. Very little space is required compared to planting in fields, and the plants can be produced all year round.

Because cloning produces the same genetics in the offspring, the most desirable characteristics in a plant can be maintained in a predictable way. Maintaining desirable characteristics can increase crop yield and quality while reducing the incidence of crop failure.

There are, however, negative consequences of mass growth of cloned or very genetically similar crops or plantations. The Irish Potato Famine of the 1840s is an example of planting crops that lack genetic diversity. Cultivation of whole fields of genetically identical potatoes left the entire crop vulnerable to pest and disease infestation. During the famine, approximately one million people died and a million more emigrated from Ireland.

Modern agricultural practice often results in a reduction in the number of crop species. Crops are grown over a wide area for a large number of consecutive years. This allows large harvests with minimal labour.

When only one species of organism is grown, such as a wheat field, **biodiversity** is reduced. This type of farming resulting in a **monoculture** (a colony of genetically identical individuals) often requires extensive use of fertilisers along with pesticides and herbicides to reduce the natural tendency of the community to diversify. Another downside of this practice is the spread of disease and susceptibility to changing environmental conditions. Cultivated plants grown in genetically homogeneous monocultures do not possess the necessary ecological defence mechanisms to tolerate the impact of pest outbreaks.

As a result of reduced biodiversity in monocultures, the natural enemies of pests are no longer present. If pest outbreaks occur, the populations of beneficial insects are missing, and if weather conditions favourable to the pest happen simultaneously the effect on the crop can be catastrophic.

RECALL

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

RECAP 8.3

1 Define 'cloning'.
2 Distinguish between genetic cloning and biological cloning.
3 Explain how embryo splitting is different from nuclear transfer.
4 List two advantages and two disadvantages of using cloning in agriculture.

Sexual reproduction

There may seem to be little in common between butterflies, wandering albatrosses and Sturt's desert pea. One starts life as a caterpillar before changing form into a butterfly, one travels the world and pairs for life, the other grows in dirt and produces beautiful pea-like flowers. However, they all use the same method of reproduction.

▼ **Figure 8.10** Butterflies, wandering albatrosses and Sturt's desert pea have more in common than you may think.


Photos.com


Auscape/Jean-Paul Ferrero


Alamy/Robert Wyatt

All the above organisms reproduce by sexual reproduction. The same basic process occurs in all of them: two parents contribute genetic information to produce unique offspring. Two cells – the sex cells or **gametes** – unite in the process of fertilisation. Any form of reproduction in which offspring result from the union or fusion of two cells is sexual reproduction.

Where asexual reproduction ensures that an ideal environment is exploited quickly, sexual reproduction incorporates a 'shuffling' of the genetic material (DNA) from one generation to the next. This shuffling results in genetic variation, which makes it more likely that, given an environmental change, at least some members of the species will have the genetic material that allows them to survive to continue the line.

So how does this initial shuffling occur? Each parent is unique in his or her genetic make-up, and in the production of each gamete, a random selection of half their genetic material is included in the cell. Therefore, each gamete contains a unique random selection of parental DNA. When gametes combine during fertilisation, this is also random, and provides another opportunity for creating diversity. For example, two siblings will each have a different selection of DNA from their mother and DNA from their father, causing their characteristics to be different from each other. Combining two sex cells from each of these individuals ensures that a unique combination of DNA is created within each offspring.

Meiosis and fertilisation

The nucleus of each **somatic cell** or body cell contains pairs of chromosomes, which are referred to as **homologous chromosomes**. The number of chromosomes in each somatic cell is called the **diploid** number and is represented as $2n$.

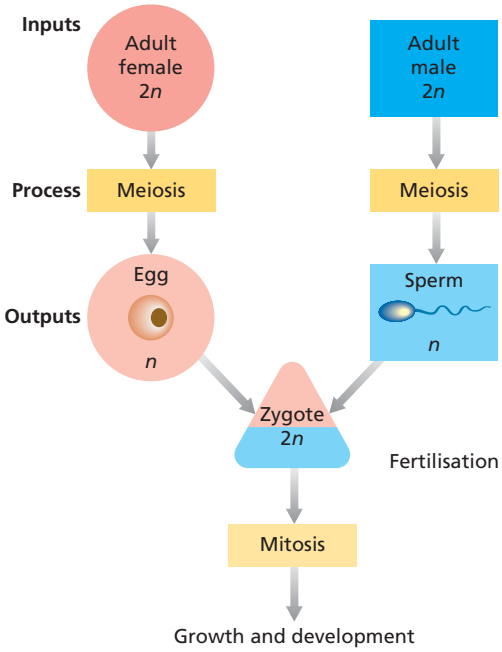


Figure 8.11 ▲
The inputs and outputs of meiosis

As chromosomes occur in pairs, *n* stands for the number of pairs that the particular species has in each of its cells. This is called the **haploid** number. A human somatic or body cell, for example, has 23 pairs of chromosomes and so its diploid number, 2*n*, is 46 and its haploid number, *n*, is 23. One chromosome of a pair comes from the male parent and the other chromosome of a pair comes from the female parent.

Meiosis occurs in specialised organs of sexually reproducing animals and plants, and results in the production of haploid gametes: the sex cells, sperm and eggs (or ova). It is a form of nuclear division that allows the return to the diploid number of chromosomes at fertilisation. In meiosis, two divisions of the nucleus of the parent cell take place. In the first division, each chromosome of a pair separates and goes to each end, or pole, of the cell. In the second division, the **chromatids** of each chromosome separate from each other. Four gametes are thus produced, each carrying half the original number of chromosomes. Gametes are therefore haploid.

As the number of chromosomes in the daughter cells has been reduced by half, meiosis is called a reduction division. During meiosis, the chromosomes of each homologous pair separate to each gamete at random. Fertilisation, the joining of the sperm and egg cells, results in the **zygote** gaining one of each pair of chromosomes from its parents. Meiosis can be broken down into a number of steps or phases, which will be discussed individually, but are actually continual.

Meiosis I

Prophase I

In prophase I the chromosomes condense, the nucleolus disappears and a spindle forms with centrioles, if present, at opposite ends. Homologous chromosomes lie side by side, in a process known as **synapsis**. A pair of homologous chromosomes, one maternal and the other paternal, is now called a **bivalent**.

As prophase proceeds, homologous chromosomes may coil around each other intimately. Later, they move slightly apart but the chromatids remain in contact at certain points called **chiasmata** (singular chiasma). At these contact points, the chromatids may break and re-join, sometimes re-joining to other chromatids. This process is called **crossing over** and results in the swapping of sections of DNA along the chromatids. Sometimes the chromatids re-join back to the same chromatid with no crossing over; that is, they have the same sequences of DNA as previously. Offspring with combinations of DNA different from those that occurred in the parents, following the process of crossing over, are called **recombinants**.

The amount of crossing over varies between species, and within species between different homologous chromosomes. The end result of crossing over is the production of gametes with new parental combinations of DNA. This is an important source of genetic variation.

Metaphase I

In metaphase I, the nuclear envelope breaks down and the homologous chromosomes move together to the equator of the spindle. Spindle fibres attach to the centromere of each homologous pair.

Anaphase I

In anaphase I, the spindle fibres retract towards the poles, pulling the maternal and paternal chromosomes of homologous pairs towards opposite poles of the spindle. The separation or **disjunction** of each pair of homologous chromosomes occurs independently of other chromosome pairs.

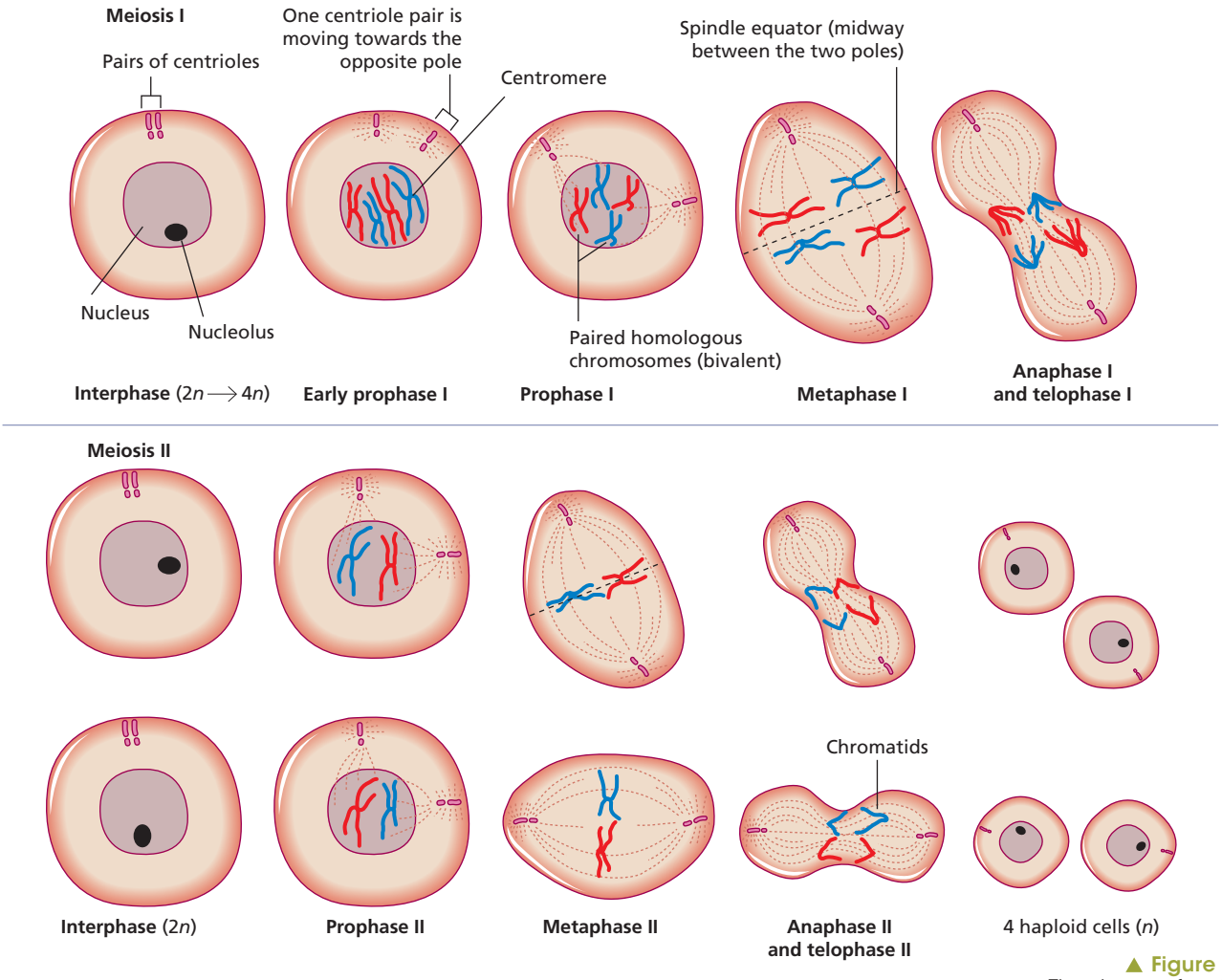
Telophase I

In telophase I, the spindle breaks down, the cell starts to separate across its middle and nuclear envelopes form around the two new nuclei.

Cytokinesis, the division of the cell and cytoplasmic contents, completes the first stage of meiosis.

Interphase

At the end of meiosis I, a brief interphase usually occurs. DNA does not duplicate during this interphase.



▲ Figure 8.12
The stages of meiosis

Meiosis II

The cell then enters the second meiotic division. In prophase II, a new spindle forms at right angles to the first one. In metaphase II, the chromosomes move to the equator of the spindle, and spindle fibres attach to the centromere of each chromosome. In anaphase II, the spindle fibres retract towards each pole and the chromatids separate and move apart from each other. The chromatids become the chromosomes of the daughter cells. When they reach the poles, the cells enter telophase II. Characteristically of telophase, the spindle apparatus disappears, the chromosomes de-condense to their thread-like form and new nuclear envelopes and nucleoli form.

Meiosis is now complete. Cytoplasmic division follows, so that four haploid cells form from the original single diploid parent cell.

Fertilisation

In the process of fertilisation, male and female haploid sex cells fuse to produce a diploid zygote. Two gametes from different individuals (usually one male and one female) of the same species need to combine to produce the new individual of that species. This is called sexual reproduction. Organisms produced by sexual reproduction will have a different combination of DNA to that of either parent.

The zygote formed is a cell with double the amount of DNA of the gamete. Therefore, meiosis halves the amount of DNA and fertilisation restores the amount of DNA to the required amount for that species. Human gametes produced by meiosis contain 23 chromosomes. Fertilisation restores the number of chromosomes to 46 (23 + 23 = 46), the chromosome number in somatic cells. Different species have different numbers of chromosomes.

In mammals, gametes from the male are called sperm, and gametes from the female are called ova. In flowering plants, pollen grains contain cells that are male gametes and ova contain an egg cell or female gamete.

RECALL

- Cells formed by meiosis are called gametes and join together in sexual reproduction to form a new cell with genetic material from two different parent cells.
- A diploid number ($2n$) of chromosomes is found in somatic cells; a haploid number (n) chromosomes (one from each homologous pair) is found in gametes.
- In meiosis, two divisions of the nucleus of the parent cell take place. In the first division, the chromosomes of a pair separate and go to opposite ends of the cell. In the second division, the chromatids of each chromosome separate from each other and go to new cells.

RECAP 8.4

1 Distinguish between gametes and normal body (somatic) cells.
2 Describe what happens in each of the two stages of meiosis.
3 Explain why the process of crossing over in meiosis is biologically important.

ACTIVITY 8.1

MODELLING MEIOSIS

Meiosis is the cell division that produces haploid cells for the purpose of sexual reproduction. The process, although similar to mitosis, has two distinct stages and results in the production of four haploid cells from each diploid parent cell.

What to do

Make two sets of chromosome pairs from coloured beads or similar materials. Make one strand of each pair one colour (maternal) and the other strand of each pair a different colour (paternal). These represent the chromatids of homologous chromosomes. Loosely tie the two chromatids together at the same position. The tie represents the centromere. On an A3 piece of paper or other surface, draw a plasma membrane surrounding a nuclear membrane large enough to fit your chromosomes. Label this prophase I.

Before removing the chromosomes to move to the next stage, use coloured pencils to draw, on the paper, a copy of where the beads are placed. Then draw a similar-sized cell without the nuclear membrane next to the first stage of meiosis, and line up the pairs of chromosomes on a central plane. This is metaphase I.

Again, draw the position of the beads on the paper. Now add two centrioles and attach spindle fibres to each of them. In a third circle on the paper put one chromosome from each pair at opposite poles of the cell. This stage is called anaphase I.

Use the same procedure to model the remaining stages of meiosis: telophase I, prophase II, metaphase II, anaphase II and telophase II.

What did you discover?

1. Explain the significance of the different-coloured homologous chromosomes.
2. State how many chromosomes were contained in this cell.
3. State the total number of strands of DNA that were contained in this cell.
4. State how many different strands of DNA there were in this cell.
5. State the number of gametes produced by this process.
6. State the number of chromosomes in each gamete.
7. Describe the stage of meiosis where mixing of maternal and paternal chromosomes occurred.
8. Describe how many different types of gametes your model produced. Suggest how many combinations would be possible.
9. Calculate how many combinations of chromosomes would be possible if you increased the number of chromosomes to six.

Chromosomes and variation

During meiosis, when homologous chromosomes pair and then move to different daughter cells independently of each other, gametes with many different combinations of parental chromosomes are possible. In fact, the number of possible combinations that can occur is 2^n, where n is the number of haploid chromosomes. Humans have 2^{23} possible combinations, which is almost 10 million.

When homologous chromosomes separate and recombine in the first division of meiosis, pieces of chromosomes sometimes break and exchange with their homologous pair during crossing over. This can lead to variations in the appearance of the offspring.

The process of fertilisation also provides the potential for different combinations of characteristics in the offspring because it is by chance that particular gametes combine.

Although these processes produce variations in characteristics in sexually reproducing organisms, they do not generate new DNA. Existing DNA is merely reshuffled through different combinations.

Sexual reproduction has biological advantages

Sexually reproducing individuals spend a considerable amount of time and energy locating mates, exchanging genetic material, and often caring for young. Only half of a parent's genetic material is transferred to each offspring, and males produce many sperm cells, many or even none of which may fertilise an egg. With these disadvantages, why did sexual reproduction evolve?

The greatest advantage of sexual reproduction is the fact that the offspring vary from one another and from their parents. This is very important in a changing environment, as some of the new organisms may turn out to be better adapted to the new conditions due to their different genetic make-up.



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Figure 8.13 ▲
Sexual reproduction leads to variation among individuals.

Evolution is discussed in Unit 4 Biology.

When a mutation arises in one individual, it can spread to offspring with a different genetic background through sexual reproduction. Mutations can be lost during the random genetic recombinations (crossing over and fertilisation) that occur as members of the population reproduce, or they can survive in the population and may later confer an advantage for survival of the individuals that carry them. When individuals carrying an advantageous mutation have a better chance of surviving and reproducing in a changed environment, the frequency of individuals in the population that carry the mutation increases in later generations. This is the basis of evolution.

Consider entering a lottery where a certain combination of numbers wins the prize. A person is much more likely to win the big prize if they enter many different combinations than if they enter the same set of numbers many times. Similarly, if individuals in a population have many unique genetic combinations there is a greater chance that at least some of their offspring will survive in an unpredictably variable environment.

Another advantage of sexual reproduction is associated with limited resources in an environment. If offspring have slightly different resource requirements because of their genetic make-up, then there will be less competition between them.

The Red Queen's Hypothesis proposes that coevolution exists between species, particularly between hosts and parasites. It can be likened to an 'evolutionary arms race', where prey and predator evolve together, responding to pressures that each puts on the other. For example, rabbits may evade predation by foxes by running faster. Foxes need to improve their speed of running to catch their prey. The only way that a species involved in competition can maintain its position in the ecosystem relative to the others is by improving its form and function. For the Red Queen's Hypothesis to happen, there needs to be some genetic mixing of genes, such as occurs in sexual reproduction, as random fluctuations and mutations allow new characteristics to appear. This principle was proposed by the evolutionary biologist Leigh Van Valen (1973), and is named after the observation to Alice by the Red Queen in Lewis Carroll's *Through the Looking Glass* that 'Now, here, you see, it takes all the running you can do, to keep in the same place'.

RECALL

- Many different combinations of parental chromosomes are possible in gametes.
- The greatest advantage of sexual reproduction is that offspring all vary from one another and from their parents. In a changing environment, there is a greater chance that some of the offspring carry genetic combinations that make them better suited to the new conditions and, therefore, better able to survive and reproduce.

RECAP 8.5

1 List three events in which chromosomes can influence variation in offspring.
2 Calculate the number of possible chromosome combinations in the gametes of an organism with a diploid number of eight chromosomes.
3 Explain why sexual reproduction might be advantageous to a species living in a changeable environment.

Investigation of an issue: Data on alcohol consumption during pregnancy – how much is enough?

Refer to Chapter 11 for more information on the investigation of an issue.

It is well established that a human embryo or foetus experiences abnormal development if a pregnant mother drinks excessive amounts of alcohol (O'Leary & Bower 2012). This is recognised in a condition described as foetal alcohol syndrome (FAS). After birth, affected children may show a collection of physical and neurological defects, including limb and facial deformities, reduced growth rates, intellectual disability and an increased incidence of mental health problems later in life.

What is less clear is what constitutes a safe level of alcohol consumption during pregnancy. Reflecting the uncertainty, Australian guidelines for alcohol consumption by pregnant women have changed at least twice since 2000 (O'Leary & Bower 2012). During the 1990s abstinence was recommended for pregnant women. In 2001, the guidelines were amended, recommending that pregnant women drink a maximum of 2 standard drinks per day or 7 standard drinks per week. In 2009, the policy reverted to one of abstinence.

Up to around 80% of Australian women drink at least some alcohol during pregnancy (Powers et al. 2010). Pregnant women may be receiving mixed messages about the alcohol guidelines, or they may receive advice from health practitioners who intuitively believe that low levels of alcohol are unlikely to harm the foetus. Adding to these perceptions is a tolerance, in Australian culture, of occasional binge drinking.

The investigations

Two separate longitudinal studies were conducted into the physical and mental health of children whose mothers consumed alcohol during pregnancy. In these studies, the same children were examined at 2, 5 and 8 years of age. Only the children of the study who could be tracked were included in each 3-year examination. The results of the two studies are shown in Tables 8.1 and 8.2.

Table 8.1 Proportion of children affected by physical problems compared with maternal alcohol consumption during the third trimester of pregnancy (adapted from O'Leary et al. 2009)

Average quantity of alcohol consumed by mother during pregnancy (g/week)	Proportion children affected (% of total examined)		
	Age 2 (Total of 115 children)	Age 5 (Total of 54 children)	Age 8 (Total of 85 children)
0 (control)	7.4	4.0	5.5
3	6.1	3.3	7.3
8	8.3	3.3	8.8
110	2.9	11.5	20.0

Adapted from O'Leary et al. 2009

Table 8.2 Proportion of children showing signs of anxiety or depression compared with maternal alcohol consumption during the first trimester of pregnancy

Average frequency of alcohol consumption by mother during pregnancy (standard drinks/ week)	Proportion children affected (% of total examined)		
	Age 2 (Total of 69 children)	Age 5 (Total of 23 children)	Age 8 (Total of 31 children)
0 (control)	4.8	2.1	1.9
< 1	3.5	0.6	2.8
1–2	4.8	4.2	5.2
> 2	10.5	0.0	5.4

Adapted from O'Leary et al. 2009

The advisory report

Data were required for a government agency (a non-scientific body) to outline a policy on alcohol consumption by pregnant women. For their benefit, the authors of the advisory report summarised the findings of the original investigations in a single table (Table 8.3).

Table 8.3 Proportion of children (% of total examined) showing signs of ill health by age 8 compared with maternal alcohol consumption during pregnancy

Level of alcohol consumed by mother during pregnancy	Proportion of children affected by physical problems (% of total examined)	Proportion of children showing signs of anxiety or depression (% of total examined)
None (control)	5.5	1.9
Low	7.3	2.8
Moderate	8.8	5.2
Heavy	20.0	5.4

Adapted from O'Leary et al. 2009

The authors of the advisory report recommended that the government agency adopt a policy of abstinence for pregnant women. Their recommendation was based on data in Table 8.3 highlighting the fact that health risks to the child increased with increased alcohol consumption during pregnancy. Furthermore, the data indicated that even moderate levels of alcohol consumption resulted in mental health consequences for the child that were similar to those of high consumption.

Over to you: Evaluating the evidence and ethics of a recommendation of abstinence

You have been assigned by the government agency to be an independent reviewer of the advisory report. You are required to write a 400–500 word response to the advisory report. Your response will be read by the non-scientific government agency. The first part of your response is to be a 150–200 word evaluation of the nature of the evidence in the advisory report. The second part is to be a 250–300 word evaluation of the ethics of the process by which the recommendation of abstinence was made.
You must do your evaluation by comparing the summarised data and the recommendations with the data in the original studies (Tables 8.1 and 8.2).

Task 1: Evaluate the summarised data presented in Table 8.3 and the data from the original studies presented in Tables 8.1 and 8.2. In your evaluation, consider the following questions.

- In the original studies presented in Tables 8.1 and 8.2:
  - Were suitable controls used in these studies?
  - Are the findings from the two original investigations comparable to each other?
  - Do the data show a correlation between signs of ill health with alcohol consumption or with the age of the children?
- In the summarised data in Table 8.3, used for the report:
  - Are the summarised data an accurate and legitimate representation of the data from the original studies (Tables 8.1 and 8.2)?
  - Is it valid to draw conclusions from the summarised data?
  - Does the summarised report show signs of **confirmation** or **cognitive bias**?

  If you believe the data could be collected or represented better, outline how you would do so.

Task 2: Evaluate the ethical considerations of the means by which the summarised report reached its recommendation of abstinence. Your response can draw on the following questions:

- What advice should be given to mothers about alcohol consumption during pregnancy?
- Who should decide on this advice?
- What information is required in order to make an informed decision about alcohol consumption during pregnancy?
- How are the following groups of people affected by the way the report reached its recommendation of abstinence?
  - pregnant mothers
  - unborn children
  - government or policy makers
  - scientists
  - the broader community
- What values and priorities have been placed on the process of reaching the decision of abstinence?
- Have any values been violated in the process?
- Are there alternatives to the report's recommendation of abstinence during pregnancy? What advantages and disadvantages are there for those affected by the recommendation of abstinence? Decide whether the recommendation of abstinence is justified, or whether a new review is required. Support your decision with reasons drawn from your evaluation.

References

O'Leary C.M. & Bower C. (2012) Guidelines for pregnancy: What's an acceptable risk, and how is the evidence (finally) shaping up? *Drug and Alcohol Review* 31: 170–83.
O'Leary C.M., Nassar N., Zubrick S.R., Kurinczuk J.L., Stanley F. & Bower C. (2009) Evidence of complex association between dose, pattern and timing of prenatal alcohol exposure and child behaviour problems. *Addiction* 105: 74–86.
Powers J.R., Loxton D.J., Burns L.A., Shakeshaf, A., Elliott E.J. & Dunlop A.J. (2010) Assessing pregnant women's compliance with different alcohol guidelines: an 11-year prospective study. *Medical Journal of Australia* 192: 690–3.

CONCEPT SUMMARY

Asexual reproduction

Advantages

- Does not require a mate
- Uses less energy
- Offspring identical to parent
- Many offspring produced

Applications

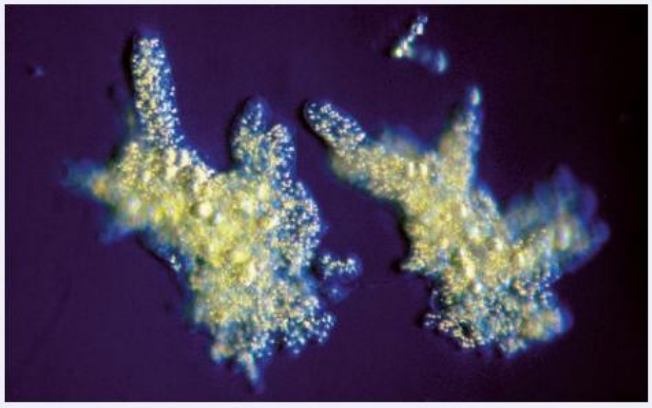
- Biological cloning (embryo splitting, nuclear transfer)
- Agricultural
- Horticultural

Disadvantages

- Offspring are genetically identical
- Parental care of offspring is limited or none
- Large numbers of offspring may compete for limited resources

Fission

- Single-celled eukaryotic or prokaryotic organisms
- Involves mitosis in eukaryotes
- The rate of reproduction is theoretically exponential but is limited by other population controls



Budding

- Development of a new organism or parts of an organism from an outgrowth of the parent organism
- Can detach or form a branching colony
- Hydra, yeast cells, some flatworms and annelids



Vegetative propagation

- Only in plants
- Grafting, growing new plants from cuttings, or runners (e.g. from strawberries)
- Commonly used for agricultural purposes to replicate desirable qualities in plants



Spore formation

- Spores are hardy, self-contained capsules containing the DNA instructions to make a new organism when conditions become favourable again
- Prokaryotes, protists, fungi, plants



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Sexual reproduction

Advantages

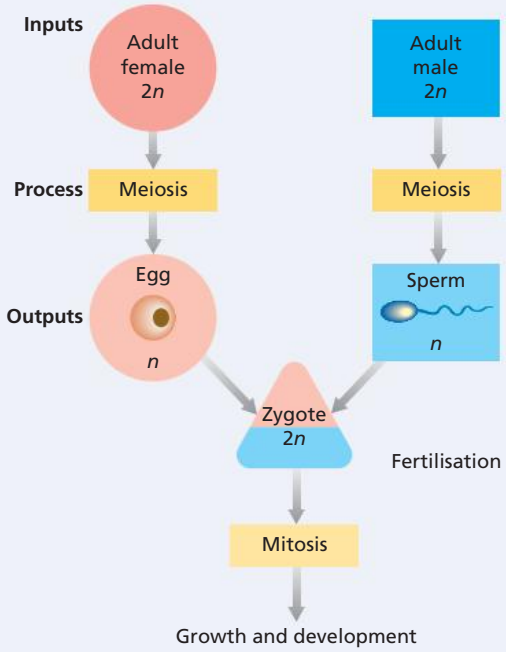
- Gametes with many different combinations of parental chromosomes are possible
- Offspring are genetically different from parents and from each other

Disadvantages

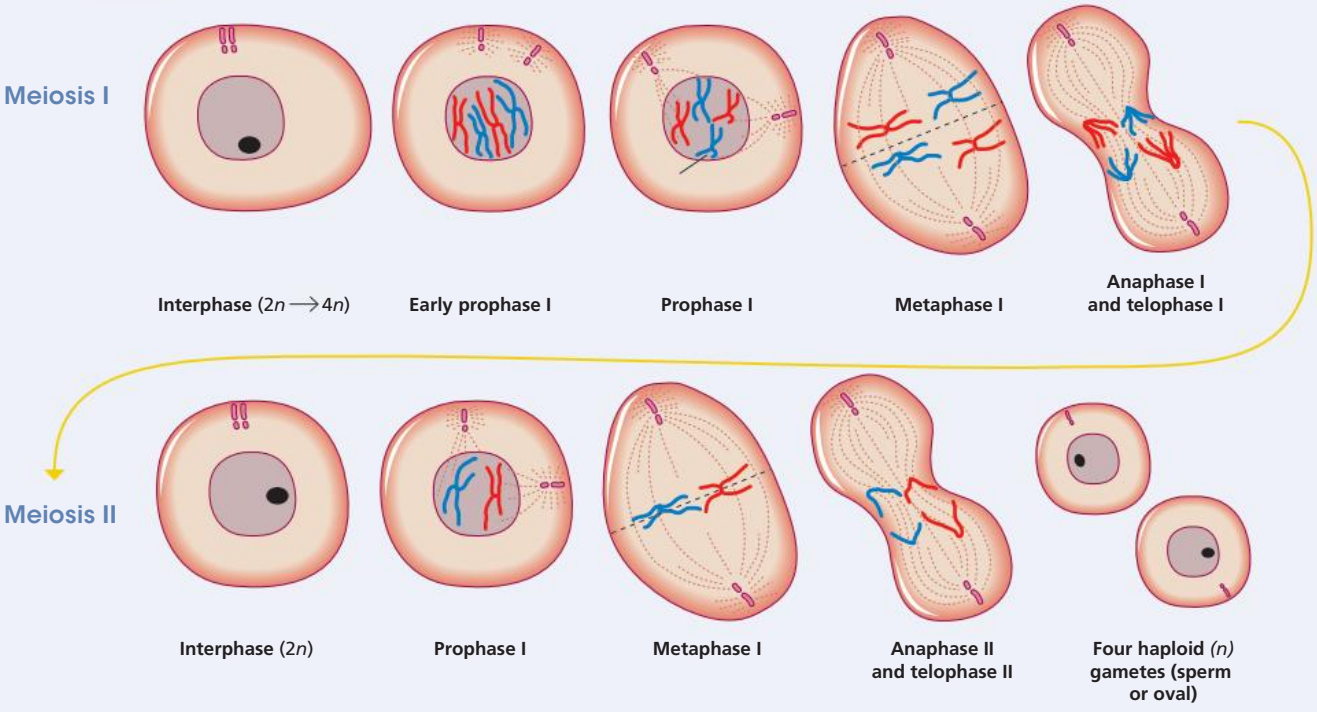
- Energy is required to produce organs for sexual reproduction
- Energy is required to find and attract a mate
- Competition for mates

Fertilisation

- In fertilisation, two haploid (*n*) gametes (one from each parent) join to form a diploid (2*n*) zygote.
- All somatic (body) cells are diploid (2*n*).
- This means they have n pairs of homologous chromosomes, one originally derived from each parent.



Meiosis



GLOSSARY

asexual reproduction a form of reproduction in which offspring are produced from a single parent

binary fission the division of a cell into two without mitosis; a prokaryotic cell splits to form two daughter cells

biodiversity the full range of different living things in a particular area or region

biological cloning producing a copy of an entire organism

bivalents visible bodies in a cell during prophase I of meiosis, made up of two homologous chromosomes joined together

blastocyst a hollow ball of cells formed during early embryonic development

budding the development of a new organism from an outgrowth of the parent organism

chiasmata the point of contact between homologous chromosomes during prophase I of meiosis

chromatids daughter strands of a duplicated chromosome that are joined by a centromere

clone an organism genetically identical to its parent

crossing over the process of chromatids breaking and re-joining during prophase I of meiosis

cytokinesis division of the cytoplasm

diploid (2*n*) describes a cell or organism that has a genome comprising two copies of each chromosome; the number of chromosomes in a diploid cell is represented by 2*n*

disjunction the moving apart of homologous chromosomes during anaphase of meiosis

exponential occurring at an increasingly rapid rate

fertilisation the fusion of gametes to produce a zygote

gamete a cell produced for sexual reproduction; combines with another gamete at fertilisation; in humans, the gametes are ova and sperm cells; in flowering plants, pollen grains contain male gametes and ova contain female gametes

genetic cloning the process of making numerous identical copies of a gene

grafting when part of one plant is artificially attached to another

haploid (*n*) describes a cell or organism that has a genome that contains one copy of each chromosome; the number of chromosomes in a haploid cell is represented by *n*

homologous chromosomes a pair of chromosomes that have the same size, shape and genes at the same locations

meiosis a two-phase type of cellular division in which the chromosome number of a cell is halved to the haploid number; meiosis is the basis of gamete formation

micropropagation a tissue culture technique for plant propagation, in which tissue is taken from a plant and grown in a laboratory to produce plantlets that are genetically identical to the parent

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

monoculture the agricultural practice of growing a single crop or plant species over a wide area for a large number of consecutive years

recombinants offspring with different combinations of DNA than their parents, due to mixing of genes

scion the piece of the plant that is artificially attached to the base of another (stock) in grafting

somatic cell a normal body cell, as compared with a germ-line cell from which a gamete (i.e. sperm or ovum) is derived

spore a reproductive body able to withstand harsh environmental conditions

stock the base of a plant, to which part of another plant (scion) is attached in grafting

synapsis the pairing of homologous chromosomes

vegetative propagation the cloning of plants

zygote the first cell of a new individual, formed by fusion of a sperm and an ovum at fertilisation

CHAPTER REVIEW QUESTIONS

Remembering

1 Distinguish between haploid and diploid cells.
2 List three differences between spores and gametes.

Understanding

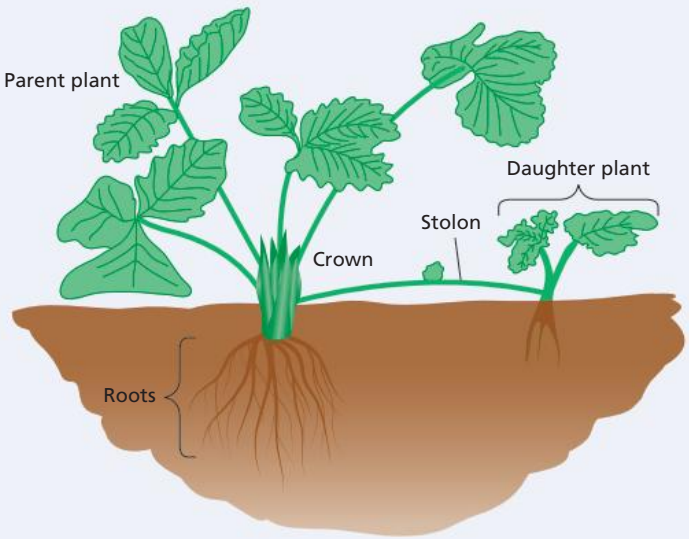
3 Explain how sexual reproduction is different from asexual reproduction.
4 Explain how gametes are produced.
5 Explain why meiosis is more appropriate than mitosis for gamete formation.
6 Describe crossing over and how this contributes to variation in offspring.

Applying

7 If you have a cut on your finger that becomes infected with one bacterial cell, explain why the number of bacteria in the cut increases so rapidly.
8 Strawberry plants can reproduce both asexually and sexually. Discuss the advantages that strawberry plants would gain from reproducing by two methods.
9 Human cells have a diploid number of 46 ($2n = 46$). Consider a cell in an ovary undergoing meiosis. State the number of chromosomes during each of the following stages of meiosis:
   a Prophase of the first meiotic division
   b At the end of telophase of the first division
   c Prophase of the second meiotic division
   d At the end of telophase of the second division.

Analysing

10 Organisms that reproduce asexually through budding rarely have a large number of different cell types. Suggest reasons why.
11 Explain why children of the same parents do not inherit identical chromosomes (except for identical twins).
12 Consider the plant shown in Figure 8.14.
   a Name the type of reproduction in this plant.
   b Explain how new plants form.
   c Discuss the likely genetic make-up of new plants.
   d Name a commercially grown plant that is propagated in this way.



▲ **Figure 8.14**
A new plant forms.

Evaluating

13 'Cells produced by meiosis only contain half the amount of DNA that their parent cells have. This means DNA does not replicate during meiosis.' Do you agree with this statement? Justify your answer.

14 Explain why offspring produced from asexual reproduction resemble their parent, whereas offspring produced from sexual reproduction are different from their parents.

15 Using monocultures in commercial crops can be both beneficial and potentially harmful. Provide arguments for and against planting monocultures.

Creating

16 Prepare a table comparing the process of mitosis (Chapter 7) with the process of meiosis.

17 Design an activity in which students act out the process of meiosis. This can be in the form of a physical movement activity or even a dance.

18 A gardener wants to grow an apricot tree in a way that ensures that her tree has all the most desirable qualities of apricot trees. Discuss the technique that the gardener would use.



CHAPTER 9
GENETICS

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

KEY KNOWLEDGE

Genomes, genes and alleles

- the distinction between a genome, gene and allele
- the genome as the sum total of an organism's DNA measured in the number of base pairs contained in a haploid set of chromosomes
- the role of genomic research since the Human Genome Project, with reference to the sequencing of the genes of many organisms, comparing relatedness between species, determining gene function and genomic applications for the early detection and diagnosis of human diseases.

Chromosomes

- the role of chromosomes as structures that package DNA, their variability in terms of size and the number of genes they carry in different organisms, the distinction between an autosome and a sex chromosome and the nature of a homologous pair of chromosomes (one maternal and one paternal) as carrying the same gene loci
- presentation of an organism's set of chromosomes as a karyotype that can be used to identify chromosome number abnormalities including Down's, Klinefelter's and Turner's syndromes in humans.

Investigation of an issue

- the 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 biological concepts specific to the investigation: definitions of key terms; use of appropriate biological terminology, conventions and representations
- the nature of evidence and information: distinction between opinion, anecdote and evidence, weak and strong evidence, and scientific and non-scientific ideas; and validity, reliability and authority of data including sources of possible errors or bias
- the influence of social, economic, legal and ethical factors relevant to the selected biological issue.

KEY SCIENCE SKILLS

Draw evidence-based conclusions

- identify, describe and explain the limitations of conclusions, including identification of further evidence required

Communicate and explain scientific ideas

- use appropriate biological terminology, representations and conventions, including standard abbreviations, graphing conventions and units of measurement
- discuss relevant biological information, ideas, concepts, theories and models and the connections between them
- identify and explain formal biological terminology about investigations and concepts
- use clear, coherent, cogent and concise expression
- acknowledge sources of information and use standard scientific referencing conventions

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Newspix/Geoffrey Foletta

Figure 9.1 ▲
Five generations of one family. Family characteristics are passed from one generation to the next through inheritance.

At a family gathering, we can be struck by how much we resemble some of our relatives but not others. Over the centuries, many people have been intrigued by the inheritance of particular features. Selective breeding of crops, plants, pets and domesticated animals has made use of this ability of living things to transfer particular characteristics through successive generations.

It is only since the secrets of DNA (deoxyribonucleic acid) were unlocked that we have been able to explain this at a cellular and molecular level. We now understand how DNA is transmitted between generations, how genes are controlled and how differences in genes can cause changes in the way organisms develop and behave. This knowledge has allowed us to manipulate genes, raising new ethical issues and opening up whole new fields of research to the social and ethical consequences of this technology. New technologies have also enabled us to accurately examine the interrelationships between species and to account for changes that have occurred to species over time.

Early studies focused on individual genes or groups of genes that directed the development of particular traits of an organism. Later research showed that proteins are the products of genes and that the inheritance of particular gene variants caused an individual to contain a specific combination of proteins. Additional research has shown that genes may code for more than one kind of protein and that genes interact in their expression – that is, in their activities.

Genes

What do we have in common with mice, plants, flies and bacteria? At first glance, not a lot. But all living things inherit DNA from their parents. DNA is the common genetic material for all organisms and carries the information coded in **genes**.

Heredity is the study of inheritance. Classic **genetics** deals with studying the mechanisms and patterns of inheritance through the transmission of coded chemical instructions from one generation to the next.

Genes are stretches of DNA, with one gene being one 'unit' of genetic information, which can be read and switched on or off independently of other genes. When a gene is switched on, the cellular machinery will 'read' the gene and produce, for example, a specific protein. The gene is then said to be 'expressed'.

DNA is the same in all organisms, but the small differences in the way the DNA molecules are put together, the **DNA sequence**, make individual genes different and species distinct from one another.

Because DNA is the same genetic material in all organisms, it must have appeared early in the evolution of species and remained essentially the same as new species evolved. This tells us that the ways in which DNA carries genetic information, and the way in which this information can be read to build organisms, must be a successful biological strategy. As we learn more about the structure and functions of DNA, and as scientists have learned to use DNA-based technologies, it has become clear that this special molecule is capable of encoding very complex information.

DNA structure

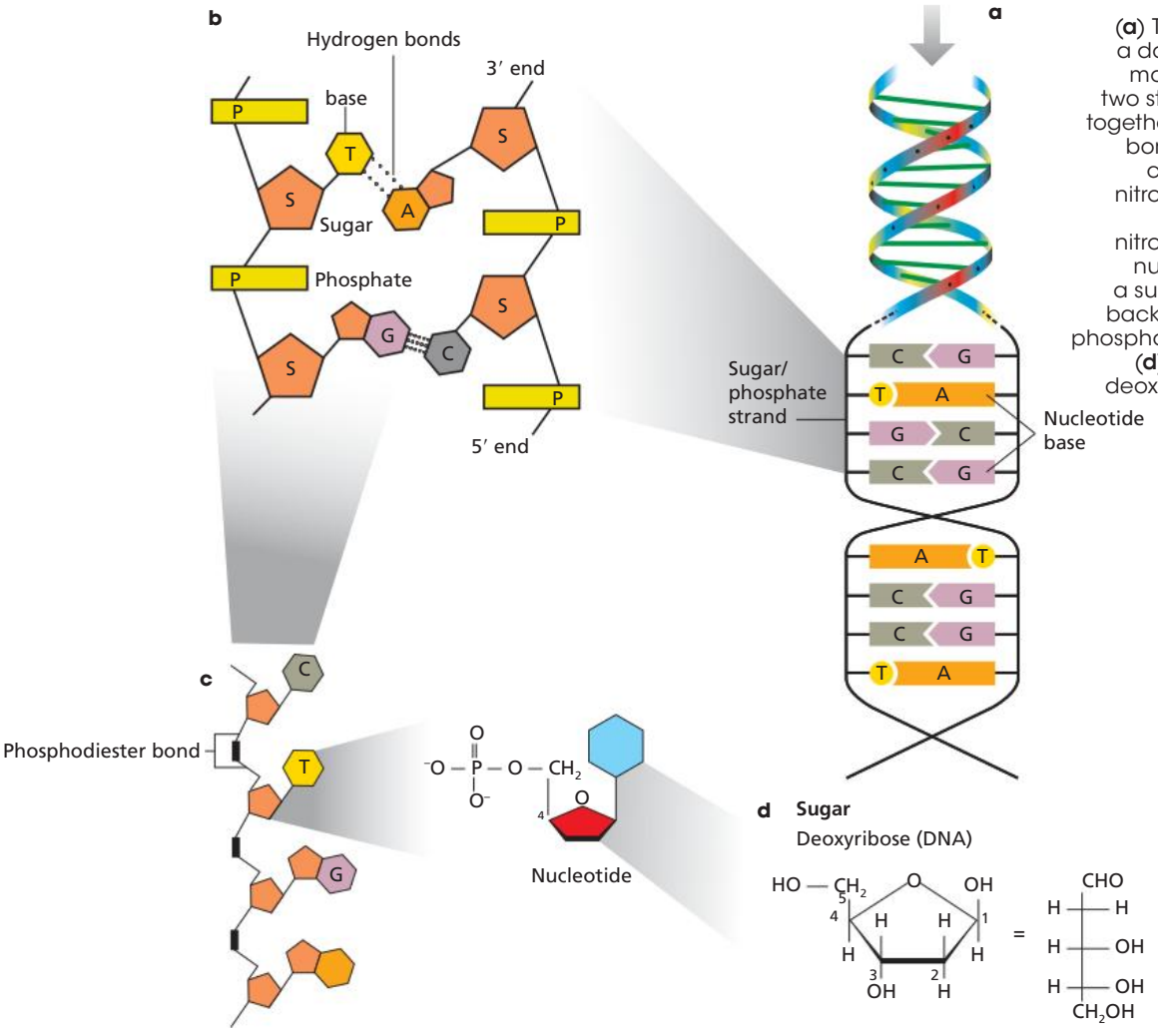
Commonly represented by the letters DNA (deoxyribonucleic acid), this large macromolecule is a type of nucleic acid. A molecule of DNA is composed of two long strands of subunits called **nucleotides**, wound around each other to form a **double helix**. DNA encodes inheritable information.

A DNA nucleotide has three distinct chemical components:

1 a five-carbon deoxyribose sugar
2 a negatively charged phosphate group
3 an organic nitrogen-containing compound called a **nitrogenous base** (Figure 9.2).

There are four kinds of nitrogenous bases in DNA:

- adenine (A)
- thymine (T)
- guanine (G)
- cytosine (C).



▼ **Figure 9.2**
(**a**) The DNA helix is a double-stranded molecule. (**b**) The two strands are held together by hydrogen bonding between complementary nitrogenous bases. (**c**) As well as nitrogenous bases, nucleotides have a sugar phosphate backbone linked by phosphodiester bonds. (**d**) DNA contains deoxyribose sugars.

In each nucleotide strand, the sugar molecule of one nucleotide binds to the phosphate group of the next nucleotide, leaving the nitrogenous base sticking out from each sugar and opposite the nitrogenous base of the second strand. **Hydrogen bonds** between the opposing pairs of nitrogenous bases hold the double helix together, much like the rungs of a twisted ladder or a spiral staircase. The bonding of the nitrogenous bases does not happen by chance: A bonds with T and C bonds with G, giving rise to the base-pairing rule (Figure 9.2).

The two strands of a DNA double helix link by hydrogen bonds between **complementary bases**: A and T link with two hydrogen bonds, G and C link with three hydrogen bonds.

There are billions of DNA **nucleotide base pairs** in human DNA but only a fraction of these, less than 2%, code for a gene product. These sections of **coding DNA** make up the genes.

RECALL

- DNA is the common genetic material of all organisms and carries the information coded in genes.
- DNA is composed of four different types of nucleotides; each nucleotide has a deoxyribose sugar, a phosphate group and one of four different types of bases: adenine (A), thymine (T), guanine (G) and cytosine (C).
- The two strands of a DNA double helix link by hydrogen bonds between complementary bases: A links with T, and G links with C.

RECAP 9.1

1. Distinguish between heredity and genetics.
2. Draw a nucleotide, labelling the three distinct chemical components.
3. State the rule for the pairing of nitrogen-containing bases in the DNA molecule.
4. Define 'nucleotide base pair'.

Alleles

Alternative forms of the same gene are called **alleles**. Alleles are versions of the same gene with slight differences. Sometimes this may be a single difference in nucleotide sequence, but this may be enough to cause large variation in the functions of a gene or the way it behaves. For example, the single gene for eye colour has several alleles. One allele gives brown eyes, another allele gives blue eyes. A normal organism has two alleles for each gene – that is, one on each chromosome inherited from each parent. For many genes, there is only one allele (or gene variant), but it is the different alleles that exist for some genes that give individuals distinct traits.

Genomics

The sum of all DNA in the cell of an organism, measured in the number of nucleotide base pairs contained in a haploid set of chromosomes, is its **genome**. Genomes differ between species, although there may be similarities. The study of the genomes of organisms is termed **genomics**. This significant branch of molecular biology and its related study of proteins – **proteomics** – have been made possible by advances in technology, particularly in robotics and **bioinformatics**. Automated processes in laboratories and the rapid collection and storage of data have made it possible to integrate, analyse and manipulate data at high speed.

These technologies assisted the complete mapping of the human genome in 2003 by the Human Genome Project. The project's ultimate goal was to generate DNA sequences for the human genome's three billion nucleotide base pairs and to identify all human genes. When the project was launched in 1990, it was thought that the human genome contained some 100 000 genes.

In 2001, after 10 years of work and at a cost of US$400 million, those involved in the Human Genome Project had completed a draft sequence of the human genome. The first analyses of the details brought the estimate down to 30 000 to 40 000 genes. The estimate

of the number of human genes has been repeatedly revised down to 20 000 to 25 000 genes and could continue to drop further. Today, such sequencing can be completed in a couple of weeks for less than US$10 000.

Even though the results of the Human Genome Project have solved some questions, they have created many more. Now the challenge is to find out what every gene actually does.

Genomic research

The rate at which genomes can be sequenced has been doubling every four months or so. With the advent of new analytical tools, biologists' ability to generate genomic data will help reveal more about how genes work and how species are related. There is a great deal of overlap in the genomes of closely related species, and some overlap even in the genomes of distantly related species. Researchers can compare the genomes of different species, or of different individuals within a species.

Sequencing is useful in finding out what a particular DNA sequence is similar to, as sequences can be compared to reference sequences stored in public databases. Identifying microbes is one example. This could help in the early detection and diagnosis of infections, or it could help biologists to characterise collections of microbes found in animal tissue or particular microenvironments. This is particularly useful when investigating the variations of microbes in humans that have been implicated in a range of medical conditions. It is used to characterise the microbes in a particular sample of soil, and in forensics to determine the geographical origins of physical evidence by its microbial signatures.

Genomic research can help scientists find genes, particularly those involved in human disease. Scientists study many families affected by a disease, tracing the inheritance of the disease and of specific genome sequences called **markers**, located close to the disease gene. Once they have identified a few such markers, scientists know the approximate location of the disease gene and can investigate this further. They might look for genes in the location that have a different sequence in people with the disease compared with healthy people. Or they might look for a gene with a function that could be related to the disease.

RECALL

- Alleles are alternative forms of a gene.
- All the DNA in the cell of an organism is its genome.
- Gene sequencing is useful in finding out how genes work and how species are related, in detecting and diagnosing infections, and in locating disease-causing genes.

RECAP 9.2

1. Explain the relationship between genes and alleles.
2. Define 'genome'.
3. Explain how robotics and bioinformatics have contributed to our understanding of molecular genetics.
4. Explain how DNA sequencing has been used to identify microbes.

Chromosomes

As we have seen previously, eukaryotic cells are complex cells containing membrane-bound organelles. In these types of cells, DNA is found in the nucleus, chloroplasts and mitochondria. In the nucleus of a eukaryotic non-dividing cell, DNA is only visible as a grainy substance without detail. Early microscopists named this seemingly grainy

substance **chromatin**. We now use the term to describe the cell's DNA together with all the proteins associated with it. One DNA molecule with its associated proteins is called a chromosome ('chromo' = colour, 'soma' = body).

When a eukaryotic cell divides, long DNA molecules appear in the nucleus as double structures, each coiled around **histone** proteins (Figure 9.3) and linked at a point called a **centromere**. Chromosomes are normally visible only during cell division and only when stained. In eukaryotes, chromosomes exist in pairs, with one chromosome being inherited from each parent.

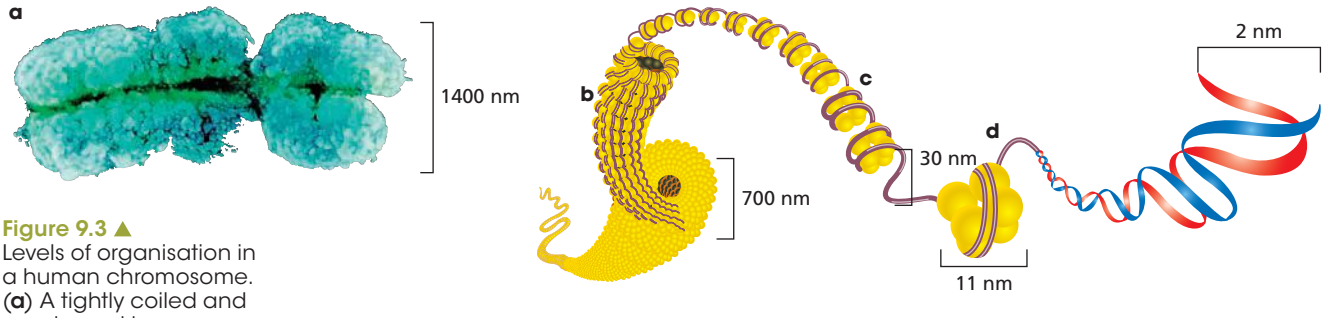


Figure 9.3 ▲
Levels of organisation in a human chromosome. (**a**) A tightly coiled and condensed human chromosome is only visible when stained during cell division. (**b**) Interacting proteins package loops of coiled DNA into a 'supercoil' to produce chromatin, which is organised as a cylindrical fibre. (**c**) The loops of coiled DNA are wound around a core of eight histone proteins to produce a nucleosome. (**d**) A nucleosome consists of a section of DNA molecule looped twice around a core of histones.

Karyotypes

Examination of a prepared microscope slide of stained cells in the process of nuclear division reveals a jumbled cluster of chromosomes that differ in size and shape. Photographic images of chromosomes are arranged into matched and ordered pairs to create a **karyotype**: this is the standard form used to display and analyse chromosomes (Figure 9.4). Chromosomes can be ordered by length, from largest to smallest, and they have characteristic banding patterns. Each species of organism is characterised by a particular number of chromosomes in each cell.

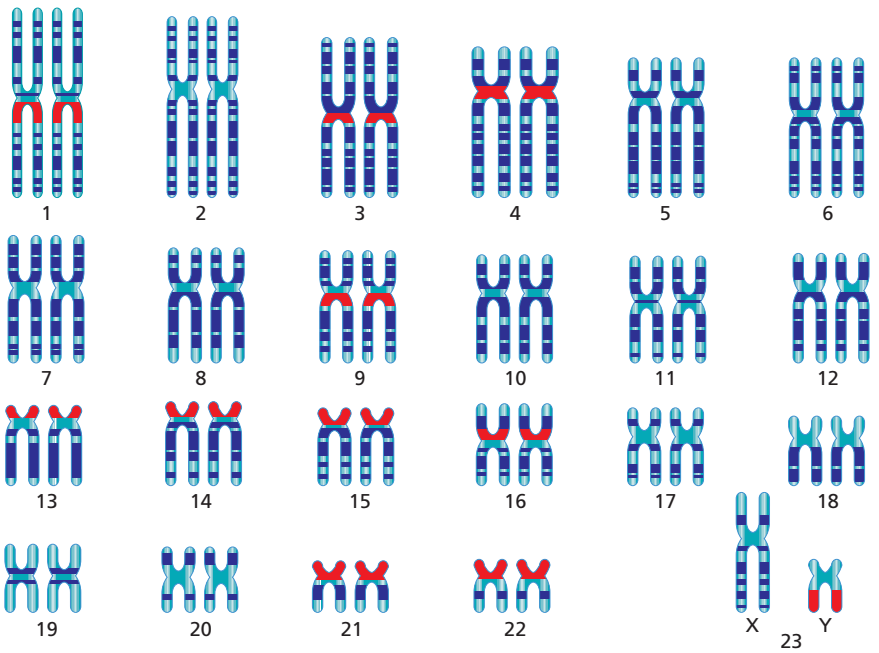
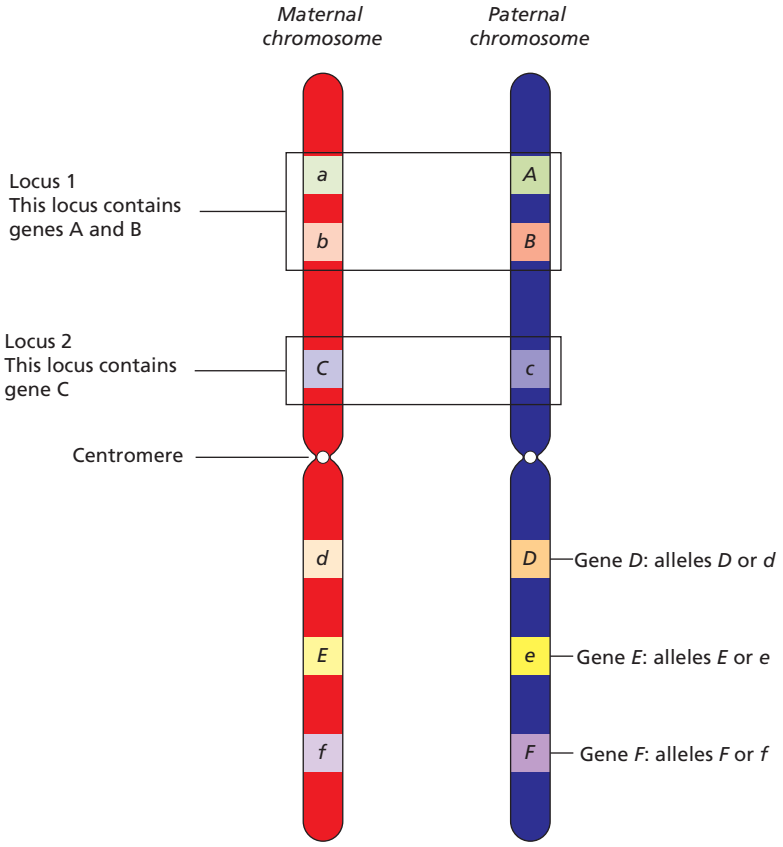


Figure 9.4 ▶
The 46 human chromosomes divide into 23 pairs. They can be recognised individually by their size, position of centromere and banding pattern: the karyotype. The bands correspond to large groups of genes.

The nucleus of each **somatic cell** (or body cell) of a human contains 46 chromosomes, which form 23 pairs, of which 22 are matched or **homologous** (Figure 9.4). One chromosome of each pair comes from the male parent via the sperm cell and the other from the female parent via the egg cell (ovum). The matched pairs are called **autosomes**, the largest of which is numbered 1 and the smallest 22. The 23rd pair, which is matched in females (XX) but unmatched in males (XY), is called a **heterosome**. Because these chromosomes determine the sex of an individual, they are also referred to as **sex chromosomes**.



◀ Figure 9.5
Stylised representation of a pair of chromosomes. In diploid organisms, chromosomes exist in pairs in somatic cells. One of the chromosomes comes from the male parent and one comes from the female parent.

Along the length of each DNA molecule, particular regions (genes) code for different proteins that can determine particular characteristics or traits. The location of a particular gene in a chromosome is referred to as its **locus** (plural loci). In homologous chromosomes, the corresponding allele of each gene is found at the same locus. Paired autosomes are identical in size, shape, and position and number of genes, but may have different alleles at each gene locus. Because each member of a pair of homologous chromosomes contains one of each corresponding gene, there is in a sense a backup for the genes on those chromosomes.

A chromosome can contain hundreds to thousands of genes. The size of the chromosome generally reflects the number of genes. For instance, the largest chromosome in humans, chromosome 1, has over 3000 genes, while human chromosome 21 has around 400 genes. Genes on the same chromosome are said to be **linked**. For example, two genes encoding proteins involved in blood clotting are located in human chromosome 1 and are therefore linked, while another blood-clotting gene is located in chromosome 13. This gene is not linked to the other two genes, because it is located in a different chromosome. Genes are often situated in close proximity to other genes that are involved in the same processes. This allows them to be regulated, switched on or off, together.

RECALL

- DNA and associated proteins together make up a chromosome.
- Eukaryotic chromosome structure consists of DNA coiled around histone proteins to form nucleosomes.
- When matched and ordered, eukaryotic chromosomes are displayed in a karyotype, and different chromosome sizes, centromere positions and banding patterns can be observed.
- Homologous chromosomes have the same genes at the same position (locus) but these genes may have alternative forms (alleles).

RECAP 9.3

1 Identify the components of a chromosome from a eukaryotic cell.
2 Describe how a karyotype is made and identify how chromosomes are ordered.
3 Draw a labelled diagram to show your understanding of the following terms:
   a homologous
   b autosome
   c locus
   d centromere.
4 Explain the difference between chromatin and nucleosomes.

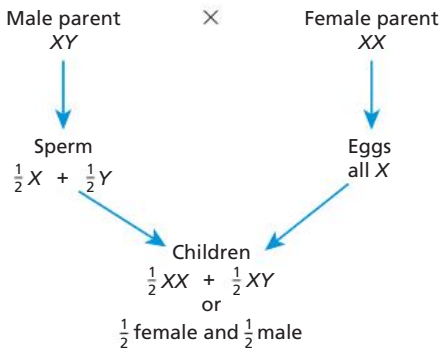


Figure 9.6 ▲
Chromosomal basis for sex determination

Sex chromosomes

Most plants and animals show different characteristics between males and females. In humans, if you compare karyotypes from females and males you will see differences in the 23rd pair of chromosomes. In males, one of the chromosomes is larger than the other. Females have two of the larger chromosomes. The large chromosome is referred to as the X chromosome and the smaller is the Y chromosome.

In humans, normally all female gametes contain 22 autosomes and an X chromosome. But 50% of male gametes contain 22 autosomes and a Y chromosome and 50% contain 22 autosomes and an X chromosome. Thus, in humans there is a 50% chance that, in fertilisation, a sperm cell bearing a Y chromosome will fuse with an egg cell, resulting in a male (XY), and a 50% chance that a sperm cell carrying an X chromosome will fuse with an egg cell, resulting in a female (XX).

In other species it is not always the male that has the unmatched sex chromosomes. For example, in birds, males are XX and females are XY. In some insects, females are XX and males are XO, with O denoting the absence of a chromosome, so the female sex cells must have two sex chromosomes but those of males have only one unmatched sex chromosome. In certain other social insects, such as honeybees, females develop from fertilised eggs and are diploid, and males develop from unfertilised eggs and are monoploid.

Genes on the sex chromosomes

Sex chromosomes contain not only the genes that determine male and female traits but also those for some other characteristics as well. Genes on the sex chromosomes are referred to as being **sex-linked**.

Compared to the autosomes, the X chromosome is medium-sized. It contains about 1300 genes, with a range of functions. Some of these X-linked genes have relatively rare alleles that are responsible for abnormal conditions such as haemophilia, Duchenne muscular dystrophy and red-green colour blindness.

The Y chromosome is small, with few active genes. It is composed largely of repetitive DNA sequences. The SRY gene on the Y chromosome is responsible for the development of a foetus into a male. There is a small region that is homologous between the X and Y and it is this area that pairs at meiosis.

RECALL

- Sex chromosomes that determine an individual's sex are generally matched in one sex (e.g. XX) and unmatched in the other sex (e.g. XY).
- Genes on the sex chromosomes are referred to as being sex-linked.

RECAP 9.4

1 Distinguish between sex chromosomes and autosomes.
2 Explain how the sex of a child is determined at the time of fertilisation.
3 Define and give three examples of sex-linked characteristics.

Variations in chromosomes

Alterations to chromosomes can affect many genes simultaneously. Some of the variations that occur with chromosomes, such as chromosome number, are quite natural in certain situations and are therefore integral to the functioning and continuity of the species. Others arise because of **anomalies** that occur during the formation of the gametes.

Chromosome alterations can be observed and analysed by examination of a prepared microscope slide of stained cells in the process of nuclear division and then displayed in a karyotype.

Chromosomal anomalies often have dire consequences for the organism harbouring them. Occasionally, however, the anomaly is a fortunate accident that confers a survival advantage upon the recipient.

In many eukaryotic organisms, somatic cells are diploid. The gametes are haploid. There are consequences for organisms when the complement of chromosomes in the somatic cells varies from the usual diploid state.



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▲ Figure 9.7
Bees maintain their colony structure with diploid females and monoploid males.

Monoploidy

The males of many colonial insects such as ants, bees and wasps are **monoploid** ($1n$). By contrast, the females, including the queen, are diploid.

The males are not haploid in the sense of the gametes of regular diploid animals. Their chromosomes represent a single complete and operational set and the males function as conventional, multicellular animals. By contrast, in haploid gametes, the chromosomes represent half the complete set and are packaged in a dormant state awaiting the fertilisation event that will activate them. In these insects, the queen produces eggs by meiosis, while the males produce sperm by mitosis. Fertilisation results in diploid female offspring. The males are instead produced by parthenogenesis, a process by which the entire organism is regenerated from a single egg cell without the need for fertilisation.

Many fungi and algae are also monoploid and, as well as insects, there are examples of monoploid fish, amphibians and reptiles. Monoploidy seems economical because only one set of chromosomes is required, so why are diploid organisms so much more common? The advantage for diploid organisms is that any defective alleles that arise can be masked by a functional allele on the corresponding chromosome. In monoploid organisms, any defective allele is the only allele available for a particular gene and the consequences are likely to be deleterious or harmful.

Polyploidy

Sometimes the cell divisions that give rise to haploid gametes fail altogether, and so half the gametes contain two copies of each chromosome (diploid, $2n$) and the rest have none. If a diploid gamete fuses with a normal haploid gamete, the resulting individual is **triploid** ($3n$), carrying three of each type of chromosome. If two diploid gametes fuse, a **tetraploid** ($4n$) individual will be produced. It is therefore possible for an organism to acquire one or more complete extra sets of chromosomes, a phenomenon called **polyploidy**.



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Figure 9.8 ▲ Polyploid varieties of fruit are bigger and have bigger cells than regular diploid varieties. The application of polyploidy to creating infertile fruit, such as these seedless grapes, is of considerable commercial significance.

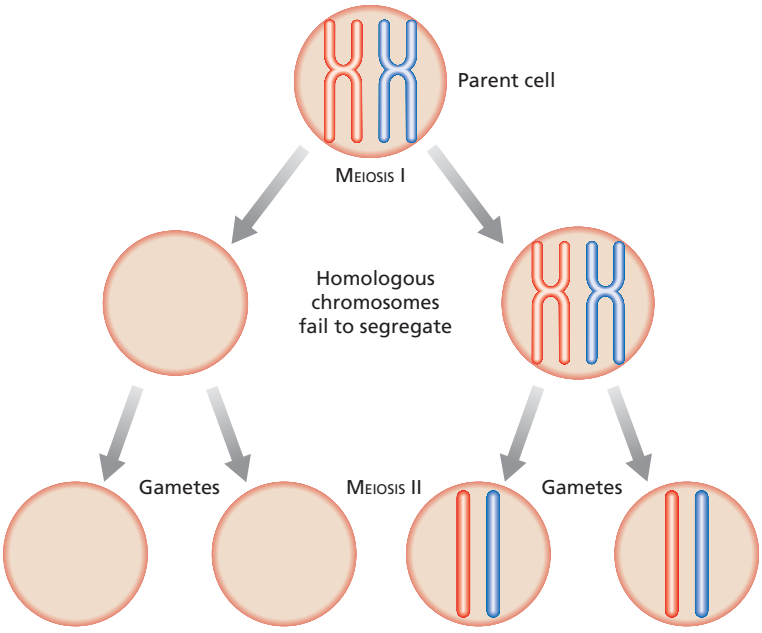
Polyploidy is particularly common in flowering plants, ferns and green algae. Approximately half of all flowering plant species are polyploid and many varieties of commercial fruit and cereals, for example, are generated polyploids (Figure 9.8). Polyploidy is often associated with advantageous features, such as increased size and greater hardiness, although such advantages are sometimes offset by reduced fertility. Polyploidy also occurs in fungi and in some fish and amphibian species.

Polyploidy is lethal in humans. In the rare situation of a pregnancy continuing to a live birth (1% of human polyploids), the newborn dies within a month.

Aneuploidy

Aneuploidy is the condition in which there is an addition or loss of one chromosome from a cell (that is, $2n + 1$ or $2n - 1$). Occasionally, more than one chromosome may be affected. Reproductive failure by miscarriage is common and it has been found that many of these embryos are aneuploids. To understand how this comes about, consider the process of meiosis. Normally in meiosis, identical chromosomes come together and then segregate into separate cells, so the gametes finish up with only one of each pair of chromosomes. Occasionally, however, instead of separating, the two identical chromosomes go into the same cell. This phenomenon is known as **non-disjunction**. It results in the formation of two types of gametes in equal proportions, but one type has two copies of a particular chromosome and the other type has none (Figure 9.9).

The fusion of a gamete containing both homologous chromosomes with a normal gamete containing one of the chromosomes gives a zygote with three such chromosomes; the normal pair plus an extra one. This condition is called **trisomy**. Fusion of a gamete with none of the homologous chromosomes with a normal gamete gives an individual with only one of this particular type of chromosome in each cell. This condition is called **monosomy**.



◀ Figure 9.9
In non-disjunction, the chromosomes fail to segregate, so half the gametes contain two chromosomes of a pair (bivalent) each and the other half contain no chromosomes at all. Generally, non-disjunction only takes place with one pair of homologous chromosomes, while the rest behave normally. It can occur during either the first or the second meiotic division.

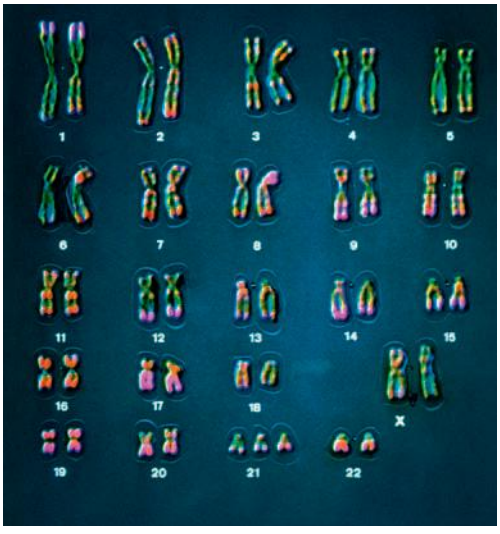
Some types of aneuploidy survive in humans. Down syndrome is caused by the presence of an extra chromosome 21 (one of the smallest chromosomes) in every cell, thus giving three copies of chromosome 21. Children with Down syndrome vary in their symptoms but most show moderate-to-severe delayed development, characteristic almond-shaped eyes and round face with shortened body parts, loose joints, and weak muscles and muscle reflexes. About 40% develop heart defects and they are more susceptible to infections, both of which often cause their lives to be shorter. On the other hand, people with Down syndrome are more than capable of deriving great pleasure from life, particularly from music and dancing.

Down syndrome is an example of autosomal trisomy as the cells contain an additional non-sex chromosome (Figure 9.11). It is the most common autosomal trisomy in humans. Its incidence increases with increasing age of the mother (Table 9.1, page 280). Older men are also more likely to father a Down syndrome child, but their age has less of an effect on the chances of having a Down syndrome baby than does the age of the mother.



Fairfax Syndication/Angela Wylie

Figure 9.10 ▲
A child with Down syndrome and her family



Science Photo Library/CNRI

Figure 9.11 ▲
False-colour karyotype of a Down syndrome female. The syndrome is the result of there being three copies of chromosome number 21. This condition is also known as trisomy 21.

Table 9.1 The risk of a child being born with Down syndrome increases with increasing age of the mother.

Maternal age at birth of child (years)	Risk of child having Down syndrome
20	1 in 1925
25	1 in 1205
30	1 in 885
35	1 in 365
40	1 in 110
45	1 in 32
50	1 in 12

Non-disjunction also causes various sex chromosome abnormalities in humans. For example, approximately two in every thousand men have the genetic constitution XXY, which is known as Klinefelter syndrome. This may result either from the fusion of a Y sperm with an XX egg or from the fusion of an XY sperm with an X egg. Although XXY individuals are phenotypically men, they have very small genitals and are infertile. In addition, they may develop breasts, but testosterone therapy at puberty can often help alleviate the symptoms.

Turner syndrome is due to the absence of one of the sex chromosomes. Foetuses with 22 normal pairs of autosomes and a single Y chromosome never survive to birth. However, children may be born with 22 normal pairs of autosomes and a single X chromosome. Such individuals have the genetic constitution XO, with O denoting the absence of a second sex chromosome. They are females and occur with an incidence of approximately 0.4 per thousand live-born girls. The phenotypic effects of Turner syndrome are relatively minor but the person is infertile. Individuals are usually shorter than normal, with a characteristic webbed neck. Oestrogen replacement therapy can allow normal pubertal development and growth can be stimulated with growth hormone.

RECALL

- Different numbers of chromosome sets can be classified as monoploidy or polyploidy.
- Chromosomal anomalies can be observed by examining a karyotype.
- Non-disjunction of chromosomes during meiosis can result in human chromosome abnormalities such as in Down, Klinefelter and Turner syndromes.

RECAP 9.5

1 In terms of sets of chromosomes, describe the relationships between:
   a haploid and diploid
   b monoploid and haploid
   c monoploid, diploid and polyploid
   d diploid and aneuploid.

2 Name the types of chromosomal abnormalities that can be identified from examining a karyotype.

3 Explain how aneuploidy arises.

4 Explain why polyploidy plants might be hardier than their diploid counterparts.

ACTIVITY 9.1

DISPLAYING CHROMOSOMES

When a prepared microscope slide of stained cells in the process of nuclear division is examined, a jumbled cluster of chromosomes can be seen. A karyotype is produced when the images of chromosomes are arranged into matched and ordered pairs. Chromosome alterations can be observed and analysed by examination of a karyotype.

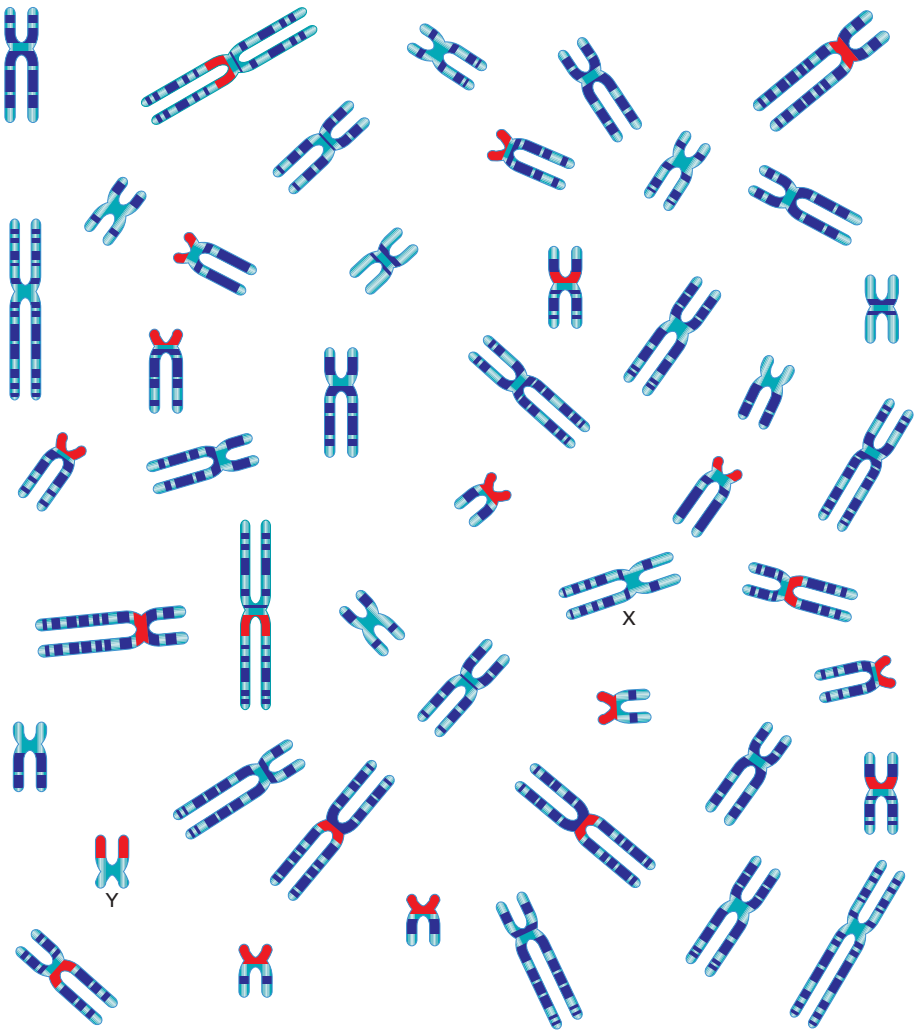
Aim

To examine a human karyotype and investigate anomalies in chromosome sets

What to do

1 Copy Figure 9.12, then cut out each chromosome and assemble into a karyotype by pairing the homologous chromosomes from biggest to smallest. Label the pairs 1 to 23. Use Figure 9.4 (page 274) as a guide.

2 Using the cut-out chromosomes, create karyotypes of cells with the following sets of chromosomes:
   - **a** monoploid
   - **b** triploid.



◀ **Figure 9.12**
Stylised representation of chromosomes of a human karyotype

3 Create a cell that would be seen in an individual with:
   a Down syndrome
   b Klinefelter syndrome.

What did you discover?

1 List three features of chromosomes that guided you in matching up the homologous pairs.
2 Identify the sex of the individual with the karyotype you have constructed. Explain what the karyotype would look like if it was from the other sex.
3 Name the type of cells that contain two sets of chromosomes.
4 Decide whether any of the cells created show polyploidy. Explain your decision.
5 Describe the type of human cells that would be monoploid.
6 Explain and draw a diagram of the event that would have occurred in cells showing Down syndrome and Klinefelter syndrome.

Chromosomes of prokaryotes

How plasmids are used in genetic engineering is explained in Unit 4.

Membrane-bound organelles, such as the nucleus, are not present in prokaryotic cells. The DNA within these cells generally forms a single circular chromosome that lies in direct contact with the cytoplasm (Figure 9.13). Chromosomes are often joined to the plasma membrane at a single point. Although not contained by any internal structure, a chromosome can be in a distinct region of the cell called a **nucleoid**. Additional numerous small rings of DNA, called **plasmids**, may also be present in the cytoplasm. Non-essential genes are commonly encoded on these plasmids. Plasmids can replicate independently of the main chromosome and have become important tools in genetic engineering because they can easily be transferred from one bacterium to another and replicate rapidly.

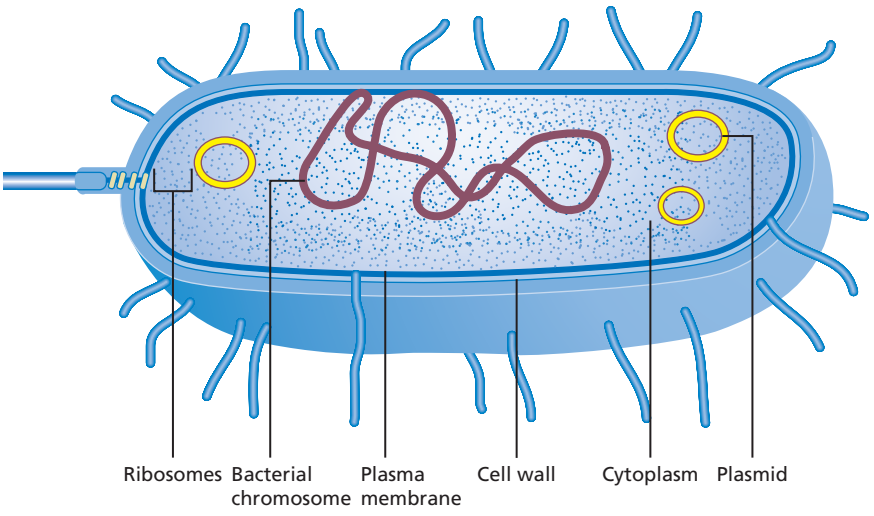


Figure 9.13 ▲
DNA in a prokaryote cell

Like eukaryotic chromosomes, the DNA of prokaryotic chromosomes needs to fit into a small area. This can be achieved by supercoiling, where a number of proteins act together to fold and condense the DNA. Prokaryotic cells are generally haploid; they contain only one copy of each gene. Furthermore, prokaryotic DNA contains very little repetitive and non-coding DNA.

However, just as with many other examples in nature, there are exceptions to the rules. Not all bacteria have a single circular chromosome. Some have more than one circular chromosome. Other bacteria have linear chromosomes and linear plasmids. Another notable difference between chromosomes in prokaryotes and eukaryotes is the presence of histones. Most prokaryotes do not have histones (with the exception of species in the domain Archaea).

Mitochondrial and chloroplast chromosomes

Mitochondria and chloroplasts contain their own chromosomes. The DNA forms single, circular chromosomes similar to those of prokaryotic cells. This feature is strong evidence for the endosymbiotic theory, which proposes that eukaryote cells were formed when a bacterial cell was ingested by another primitive prokaryotic cell.

Plant cells have DNA in their chloroplasts. The chloroplast genome – **chloroplast DNA (cpDNA)** – is a circular, double-stranded molecule. It contains about 100 genes that code for proteins involved in photosynthesis.

Each mitochondrion contains **mitochondrial DNA (mtDNA)** in its chromosome. The genes within this chromosome code for some, but not all, of the proteins that make up that mitochondrion. Mitochondrial DNA usually comes only from the mother, because it is the ovum that provides the cytoplasm including all the organelles within it. Mitochondria from the sperm usually do not become part of the developing embryo as the sperm mitochondria are contained in the tail, which is not involved in fertilisation. Because of its simple pattern of maternal inheritance, mitochondrial DNA has been used extensively in evolutionary studies of animals.

RECALL

- Chromosomes in prokaryotic cells are generally circular.
- Small rings of DNA, called plasmids, may also be present in the cytoplasm of prokaryotic cells.
- Chromosomes in mitochondria and chloroplasts are similar to those in prokaryotes.

RECAP 9.6

1 List two differences between prokaryotic and eukaryotic chromosomes.
2 Compare chloroplast chromosomes with human chromosomes.
3 Explain why mitochondrial DNA can be used to trace a direct maternal genetic line.

Investigation of an issue: De-extinction – is there a moral obligation to invest in this direction?

Refer to Chapter 11 for more information on the investigation of an issue.

A number of scientists have proposed that extinction rates for animal and plant species have increased dramatically in the past 10000 years. The major cause is suggested to be the increase and spread of human populations linked to developments in technology and society. Wildlife species have become threatened, endangered or extinct through human activities, including overhunting, pollution, habitat destruction and the relocation of invasive species. De-extinction has been advocated by some scientists as a moral imperative to redress past extinction events attributed to human activities (Sandler 2013). It has also been promoted as an 'insurance' strategy against future extinctions, a means to restore lost biodiversity (Sandler 2013).

De-extinction refers to resurrecting a lost species by cloning the extinct organism. The basic premise is a variation of somatic cell nuclear transfer in which the genome, if not the nucleus, of the donor is that of the extinct species. The recipient zygote and surrogate mother are from a closely related, living species.

Over to you: Consulting on the issue

Imagine that the Federal Government is considering how best to allocate funding for conservation projects, which have traditionally been aimed at minimising environmental impact. They are interested in the concept of de-extinction and are questioning whether conservation funds should be redirected to de-extinction projects. They have called you in as a consultant to advise them. Your brief is to:

1 Determine how feasible de-extinction is. You will communicate your findings to an expert scientific committee.

2 Evaluate how socially responsible de-extinction is as a strategy. Use this evaluation and the feasibility study (in **1** above) to propose what proportion of the conservation funds to allocate to de-extinction projects. You will communicate your findings to a minister, who is not a scientific expert.

Task 1: Determine how feasible de-extinction is

a To consider the technical issues, investigate one extinct Australian species from Table 9.2.

Table 9.2 Some extinct Australian species

Scientific name	Common name	Distribution	Last recorded
Chaeropus ecaudatus	Pig-footed bandicoot	Arid and semi-arid regions of mainland Australia	1926; unverified reports to 1950s
Dromaius ater	Dwarf King Island emu	King Island, Bass Strait	1802
Macropus greyi	Toolache wallaby	South-eastern mainland Australia	1939
Macrotis leucura	Lesser bilby	Central Australia	1931
Psephotus pulcherrimus	Paradise parrot	South-eastern Queensland	1927
Rheobatrachus silus	Gastric-brooding frog	South-eastern Queensland	1981
Thylacinus cynocephalus	Tasmanian tiger	Tasmania	1936

For this investigation, consider the questions that need to be asked in order to address the technical issues for your selected extinct species (Table 9.3).

Table 9.3 Technical issues: questions to ask

Technical issue	Questions to direct your research
Reconstructing the genome	• Is the genome already sequenced? • If not, how well preserved is the material from which the DNA must be recovered?
Generating intact chromosomes	• Can chromosomes be recovered intact from preserved material? • If not, can chromosomes be made artificially? • If the genome is incomplete, how might the sequence gaps be filled in?
Choosing a surrogate zygote and mother	• Which species might be the best candidate surrogate zygote and mother? • How similar are the genomes of the candidate surrogate organism and the donor organism?

Record the sources of information you used to assist your investigation (e.g. websites, news articles, scientific reports, etc.).

b Write a 400–500 word report to the scientific expert committee that advises the Federal Commissioner of Threatened Species. In your report, deliver a verdict about how achievable de-extinction is for your selected organism, and support your conclusion with arguments drawn from your analysis in **1a** above. Use language appropriate for the scientific committee. Cite the sources of information that assisted in your analysis and provide a brief assessment (1–2 sentences) of their reliability.

Task 2: Evaluate how socially responsible de-extinction is as a conservation strategy

a In your evaluation consider the relative diversion of resources between extinct and living species, and answer the questions in Table 9.4.

Table 9.4 Guiding principles: questions to ask

Guiding principle	Questions to ask yourself
Individual rights	• What are the expectations for the welfare of resurrected animals? • Are the animals intended to be used for scientific research, public exhibition, or reintroduction into the wild?
Beneficence	• Which species stand to benefit by pursuing this strategy? • How many species stand to benefit? • Do people stand to benefit? • How do people stand to benefit?
Non-maleficence	• Which species could be harmed by pursuing this strategy? • How many species may potentially be harmed? • Could people be harmed? • How might the harm come about? • Can the harm be minimised?
Justice and equity	• Is the strategy fair for all species? • How can fairness be maximised?

b Using appropriate language, write a 400–500 word letter of recommendation to the Federal Commissioner of Threatened Species, who is not a scientific specialist. Outline your assessments of the (1) technical and (2) ethical considerations. Express your opinion as to whether de-extinction should or should not be pursued in principle, and support your opinion with arguments based on your answers to the questions in **2a** above. Provide a recommendation for whether conservation funding should be re-allocated away from conservation efforts towards de-extinction, supported with reasons derived from your analysis.

References

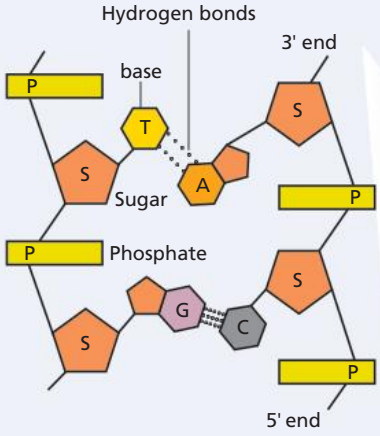
Sandler R. (2013) The ethics of reviving long extinct species. *Conservation Biology* 28: 354–60.

CONCEPT SUMMARY

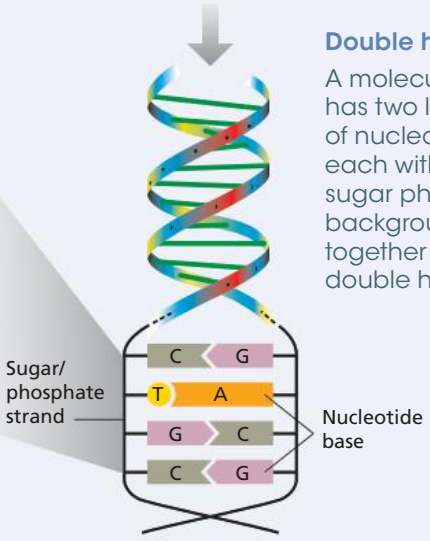
Genetics

Nucleotides contain:

- A five-carbon deoxyribose sugar
- A negatively charged phosphate group
- A nitrogen-containing nitrogenous base (can be A, T, C or G)



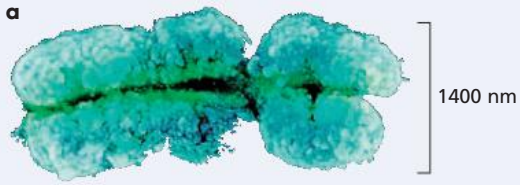
DNA structure

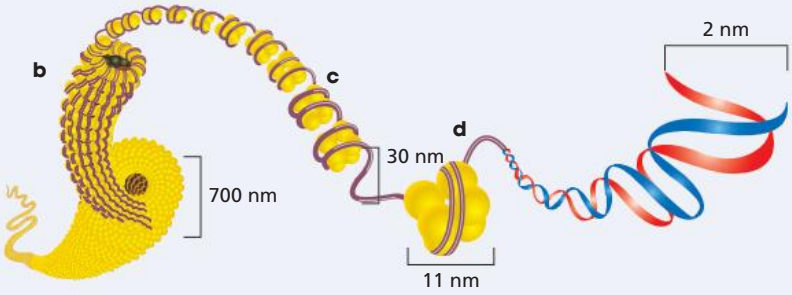


Double helix

A molecule of DNA has two long strands of nucleotides each with a sugar phosphate background, wound together to form a double helix.

Chromosomes

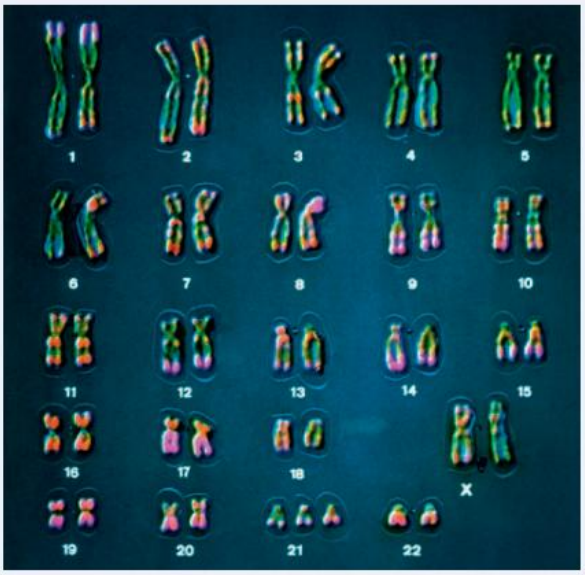




DNA and its associated proteins make up chromosomes. DNA is coiled around histone proteins to form nucleosomes.

Karyotypes

Matched and ordered display of eukaryotic chromosomes. Helps identify chromosomal disorders such as Down syndrome, Klinefelter syndrome and Turner's syndrome.



9780170368377

Genes

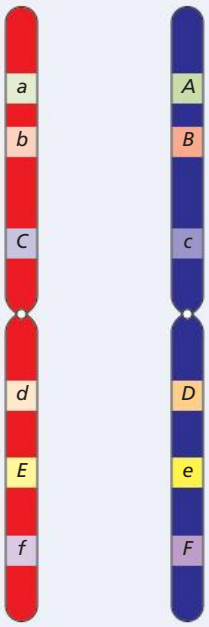
Units of hereditary information

- Each gene codes for a product (usually a protein).
- The information is encoded in the sequence of nitrogenous bases of nucleotides (A, T, C or G).
- The sequence of a particular gene can have some variations.

Alleles

Different forms of genes

- Different variants of genes are called alleles.
- Because an individual has two homologous chromosomes, they can have two possible alleles for each gene.
- Different alleles are positioned at the equivalent *loci* on each of the chromosomes.



Genomes

All the genetic information

- All of the DNA in the cell of an organism
- Measured in a haploid set of chromosomes
- Relatively minor differences between members of the same species
- Differences between species reflect how distantly related the species are in evolutionary terms

Genomic research

Sequencing many genomes

- The Human Genome Project revealed the entire human genome sequence.
- It revealed many fewer genes than were expected.
- The effort pushed major developments in technology
- Since then, it has been possible to sequence genomes of many species.

Relatedness between species

- Changes in the DNA sequence occur at a standard rate over time.
- Comparing the genomic sequences of two species can give an estimate of the time since they shared a common ancestor.
- The degree of similarity between genomes is therefore indicative of the degree of relatedness.

Determining gene function

- Clues to the function of an unknown gene can be found in its sequence similarity with other known genes.
- Reference sequences can be known genes in other species or related genes in the same species.

Applications in human disease

- Specific alleles can cause diseases such as Huntington's disease.
- Sequencing a person's genome or specific genes can be used to predict their likelihood of developing the disease.
- A suspected disease can be confirmed by checking the sequence of an associated gene.

CHAPTER GLOSSARY

allele one of different versions of the same gene (at the same locus) determined by small differences in the DNA sequence of the gene

aneuploidy describes a genome that varies from the conventional by the loss or addition of one or just a few chromosomes

anomaly something that deviates from what is standard, normal or expected

autosome a chromosome that is the same in both males and females of a species; autosomes do not include sex chromosomes

bioinformatics the science of managing and analysing biological data using advanced computing techniques; it is especially important in genomics research because of the large amount of complex data this research generates

centromere the waist-like constriction in a chromosome required for the movement of chromosomes during cell division

chloroplast DNA (cpDNA) DNA contained in a chloroplast

chromatin a complex of proteins and DNA in eukaryotic chromosomes

coding DNA a sequence of DNA that codes for a protein

complementary bases the nucleotide bases that pair on the opposite strands of DNA; A pairs with T and C pairs with G

DNA sequence the order of nucleotide bases within a DNA molecule

double helix the spiral shape of a DNA molecule

gene a unit of heredity that transmits information from one generation to the next; a segment of DNA that codes for a polypeptide

genetics the study of the mechanism and patterns of inheritance through the transmission of coded chemical instructions from one generation to the next

genome all the genetic material contained in an organism or a cell; includes the chromosomes within the nucleus and the DNA in mitochondria and chloroplasts

genomics the study of the genome – how genes interact with each other and the environment, and the resultant proteins produced; it requires a knowledge of an organism's entire DNA sequence, so studies rely on powerful technologies and bioinformatics

heredity the study of inheritance; the genetic transmission of characteristics from one generation to another

heterosomes non-identical chromosomes that pair up at meiosis (e.g. the X and Y chromosomes in human males)

histone a protein around which DNA winds in eukaryotic cells

homologous chromosomes a pair of chromosomes that have the same size, shape and genes at the same locations

hydrogen bond a weak molecular chemical bond

karyotype a display of the number and appearance of the chromosomes of an organism or cell observed at metaphase

linked genes genes on the same chromosome

locus the position a gene occupies in a chromosome

marker a DNA sequence with a known physical location on a chromosome that is located close to the gene of interest

mitochondrial DNA (mtDNA) DNA contained in mitochondria

monoploid describes a cell or organism that has a functional genome consisting of one copy of each chromosome, represented by 1*n*

monosomy the condition in which somatic cells contain one copy of a particular chromosome

nitrogenous base a structural component of nucloetides, DNA has adenine (A), cytosine (C), guanine (G) and thymine (T); in RNA thymine is replaced with uracil (U)

non-disjunction the failure of sister chromatids in mitosis or homologues in meiosis to separate and go to opposite poles

nucleoid the region within a prokaryotic cell that contains the genetic material

nucleotide the basic building block of nucleic acids (DNA and RNA), which are linked together by phosphodiester bonds; each nucleotide is made up of a five-carbon sugar, a phosphate group and a nitrogenous base

nucleotide base pair two complementary nucleotide bases that are joined together by hydrogen bonding in a DNA double strand

plasmid a small circular piece of DNA, found in bacteria, which is able to replicate independently of the cell's chromosomes

polyploidy when a cell or organism has a genome comprising three or more copies of each chromosome, represented by 3*n*, 4*n*, 5*n*, 6*n* etc.

proteomics the study of the entire protein content expressed by a cell

sex chromosomes the pair of chromosomes that determines the sex of an individual

sex-linked genes genes found on the sex chromosomes

somatic cell a normal body cell, as compared with a germ-line cell from which a gamete (i.e. sperm or ovum) is derived

tetraploid having four haploid sets of chromosomes in each cell, represented by 4*n*

triploid having three haploid sets of chromosomes in each cell, represented by 3*n*

trisomy the condition in which somatic cells contain three copies of a particular chromosome

CHAPTER REVIEW QUESTIONS

Remembering

1 State the type of chemical bond that holds strands of DNA together.
2 Describe the composition of an organism's genome.
3 **a** In humans, the diploid number is $2n = 46$. State what n equals.
  b State what type of cells have the $2n$ number of chromosomes.
4 Describe the difference in appearance between the X and Y chromosomes.

Understanding

5 Relate the concept of a chromosome to the concept of a gene.
6 Relate the size of chromosomes X and Y to the number of genes you would expect to find on each.
7 Explain how genomic research can improve detection and diagnosis of human diseases.

Applying

8 Turner syndrome is described as an example of aneuploidy. Give reasons why.
9 Construct a table to show the similarities and differences in chromosomes between eukaryotic and prokaryotic cells.
10 Compare the four human karyotypes labelled **i** to **iv** in Figure 9.14.
  a Determine which of the four is a normal karyotype and identify the sex of the individual.
  b Determine the aberration in each of the other three karyotypes.
  c Explain how the three aberrations could have come about.

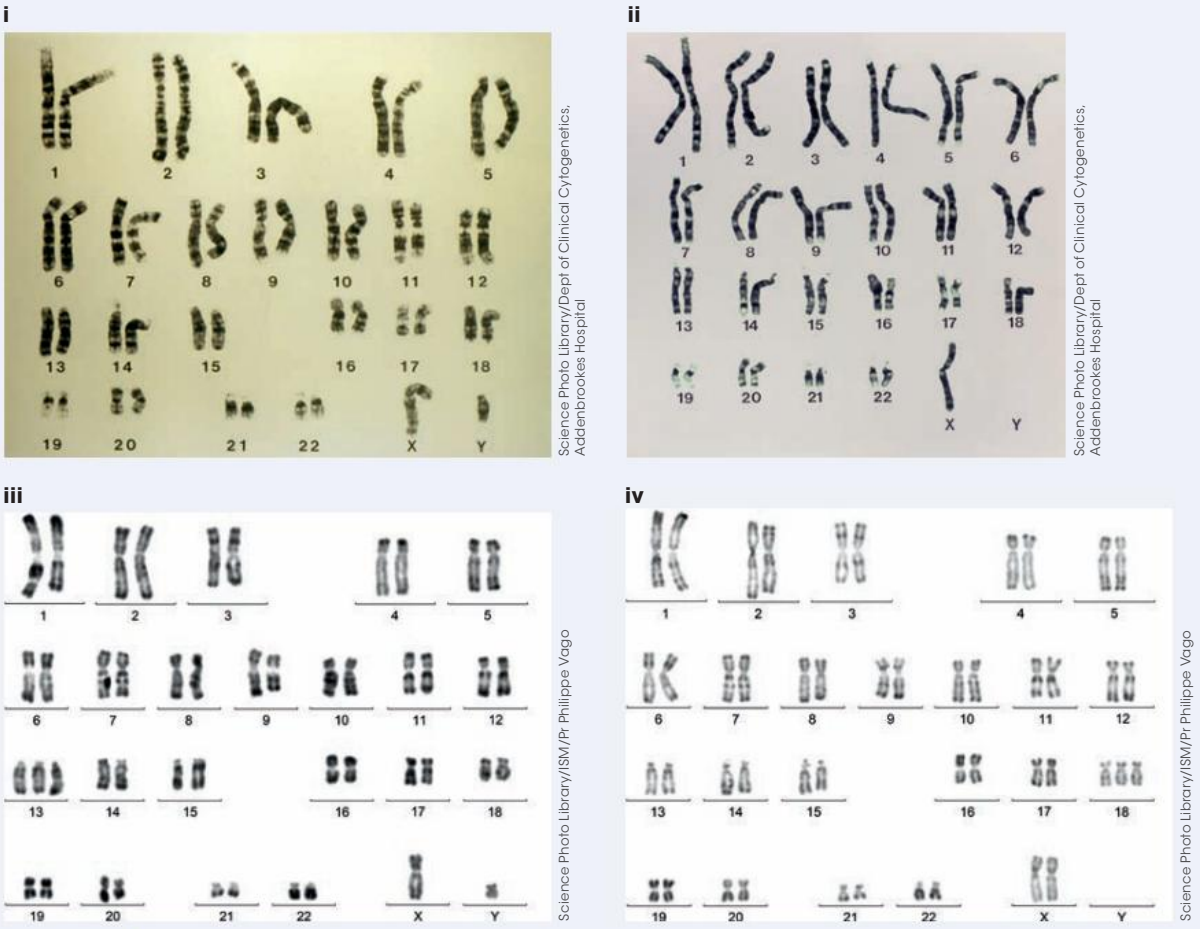


Figure 9.14 ▲
Four human karyotypes

11 The time taken to sequence the genome of an organism has been dramatically reduced in the past few years. Describe some applications resulting from improved understanding of the variation and commonality of the genomes of similar species, such as bacteria.

Analysing

12 Scientists from the Australian Museum and Queensland University of Technology have sequenced the koala genome. Analysis of the data should reveal between 12000 and 20000 genes on the 16 chromosomes.

- **a** Name the nucleotide expected to have approximately the same number as the adenine nucleotides sequenced.
- **b** Explain whether you would expect the sequence of DNA to be exactly the same in all members of the koala species.
- **c** Estimate how many chromosomes a baby koala would get from its mother.
- **d** State a koala's diploid number and its haploid number.
- **e** Find out how the knowledge gained by sequencing the genome can help in managing koala populations.

13 A cell from an unknown source has been prepared and stained, and a karyotype has been displayed. Explain how you could tell if it was likely to be from a human and, if so, what sex the human was.

14 An exceptionally large plant with enlarged fruit grows among a natural population. Discuss what genetic change might have occurred in this individual and describe how you could test it to find out.

15 Chromosome 1 in humans contains over 3000 genes, while chromosome 21 contains about 400 genes. Using this data, discuss reasons why embryos with an extra chromosome 1 will not develop, yet embryos with an extra chromosome 21 will often survive to develop into a baby with Down syndrome.

Evaluating

16 Decide whether two number 21 chromosomes in humans are homologous, and justify your answer. Explain whether all human chromosomes have a homologous pair.

17 All chromosomes are double stranded and linear in shape. Do you agree with this statement? Justify your answer.

18 Defend or refute this statement: 'Aneuploidy is always deleterious.' Explain your reasoning.

Creating

19 If non-disjunction occurs in a diploid cell with four chromosomes undergoing meiosis, predict the kind of chromosome anomalies that can arise in a zygote formed by fertilisation with each of the resulting gametes and one normal gamete. Draw an annotated diagram of your predictions.

20 Develop a flow chart showing the possible steps in identifying a human disease gene. You may want to consider computer input, clinical input and laboratory work.



CHAPTER 10
INHERITANCE

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

KEY KNOWLEDGE

Genotypes and phenotypes

- the use of symbols in the writing of the genotypes for the alleles present at a particular gene locus
- the distinction between a dominant and recessive phenotype
- the relative influences of genetic material, environmental factors and interactions of DNA with other molecules (epigenetic factors) on phenotypes
- qualitative treatment of polygenic inheritance as contributing to continuous variation in a population, illustrated by the determination of human skin colour through the genes involved in melanin production or by variation in height.

Pedigree charts, genetic cross outcomes and genetic decision-making

- pedigree charts and patterns of inheritance including autosomal dominant, autosomal recessive, X-linked and Y-linked traits
- the determination of genotypes and prediction of the outcomes of genetic crosses including monohybrid crosses, and monohybrid test crosses
- the inheritance of two characteristics as either independent or linked, and the biological consequence of crossing over for linked genes.
- the nature and uses of genetic testing for screening of embryos and adults, and its social and ethical implications.

Investigation of an issue

- the 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
- the nature of evidence and information: distinction between opinion, anecdote and evidence, weak and strong evidence, and scientific and non-scientific ideas; and validity, reliability and authority of data including sources of possible errors or bias
- the influence of social, economic, legal and ethical factors relevant to the selected biological issue.

KEY SCIENCE SKILLS

Conduct investigations to collect and record data

- systematically generate, collect, record and summarise both qualitative and quantitative data

Draw evidence-based conclusions

- critically evaluate various types of information related to biology from journal articles, mass media and opinions presented in the public domain

Communicate and explain scientific ideas

- use appropriate biological terminology, representations and conventions, including standard abbreviations, graphing conventions and units of measurement
- discuss relevant biological information, ideas, concepts, theories and models and the connections between them
- identify and explain formal biological terminology about investigations and concepts
- acknowledge sources of information and use standard scientific referencing conventions

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Can you roll your tongue into a U-shape? When you clasp your hands together, is your left or right thumb on top? Look at a classmate's ears. Are the lobes attached or free? These and many more of your characteristics are inherited from your parents. Because you have two sets of homologous chromosomes, one from each parent, you have two copies, or **alleles**, of the **genes** for each characteristic. If a gene has different alleles, alternatives are possible. Either you can roll your tongue or you cannot. Either your left thumb or your right thumb is on top when you clasp your hands together. Either your ear lobe is attached or it is free.

To study patterns of **inheritance**, we will turn back the clock to examine the innovative experiments and observations of an Austrian monk, Gregor Johann Mendel. Unfortunately, the significance of his painstaking work was not realised during his lifetime. Today his contribution is recognised by the term used to describe the patterns of inheritance he discovered: **Mendelian genetics**.



Getty Images/Time Life Pictures

Figure 10.1 ▲
Mendel discovered key principles of inheritance in his pea garden.

Patterns of inheritance

The principles of **heredity** and patterns of inheritance were first established by Gregor Mendel (1822–84) in the 19th century. Gregor Mendel (Figure 10.1) was unique in his time. He spent two years studying mathematics at the University of Vienna. He was also something of an expert in agricultural practices, being a member of the regional agricultural society and reading the available literature to keep up to date with developments in breeding experiments. In about 1856, Mendel carried out a number of breeding experiments on pea plants in the garden at his monastery. The conclusions he drew from his studies form the foundations on which the study of heredity is built.

Mendel's peas

In the early stages of his work, Mendel studied the inheritance of seven pairs of contrasting characteristics in pea plants. These included variations such as yellow or green pea pods, round or wrinkled seeds and tall-stemmed or dwarf-stemmed plants. Pea plants were ideal for his work: the characteristics, or variables, had no intermediate forms, pea plants self-pollinated and therefore self-fertilised, and the characteristics that he studied were largely unaffected by environmental factors.

In one such experiment, Mendel took a **purebreeding** tall pea plant and crossed it with a purebreeding short pea plant. Purebreeding plants, when crossed among themselves, always give rise to offspring that are like the parents. This is because their alleles are identical. Mendel crossed the plants by taking pollen grains containing sperm cells from the anthers of one plant and dusting them onto the stigma of another plant, having first removed the anthers of this second plant to ensure that it could not self-pollinate (Figure 10.2).



Alamy/Edward Parker

Figure 10.2 ▲
Hand pollination involves taking the pollen from the anther of one plant and dusting it onto the stigma of another plant, after removing the second plant's anthers to ensure that no self-pollination occurs.

Mendel collected the seeds that resulted from the crosses between the tall pea plants and the short ones, and sowed these. He found that the seeds, once they had germinated and grown into adult plants, always developed into tall offspring (Figure 10.3). This was the case whether pollen grains from tall plants were

placed on to the stigmas of short plants, or pollen grains from short plants were placed on to the stigmas of tall plants. In these crosses, we refer to the original parent plants as the **parental generation (P)** and the offspring as the **first filial generation (F_1)**.



Visuals Unlimited/Nigel Cattlin

Figure 10.3 ▲
Tall and short pea plants: two different phenotypes for plant height

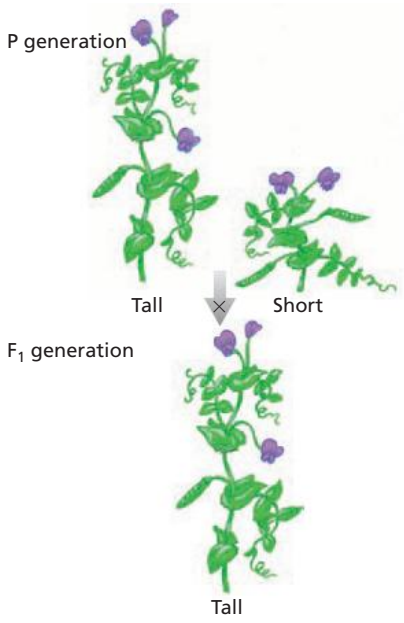


Figure 10.4 ▲
Mendel found that tall pea plants crossed with short pea plants always gave rise to tall pea plants.

Mendel then took the tall F_1 plants and self-pollinated each of them, again taking precautions to prevent them being pollinated by any other kind of pollen. The resulting seeds were sown and the offspring, belonging to the **second filial generation (F_2)**, were examined. Mendel found that some of these F_2 plants were tall and some were short. Overall, he counted 1064 plants. Of these, 787 (74%) were tall and 277 (26%) were short. It seemed as though approximately three-quarters of the F_2 generation were tall and one-quarter were short. In other words, the ratio of tall to short plants was approximately 3:1.

RECALL

- Gregor Mendel's study of peas in the 19th century established the principles of heredity.
- Purebreeding parental generations of tall and short pea plants produced offspring (F_1) which were all tall. When crossed, these F_1 plants produced tall and short offspring (F_2) in the ratio of 3:1.

RECAP 10.1

1 Define 'purebreeding'.
2 Define the P, F_1 and F_2 generations.
3 Describe Mendel's experiments with short and tall pea plants.

The relationship between genes and traits

What conclusions can we draw from Mendel's results? The first striking fact to notice is that in the F_1 and F_2 generations there are no medium-sized plants; that is, there are no plants that are intermediate between the tall and the short parents. From this, we conclude that inheritance is not necessarily a process in which features of two parents blend together to produce an intermediate result, like the mixing of black and white paints to produce grey. Rather, definite factors, which may or may not show themselves in the outward appearance of the organism, pass from parents to offspring. That such factors exist is borne out by the observation that, despite its absence in the F_1 generation, the short form reappears in the F_2 generation.

The second conclusion is drawn from the observation that there were no short plants in the F_1 generation, despite the fact that one of the parent plants was short. Short plants reappeared, however, in the F_2 generation. From this we can conclude that, although the F_1 plants are tall, they must receive a factor for shortness from their short parent, which remains 'hidden' in the F_1 plants and does not reveal its presence until the F_2 generation.

A third conclusion is that the factor for shortness, which fails to show itself in the F_1 generation, must be masked in some way by the factor for tallness. Only in the absence of this factor will the factor for shortness show itself in the outward appearance of the plant. In other words, the factor for tallness is **dominant** to the factor for shortness. Shortness is described as **recessive**.

Although Mendel knew nothing of chromosomes and genes, he suggested that the factors he described pass from parents to offspring via the gametes. If we are right in assuming that the F_1 plants contain factors for shortness as well as for tallness, it is reasonable to suppose that each F_1 plant receives one factor for tallness from its tall parent and one factor for shortness from its short parent via the gametes. That is, the gametes contain only one of the two factors for size, while the plants to which these gametes give rise contain a pair of such factors.

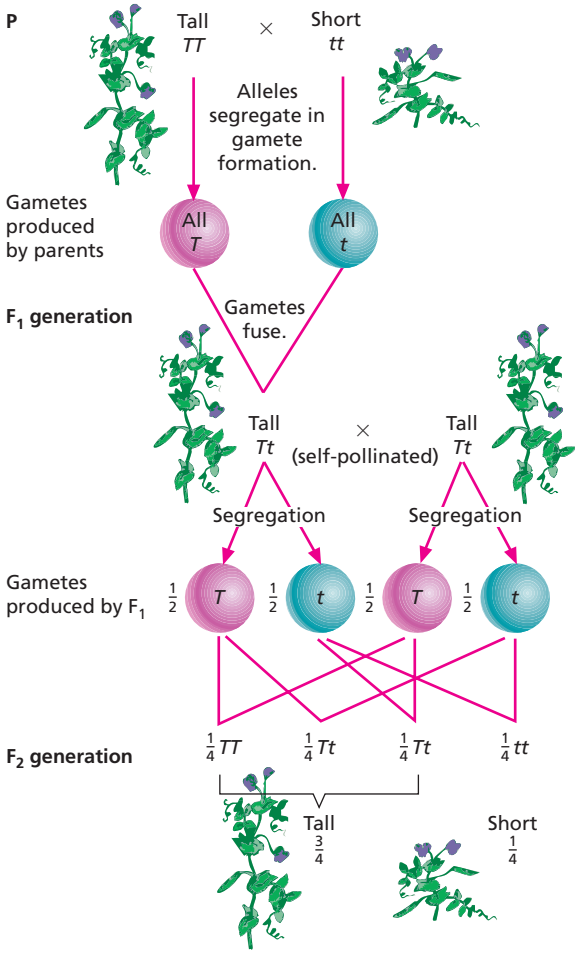


Figure 10.5 ▼
Summary of what happens when a purebred tall pea plant is crossed with a purebred short pea plant. Gametes are circled.

Figure 10.5 shows a summary of what Mendel discovered. Instead of 'factors' we use the term 'gene'. As Mendel observed, the gene controlling height in the pea plant exists in two forms, which we now call alleles. One allele functions in a certain way and is responsible for producing a tall plant. The other influences development in such a way that, if two copies of this allele are present together, a short plant is produced.

In Figure 10.5 the allele for tallness is represented by *T*, and the allele for shortness by *t*. We shall assume that each parent plant (or, more strictly, each somatic cell of each parent plant) contains a pair of identical alleles: *TT* in the case of the tall parent, *tt* in the case of the short parent. When an organism contains identical alleles like this, it is said to be **homozygous**. In making this statement, we are describing the genetic make-up of the parent plants, or at least the gene that determines the size of the plant. The genetic composition of an organism is known as its **genotype**. In essence, the genotype describes the alleles that a cell or organism has at a particular gene locus for a particular **trait**. The way in which genes are expressed in the outward appearance of the organism is known as its **phenotype**. In the case of the parent generation of pea plants described earlier, plant height is the phenotype (Figure 10.5). Pea plants with the 'tall' phenotype have the genotype *TT*. Pea plants with the 'short' phenotype have the genotype *tt*.

The *T* allele is present in each of the gametes produced by the tall parent and the *t* allele is present in each of the gametes produced by the short parent. Fertilisation brings the *T* and *t* alleles together, so that all the F_1 offspring have the genotype *Tt*. Phenotypically they are all tall, as tallness is dominant to shortness. When an organism contains two dissimilar alleles, it is said to be **heterozygous**. In this particular instance, the *T* allele expresses itself in the phenotype and the expression of the *t* allele is being masked by the expression of the *T* allele. A dominant phenotype is expressed whether it occurs in the homozygous or the heterozygous condition. However, a recessive trait is only expressed when in the homozygous condition.

RECALL

- The combination of alleles an organism has for a particular gene is its genotype. The two alleles may be identical (homozygous) or different (heterozygous).
- A dominant trait is expressed in both homozygous and heterozygous conditions.
- A recessive trait is expressed only in a homozygous condition.
- The way a genotype is expressed is termed its phenotype.

RECAP 10.2

1. List three conclusions that can be drawn from Mendel's experiments.
2. Describe the difference between a genotype and a phenotype.
3. Define 'heterozygous' and 'homozygous'.
4. How many different genotypes are possible for the tall and short traits of Mendel's peas? List them, and classify them according to whether they are homozygous or heterozygous and whether they result in a dominant or recessive phenotype.

Dominance is not always clear cut

Mendel's experiments were based on characteristics that were not only determined by genes found on different chromosomes, but also all showed one phenotype dominant over another phenotype. However, the expression of genes is not always so straightforward. Phenotypic variations can result when the characteristics of offspring show both parental characteristics or are a combination of parental characteristics.

If a purebreeding red snapdragon plant is crossed with a purebreeding white snapdragon plant, as shown in Figure 10.6, the F_1 offspring all have pink flowers. When these F_1 pink snapdragons are crossed, the F_2 offspring have flowers in the ratio of 1 red : 2 pink : 1 white. This is known as **incomplete dominance** or **partial dominance** because one trait is not fully dominant over its partner and the heterozygous phenotype (pink) is intermediate between the homozygous parental phenotypes (red and white).

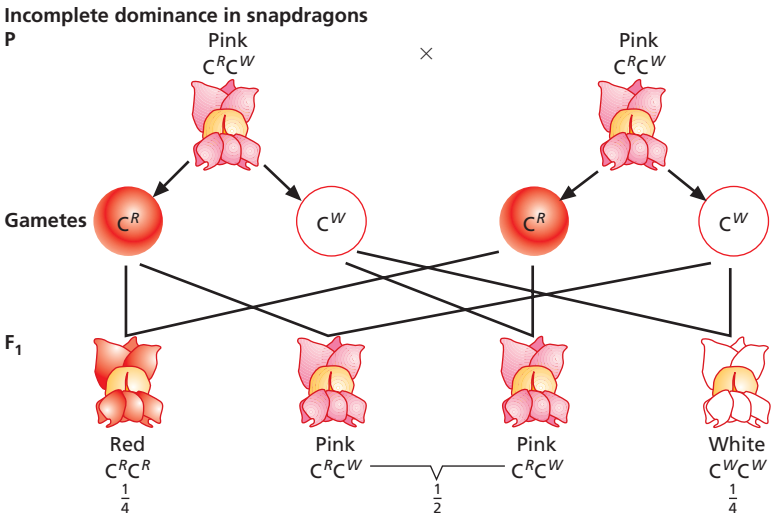
A special notation is used to indicate inheritance of partially dominant traits. A suitable upper-case letter designates the gene for the trait (e.g. *C* for colour) and upper-case superscript letters indicate the alleles (e.g. C^R = red colour, C^W = white colour). Figure 10.7 on page 296 shows a diagram using the appropriate notation to describe inheritance of colour in snapdragons.



Science Photo Library/Adrian Thomas

▲ **Figure 10.6** In purebreeding snapdragons, incomplete dominance of the red flower colour and white flower colour results in a pink flower colour.

Figure 10.7 ▶
The result of crossing snapdragons with pink flowers among themselves. A phenotypic ratio of approximately 1 red : 2 pink : 1 white results.



The study of certain coat colours in horses and cattle reveals another type of dominance relationship. In this case, both alleles in the genotype are fully expressed in the heterozygote. Such traits are said to be **co-dominant**. In shorthorn cattle, alleles for coat colour are inherited in this way and the two alleles are expressed as red (C^R) and white (C^W). This is similar to the incomplete dominance shown in snapdragons but, in this case, the offspring of purebreeding red and white parents have roan coats (C^WC^R), which are a mixture of red and white hair. The co-dominant inheritance of coat colour in shorthorn cattle is shown in Figure 10.8. An outline of the differences between the types of dominance relationships is given in Table 10.1.

Figure 10.8 ▶
In shorthorn cattle, co-dominant inheritance results in a roan coat colour in the offspring of purebreeding red and white parents.

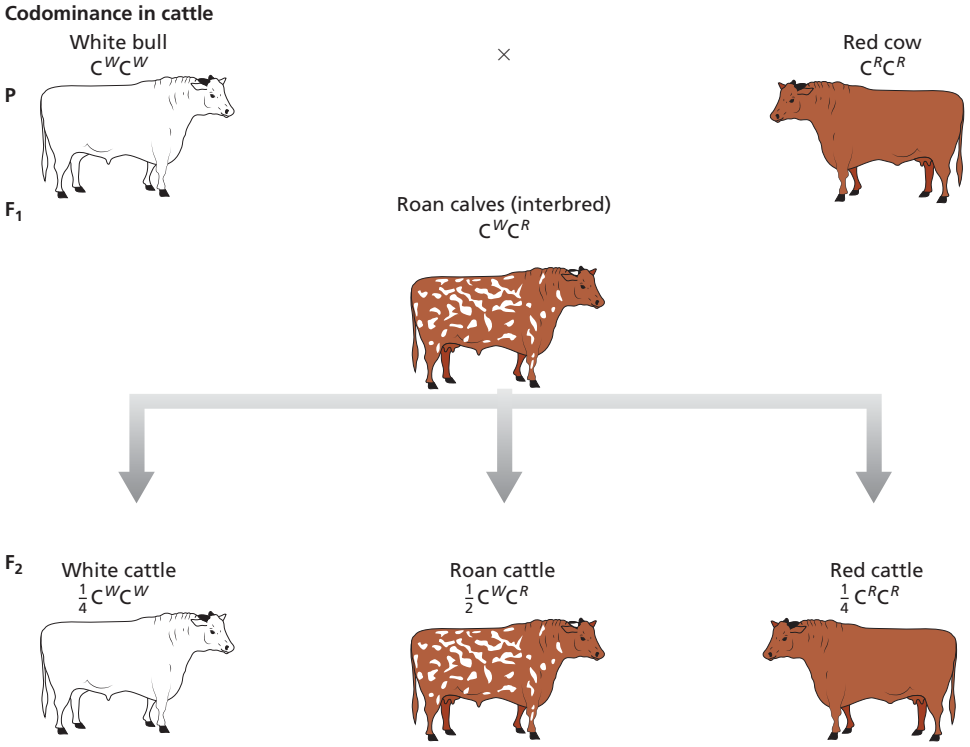


Table 10.1 Differences between the types of dominance relationships

	Complete dominance	Incomplete (partial) dominance	Codominance
Parents	*BB, bb*	C^BC^B, C^WC^W	C^BC^B, C^WC^W
Gametes	(B) (b)	(C^B) (C^W)	(C^B) (C^W)
F_1 genotype	*Bb*	C^BC^W	C^BC^W
Phenotype	Black	Grey	Black and white stripes
Gametes	(B) (b) × (B) (b)	(C^B) (C^W) × (C^B) (C^W)	(C^B) (C^W) × (C^B) (C^W)
F_2 genotype	*BB, Bb, bb*	C^BC^B, C^BC^W, C^WC^W	C^BC^B, C^BC^W, C^WC^W
Phenotype	Black White	Black Grey White	Black Black and white stripes White
Heterozygote	Same as dominant	Intermediate between homozygous parents	Properties of both homozygous parents

Note: *B* and C^B = alleles for black coat colour; *b* and C^W = alleles for white coat colour.

RECALL

- The interaction between alleles determines an organism's phenotype.
- Incomplete dominance or partial dominance refers to a situation when one trait is not fully dominant and the heterozygous phenotype is intermediate between the homozygous parental phenotypes.
- When both alleles in a genotype are fully expressed in the heterozygote, such traits are said to be co-dominant.

RECAP 10.3

1 The petal colour of carnations is determined by a single gene with two alleles: one for white, one for red. Describe the phenotypes you would expect in the F_1 generation of two purebreeding parents, one white, one red, in the following circumstances.
   - **a** White is dominant to red.
   - **b** The two traits are co-dominant.
   - **c** The two traits are partially dominant.

2 Explain why the offspring of a tall pea plant and a short pea plant are not all of intermediate height.

Genetic material, environmental factors and epigenetic factors influence phenotypes

Even though identical twins have the same genes, they often show variations in their characteristics. They may have slightly different weights and heights, for instance. How can we explain this if there is a direct relationship between genes and their expression?



iStock.com/manley099

Figure 10.9 ▶
Even identical twins show variations in their characteristics.

It seems that environmental conditions affect gene expression. A well-known case of fur colour in the Himalayan rabbit demonstrates this. The Himalayan rabbit has a white body with black ears, nose, feet and tail (Figure 10.10). At first glance, it seems that this pattern is simply under genetic control, but a simple experiment shows that this is not the case. If a cold pad is fixed to the rabbit's back, left in position for a few weeks and kept cold, black hair starts to develop beneath the pad.



Shutterstock.com/Linn Currie

Figure 10.10 ▶
The Himalayan rabbit normally has black hair only on its long ears, nose, tail and lower leg limbs. In one experiment, a patch of a rabbit's white fur was removed, and then an icepack was secured over the hairless patch. Black hairs grew back where the colder temperature had been maintained.

What seems to be happening is that heat prevents the development of the black pigment. Black fur only grows in those parts of the body that are cool enough – that is, the extremities. The same thing happens in seal-point Siamese cats. Owners of such cats sometimes find that, in winter, the black areas enlarge, only to get smaller in warmer weather.

There are many other cases of the environment influencing an organism's development. For example, in plants, chlorophyll will only develop if light is available, and flowers will only appear if the day length is of a certain duration and the temperature is suitable, and so on. It is easy to underestimate the importance of the environment on the development of organisms and to assume that everything is under genetic control. In reality, development is the result of a subtle and complex interaction between heredity and the environment.

Chemical modification of DNA also seems to influence the phenotypic expression of genes. One of the first observations of chemical modification was in the 1970s when scientists noticed a particular pattern in DNA. Some cytosine bases in DNA had a methyl group attached. When this modified base appears, the DNA is said to be methylated. Wherever genes were active, **DNA methylation** was not found. It is now known that methylation usually switches off gene expression.

What is also intriguing is that these chemical signatures can be altered by environmental factors and they can sometimes be passed on through cells from parent to offspring. These modifications therefore represent an alternative form of inheritance apart from the specific alleles offspring may receive from their parents. The study of the acquisition and inheritance of these modifications without involving changes in DNA sequences underpins the field of **epigenetics**. Epigenetic mechanisms include a number of different interactions of molecules with DNA. The **epigenome** consists of the genome plus the chemical compounds, such as methyl groups, attached to the DNA that modify expression of the genome. The chemical modifications are not part of the genome but affect how the genes are expressed, and therefore affect the phenotype of the organism.

RECALL

- The phenotypic expression of genes can be influenced by the environment and chemical modifications.
- Epigenetic mechanisms such as DNA methylation can alter the phenotype.

RECAP 10.4

1 Describe how the environment can affect a phenotype.
2 Recount the effect of temperature on the colour of Himalayan rabbits.
3 List two environmental conditions that affect plant characteristics.
4 Define 'epigenetics'. Describe the effect of methylation on gene expression.

Inheritance of a single autosomal gene

Mendel's studies at the University of Vienna helped him to explain the outcome of breeding experiments between tall and short pea plants in mathematical terms. The 3:1 ratio he predicted in the F_2 generation was based on observations of many different crosses using a variety of pea plant characteristics (Table 10.2). Mendel could not explain why this ratio occurred, because he had no knowledge of meiosis.

Table 10.2 Results of some of Mendel's crosses on the garden pea (*Pisum sativum*)

Purebreeding parental phenotypes	F_1 phenotypes	F_2 phenotypes	Ratio
Tall plants × short plants	All tall	787 tall, 277 short	2.84 : 1
Purple flowers × white flowers	All purple	705 purple, 224 white	3.15 : 1
Green pods × yellow pods	All green	428 green, 152 yellow	2.82 : 1
Yellow peas × green peas	All yellow	6022 yellow, 2001 green	3.01 : 1
Round peas × wrinkled peas	All round	5474 round, 1850 wrinkled	2.96 : 1

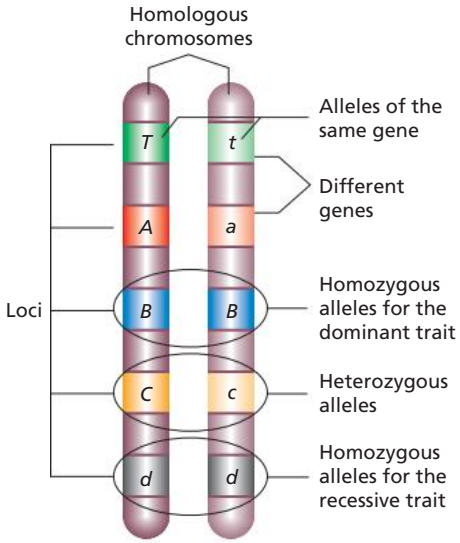


Figure 10.11 ▲
Homologous chromosomes contain alleles in pairs. This diagram shows the various combinations of alleles possible.

We can relate the behaviour of chromosomes at meiosis to the 3:1 ratio obtained. In meiosis, homologous chromosomes separate from each other, so haploid gametes receive only one of each type of chromosome instead of the two chromosomes present in diploid cells. In diploid cells, alleles occur in pairs, one of each pair being located on one of two homologous chromosomes (Figure 10.11). When homologous chromosomes separate in meiosis, the alleles are separated and thus each gamete receives only one of a pair of alleles, just as they only receive one of a pair of homologous chromosomes (Figure 10.12). Historically, it was the striking similarity between the segregation of Mendel's factors in inheritance and the separation of homologous chromosomes in meiosis as observed under the light microscope that provided evidence that genes are carried on chromosomes.

Equipped with an understanding of meiosis, the outcomes of several different types of crosses can be predicted. We will now explore how this is done, beginning with the simplest type of cross, the **monohybrid cross**.

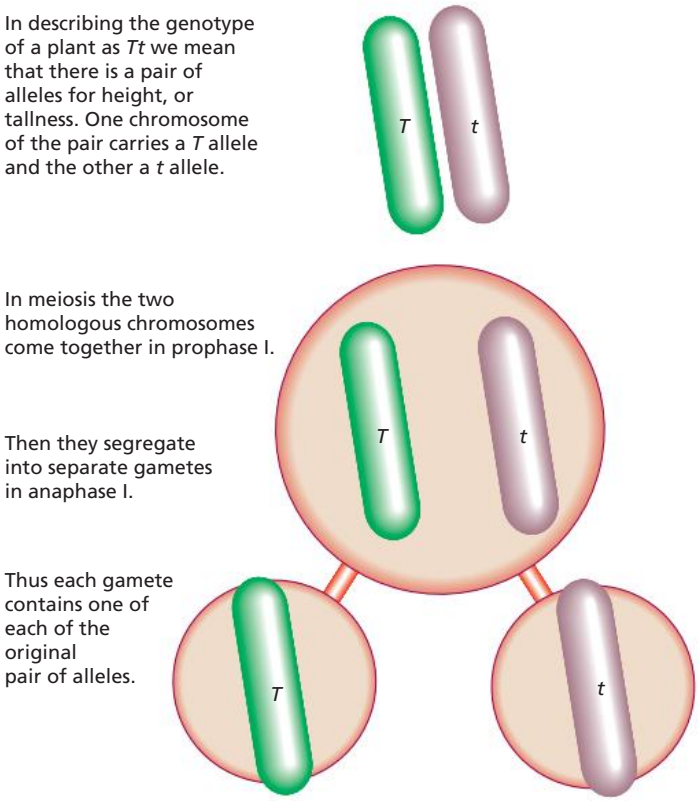


Figure 10.12 ▶
The segregation of alleles in inheritance corresponds to the segregation of homologous chromosomes in meiosis.

The monohybrid cross

A monohybrid cross involves one pair of contrasting phenotypes. The cross between the tall and short pea plants studied by Mendel is an example of a monohybrid cross. The parental generation had the genotypes *TT* (tall) and *tt* (short). Segregation of the alleles into the gametes can be explained in terms of meiosis. If homologous chromosomes contain *TT* or *tt* alleles, each gamete produced after meiosis must contain only a *T* (from a *TT* parent) or a *t* (from a *tt* parent). When these gametes fuse at fertilisation, the offspring will have two homologous chromosomes, one from each parent. One way of showing how this comes about is illustrated in Figure 10.13. If the parent has one homologous chromosome containing a *T* and its pair containing a *t* (*Tt*), then half the gametes will be expected to contain a *T* and the other half a *t*.

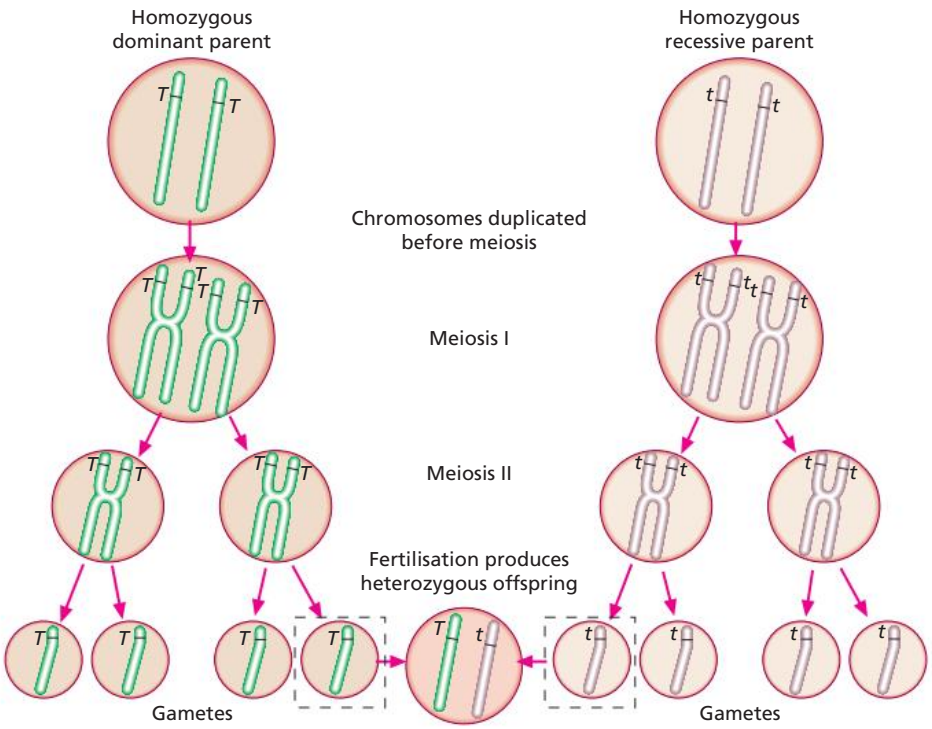


Figure 10.13
The segregation of chromosomes in a monohybrid cross. Two homozygous parents with different phenotypes can only produce heterozygous offspring.

The most straightforward way of showing how this arises is with a **Punnett square**, conceived by Sir Reginald Punnett. In a Punnett square, the possible alleles in the gametes of one parent are written along the top of a series of boxes and the possible alleles in the gametes of the other parent are written down the side. The products of the various fusions are written in the appropriate boxes and their relative numbers can be estimated (Worked Example 10.1).

WORKED EXAMPLE 10.1

A pea plant that is purebred for green pea pods is crossed with a pea plant purebred for yellow pods (Figure 10.14). Their offspring all have green pods. If two of the F_1 generation plants are crossed, work through the stages to predict the proportion of the F_2 generation that will also produce green pea pods.

a Assign the alleles with respect to dominance. (1 mark)
b Draw the Punnett square and enter the female and male gametes. (1 mark)
c Determine the genotypes of all the possible offspring. (2 marks)
d Determine the proportions of the phenotypes of the offspring. (2 marks)

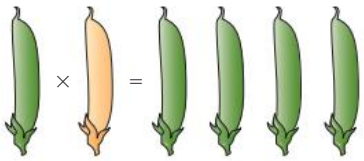


Figure 10.14
A purebreeding pea plant with green pods is crossed with a purebreeding pea plant with yellow pods, giving offspring that all have green pods.

Answer

a

G = green pods
g = yellow pods

Logic

If the plants of the parental generation are purebreeding, each must be homozygous for their respective trait. 1 mark

As both the parents are homozygous, all the offspring must be heterozygous (Figure 10.13), and they carry one allele for the green phenotype and one allele for the yellow phenotype.

All the heterozygous F_1 plants have green pods, proving that the green phenotype is dominant.

Choose a capital letter to represent the allele for the dominant phenotype. In this case, *G* is appropriate for 'green'.

The corresponding lowercase letter is used to represent the allele for the recessive phenotype. In this case, *g* is appropriate for 'yellow'.

b

		Female gametes	
		$\frac{1}{2}G$	$\frac{1}{2}g$
Male gametes	$\frac{1}{2}G$		
	$\frac{1}{2}g$		

All the F_1 plants have the genotype *Gg*. The alleles segregate on their homologous chromosomes during meiosis (Figure 10.12), so half their gametes acquire the G allele and the other half acquire the g allele.

In effect, the top row and the left column display the haploid gametes.

1 mark

c

		Female gametes	
		$\frac{1}{2}G$	$\frac{1}{2}g$
Male gametes	$\frac{1}{2}G$	$\frac{1}{4}GG$	$\frac{1}{4}Gg$
	$\frac{1}{2}g$	$\frac{1}{4}Gg$	$\frac{1}{4}gg$

All the remaining squares of the Punnett square represent the product of the fertilisation events of each of the gametes. These will be filled with the genotypes of the diploid offspring.

Start with the empty top left square. This square is the intersection of the female column headed '$\frac{1}{2}G$' and male row headed '$\frac{1}{2}G$'. As half the female gametes possess a *G* allele and half the male gametes possess a *G* allele, the proportion of offspring inheriting these alleles together is $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$. The same logic applies to the alleles themselves: $G \times G = GG$. The empty square must therefore be filled with the product of the two gametes: $\frac{1}{2}G \times \frac{1}{2}G = \frac{1}{4}GG$.

The next square to the right is the intersection of the female column headed '$\frac{1}{2}g$' and male row headed '$\frac{1}{2}G$'. The empty square must be filled with the product of these two gametes: $\frac{1}{2}g \times \frac{1}{2}G = \frac{1}{4}Gg$.

Note: By convention, the allele for the dominant phenotype is always written first.

Continue through each square until the Punnett square is complete.

2 marks

d Three-quarters, or 75%, of the F_2 offspring are predicted to be green.

Each genotype with at least one *G* allele must express the dominant phenotype. The Punnett square shows that three of the four squares for the offspring have at least one *G* allele.

In other words, $\frac{1}{4}GG + \frac{1}{4}Gg + \frac{1}{4}Gg$, a total of $\frac{3}{4}$ of the offspring will show the dominant phenotype, green. This solves the original problem.

Only the *gg* genotype will express the recessive phenotype. The Punnett square shows that just one of the four squares for the offspring has this genotype. In other words, $\frac{1}{4}$ of the offspring will show the recessive phenotype, yellow.

2 marks

Try these yourself

Using the alleles *T* and *t*, draw Punnett squares to show the ratio of tall to short plants among the offspring from the following crosses:

1 a purebreeding tall pea plant crossed with a purebreeding short pea plant, yielding all tall plants

2 a cross between two pea plants of the F_1 generation from the parental cross in **1**.

Probability in genetic ratios

It is important to clarify the statement that three-quarters of the F_2 generation will be tall and one-quarter short. This is what is predicted based on probability, and this outcome will most likely only be seen when there is a large number of F_2 individuals. Another way of putting it is to say that if an F_2 plant is selected at random, there is a 3 in 4 chance of it being tall and a 1 in 4 chance of it being short. In other words, the probability of it being tall is $\frac{3}{4}$ or 75%.

Now, even if we looked at a large number of the F_2 plants, we should not expect the ratio of tall to short individuals to be exactly 3:1. Rather, we would expect approximately three-quarters of the F_2 plants to be tall. It is true that, based on *probability*, half the gametes (or potential gametes) should have *T* alleles and half *t* alleles. However, many of these gametes will fail to develop, die or fail to give rise to a zygote.

Another point is that even if exactly half of the gametes that gave rise to the F_2 plants had *T* alleles and exactly half had *t* alleles, the random fusion of gametes means that we could end up with most or all of the offspring being heterozygous and so all being tall.

For all these reasons, the actual ratios obtained in genetic crosses only approximate the expected ratios. However, the more individuals that are counted, the closer the observed ratios come to the expected ones. This is why Mendel looked at more than 1000 pea plants. Only then was he convinced that the ratios he observed were the ones he expected.

RECALL

- Punnett squares are a convenient way to represent crosses and predict the resulting genotypes and phenotypes and their proportions.
- Inheritance for alleles of a single autosomal gene can be analysed using a monohybrid cross.
- Observed phenotypic ratios for any cross may vary from those predicted by a Punnett square. This is due to random assortment of alleles on chromosomes during meiosis and the fertilisation of random gametes.

RECAP 10.5

1 Define 'monohybrid cross'.
2 Draw a Punnett square to represent the cross of two offspring from a purebred tall pea plant parent and a purebred small pea plant parent.

The test cross

How do we determine whether an organism that expresses a dominant trait is homozygous dominant or heterozygous at a particular locus if the organism is incapable of self-fertilisation, which is the case for most animals? A technique used by geneticists is to cross the individual whose genotype is unknown with an individual that is homozygous recessive at the locus in question. This is called a **test cross**. We can illustrate this by reference to an animal that is used in many genetic experiments, the fruit fly *Drosophila melanogaster*.

D. melanogaster has four pairs of chromosomes and is known to exist in a large number of variants or forms. For instance, most individuals have red eyes but some have white eyes. Similarly, most individuals have long wings, but some have small or 'vestigial' wings (Figure 10.15). The long-winged condition (*V*) is dominant to vestigial wing (*v*). Accordingly, if a purebred long-winged fly (*VV*) is mated with a vestigial-winged fly (*vv*) the F_1 individuals are all heterozygous at this locus (*Vv*) and have long wings. If two of these F_1 flies mate with each other, a mixture of long-winged and vestigial-winged flies are produced in a ratio of approximately 3:1 (Figure 10.16).

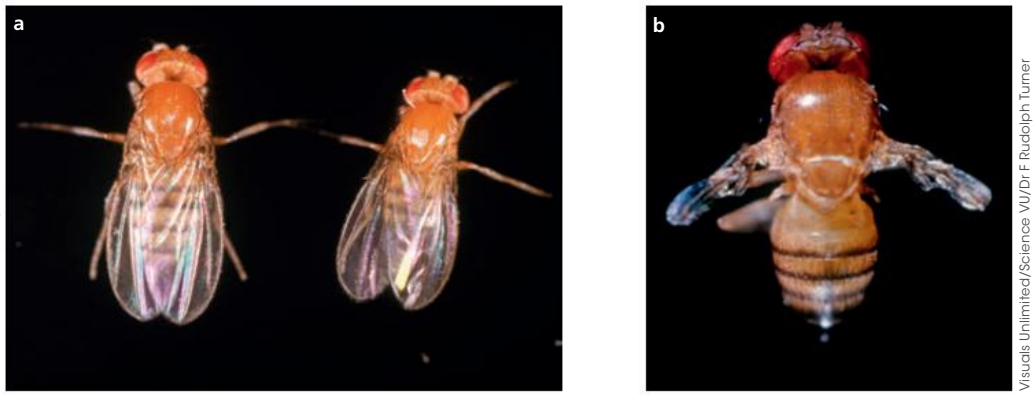


Figure 10.15 ▶
The fruit fly *D. melanogaster* may have (**a**) long wings or (**b**) vestigial wings. Flies with vestigial wings cannot fly and instead move by running and jumping.

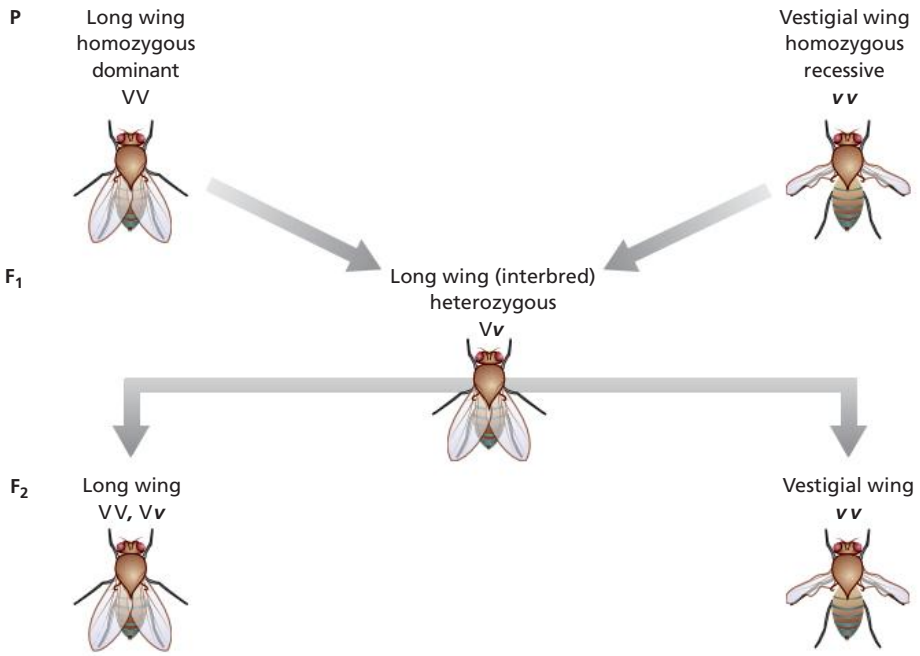
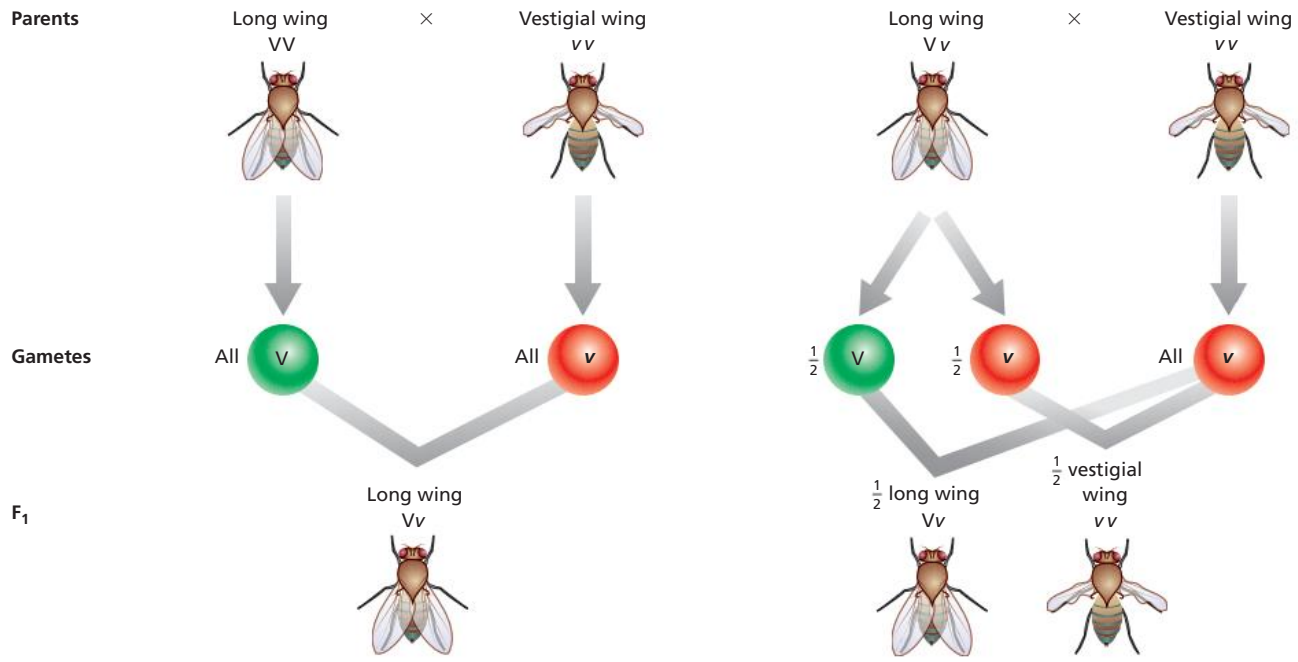


Figure 10.16 ▶
Summary of a monohybrid cross in fruit flies

This is expected for a monohybrid cross. But how can we decide whether a given F_2 long-winged fly is homozygous dominant (*VV*) or heterozygous (*Vv*)? The simplest way is to cross it with a vestigial-winged fly. We know that a vestigial-winged fly must be *vv* (homozygous recessive); it cannot be anything else. If the long-winged fly whose genotype we wish to determine is *VV*, then crossing it with a vestigial-winged fly will give nothing but long-winged flies. If, however, the unknown fly has the genotype *Vv*, then the cross will give a mixture of long and vestigial-winged flies in approximately equal numbers. This is summarised in Figure 10.17.



▲ **Figure 10.17**
A test cross to determine whether a fruit fly is homozygous dominant or heterozygous for long wings

Test crosses with individuals that are known to be homozygous recessive at the locus in question are a routine method of establishing an organism's genotype.

RECALL

- A test cross can be used to determine the genotype of an individual displaying a dominant phenotype.
- A test cross is made between an organism exhibiting the dominant trait and another organism displaying the recessive trait.

RECAP 10.6

1 Describe the purpose of a test cross and how it is achieved.

2 Explain how offspring may have a different genotype from either of their parents at a particular locus.

Deadly combinations and lethal phenotypes

Experiments looking at fur colour in mice demonstrate that yellow (*Y*) is dominant to grey (*y*). In a cross between two heterozygous yellow mice, offspring are produced in the following proportions: 23 yellow, 13 grey, a ratio of approximately 2:1. For a total of 36 offspring, the expected observation should have been approximately 27 yellow and 9 grey (3:1), so what is happening? One explanation is that mice homozygous for the *Y* allele die before birth. In other words, the genotype *YY* presents a **homozygous lethal phenotype**. This would explain why the proportion of yellow offspring is reduced (Figure 10.18 on page 306). Alleles for lethal phenotypes are known to exist in a wide range of organisms.

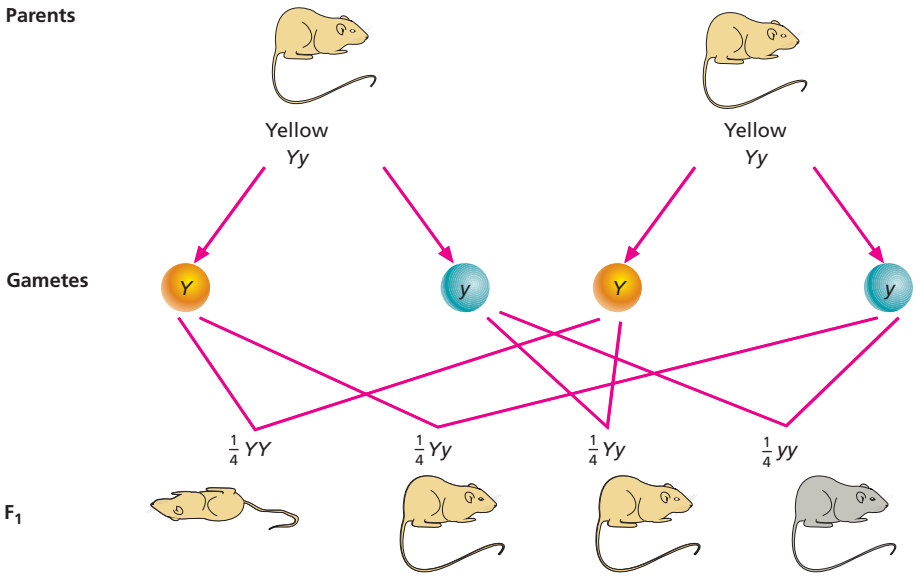


Figure 10.18 ▶
Mice that are homozygous *YY* for fur colour die before birth, so a cross of two mice with the *Yy* genotype fails to produce the 3:1 ratio typical of monohybrid crosses.

Certain dominant phenotypes are so important for normal development that an individual homozygous for a mutant recessive form of the trait cannot survive. The alleles for the mutant recessive phenotype can be perpetuated in the population by heterozygotes. In most cases, lethal phenotypes are recessive. Occasionally, though, the presence of an allele in a heterozygous genotype is sufficient to cause death. Such alleles are expressed as dominant lethal phenotypes. An example of a medical condition in humans caused by a dominant lethal allele is Huntington disease, which is characterised by deterioration of the nervous system. Here, individuals with a single copy of the malfunctioning allele always develop the disease. Such dominant lethal phenotypes usually only persist in a population if they cause death after the reproductive age.

Multiple alleles for one gene

Sometimes there are more than two types of alleles for a gene. In any one individual, of course, only two alleles are normally present. A **multiallelic** system is present when three or more alleles of a gene exist among the members of a population. An example of this is seen in the ABO blood group system in humans. Blood group is therefore said to be a multiallelic trait. In the human population, the phenotype expressed by allele I^A, which is co-dominant with I^B, produces molecular markers on red blood cells. The phenotype expressed by the third allele i is recessive to both I^A and I^B and produces no marker (O). Figure 10.19 summarises the range of genotypes and the resulting phenotypes (blood groups).

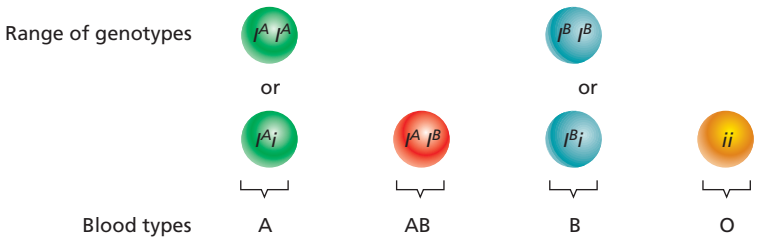


Figure 10.19 ▶
Different blood types are found in humans due to combinations of multiple alleles.

The fact that there are more than two alleles responsible for determining the blood group makes no difference to their transmission, which takes place in normal Mendelian fashion. Thus, a child whose parents are both blood group O must be blood group O.

However, consider what happens when two people, one of whom is blood group A and the other blood group O, have children. The genotypes of the children depend on the genotype of the A parent. If he or she is homozygous with the genotype $I^A I^A$, the children can only have the genotype $I^A i$ and be blood group A. However, if the group A parent is heterozygous with the genotype $I^A i$, each child has a 50% chance of being blood group A ($I^A i$) or blood group O (ii).

RECALL

- Certain combinations of alleles at a locus result in the death of an organism. Such alleles are recessive lethal.
- Some characteristics are multiallelic. This is when more than two alleles of a gene occur and can determine a particular characteristic. The ABO blood group system is an example where an individual can have two or three possible alleles.

RECAP 10.7

1 Describe the effect of lethal alleles.
2 Define 'multiallelic trait'. Discuss dominance and recessiveness in the inheritance of multiallelic traits.
3 List the possible phenotypes in relation to ABO blood groups when a couple with the genotypes $I^A i$ and $I^B i$ have children.

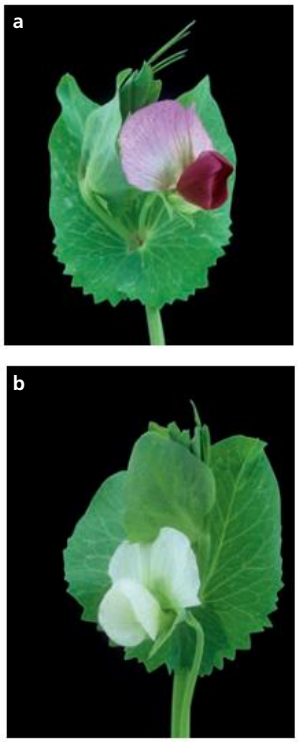
Inheritance of multiple autosomal genes

So far, we have considered the inheritance of only one pair of contrasting characteristics. However, Mendel also studied **dihybrid inheritance**, which is the inheritance of two different genes controlling two different characteristics.

The dihybrid cross

In one experiment, Mendel crossed a purebred tall pea plant possessing purple flowers with a short plant possessing white flowers (Figure 10.20). In the F_1 generation, all the plants produced were tall and had purple flowers. These were then self-pollinated. In the F_2 generation, there were four different phenotypes: tall plants with purple flowers; tall plants with white flowers; short plants with purple flowers; and short plants with white flowers. In other words, the offspring showed the two pairs of characteristics (tall, short; purple, white) combined in every possible way.

As before, Mendel counted the different types of plants and found 96 tall purple plants, 31 tall white plants, 34 short purple plants and 11 short white plants, giving a ratio of approximately 9:3:3:1. The experiment is summarised in Figure 10.21 on page 308. What conclusions can be drawn from these results? First, the observation that all the F_1 plants are tall with purple flowers confirms that tall is dominant to short and purple flower is dominant to white flower. This is as expected from the results of the monohybrid crosses.



▲ Figure 10.20
Pea plant flowers may be (**a**) purple or (**b**) white.

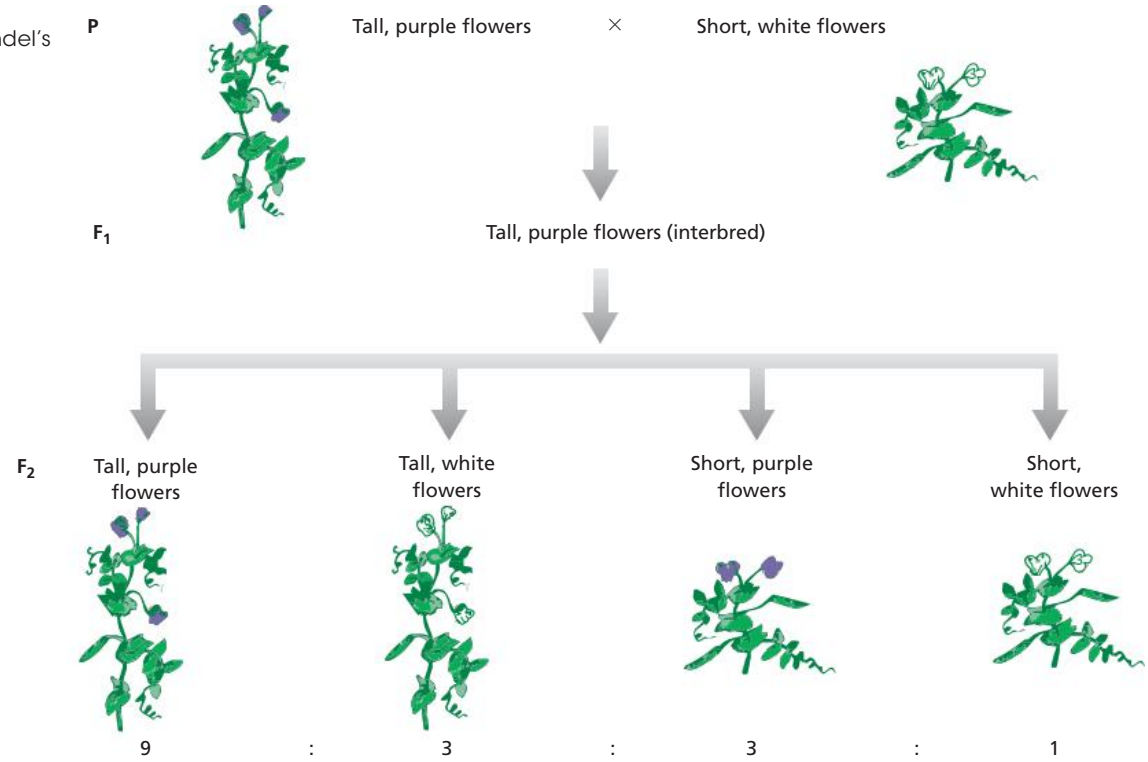


Figure 10.21 ▶
Summary of Mendel's dihybrid cross

Figure 10.22 shows how the alleles are transmitted in this **dihybrid cross**. *T* represents the allele for tallness, *t* for shortness, *P* for purple flowers and *p* for white flowers. Mendel always started his experiments with purebred plants, so the parent plants must be homozygous for both genes. The genotype of the tall plant with the purple flowers is, therefore, *TTPP*, and that of the short plant with white flowers is *ttpp*.

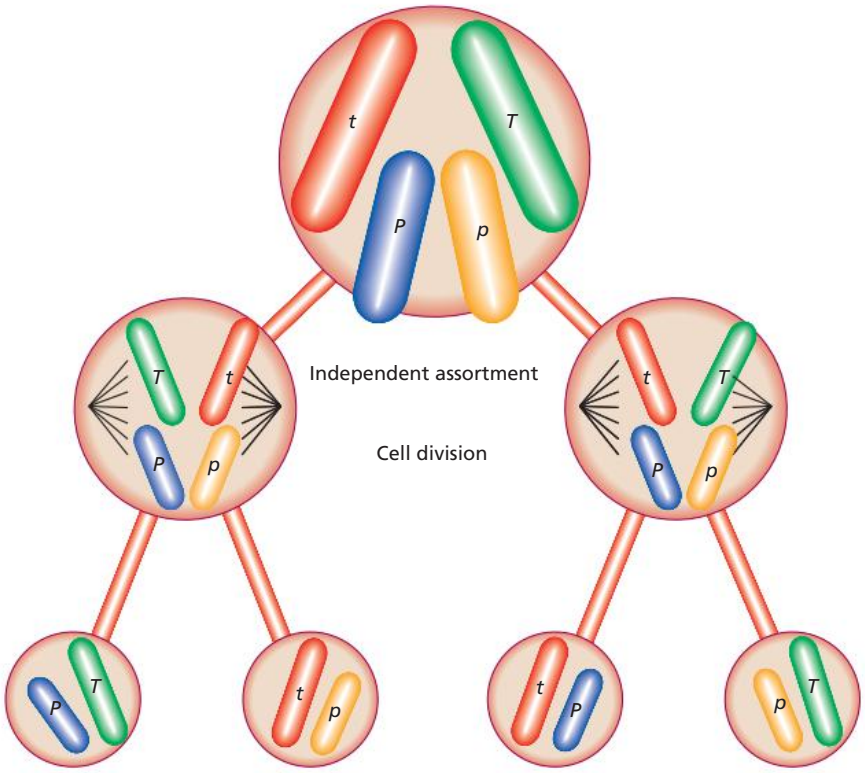


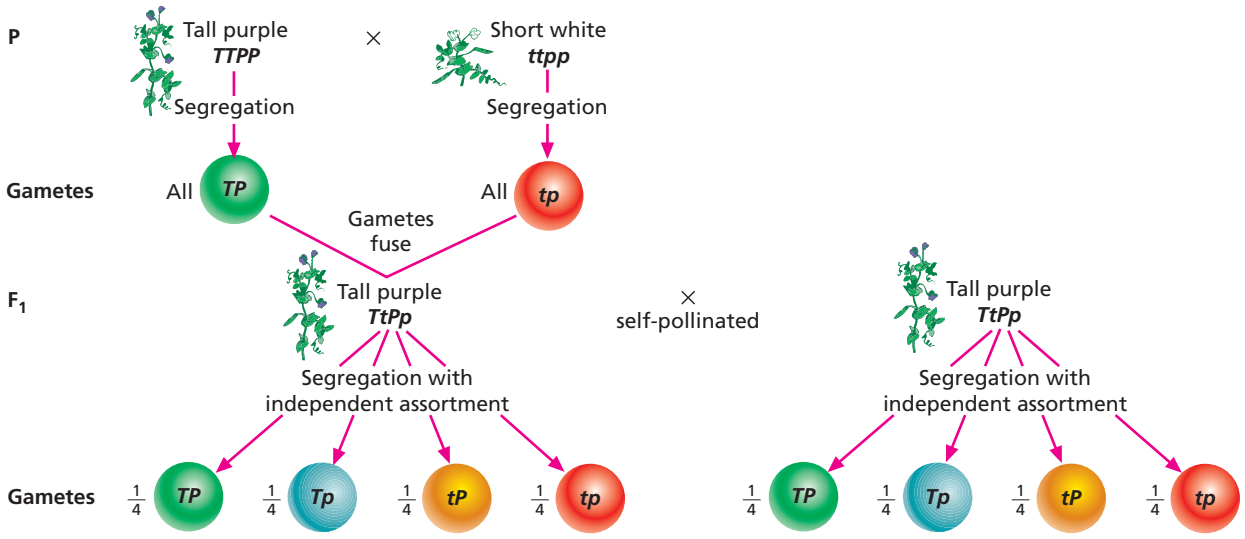
Figure 10.22 ▶
Meiosis explains the independent assortment that Mendel found in his dihybrid crosses. The independent assortment of alleles in inheritance corresponds to the free assortment of chromosomes during meiosis.

From Mendel's earlier work, we know that the gametes produced by the parent plants are all *TP* from the purebreeding tall purple parent and all *tp* from the purebreeding short white parent. All the F_1 offspring will, therefore, have the genotype *TtPp*, heterozygous for both genes.

The next step in the argument is crucial. If all four possible combinations of characteristics are to show up in the F_2 generation, we must conclude (as Mendel did) that the F_1 plants produce four kinds of gamete: *TP*, *Tp*, *tP* and *tp* (see Figure 10.22).

The Punnett square in Figure 10.23 shows the different ways in which these gametes can fuse, together with the genotypes of the F_2 offspring. To be tall, the genotype of the plant must contain at least one *T* allele; to be purple, it must contain at least one *P* allele. From the Punnett square we can see that there are 16 possible combinations. Of these, 9 give rise to tall purple plants, 3 to tall white plants, 3 to short purple plants and 1 to short white plants. The observed 9:3:3:1 ratio can be accounted for if all the possible combinations occur with equal likelihood.

▼ **Figure 10.23** Dihybrid cross of a purebred tall pea plant with purple flowers with a short pea plant with white flowers



Punnet square to show fusion of F_1 gametes

		Male gametes			
		1/4 TP	1/4 Tp	1/4 tP	1/4 tp
Female gametes	1/4 TP	1/16 *TTPP* Tall purple	1/16 *TTPp* Tall purple	1/16 *TtPP* Tall purple	1/16 *TtPp* Tall purple
	1/4 Tp	1/16 *TTPp* Tall purple	1/16 *TTpp* Tall white	1/16 *TtPp* Tall purple	1/16 *Ttpp* Tall white
	1/4 tP	1/16 *TtPP* Tall purple	1/16 *TtPp* Tall purple	1/16 *ttPP* Short purple	1/16 *ttPp* Short purple
	1/4 tp	1/16 *TtPp* Tall purple	1/16 *Ttpp* Tall white	1/16 *ttPp* Short purple	1/16 *ttpp* Short white
	F_2	9/16 Tall purple	3/16 Tall white	3/16 Short purple	1/16 Short white

What general conclusion emerges from all this? The main one is that the alleles of the two genes are transmitted independently of each other from parents to offspring and, therefore, 'assort freely'. In other words, each of the alleles of one gene may combine with each of the alleles of another gene in equal probabilities. This is known as **independent assortment**.

Independent assortment requires that the genes concerned be carried on different chromosomes; for example, the alleles of the gene for flower colour are located on one pair of chromosomes and the alleles of the gene for height on another pair of chromosomes (Figure 10.22). In metaphase I of meiosis, homologous chromosomes line up side by side on the spindle prior to separating at anaphase I. In doing this, different pairs of homologous chromosomes behave independently of each other; the way one pair of homologous chromosomes arranges itself on the spindle and subsequently separates has no effect on the behaviour of any other pair of chromosomes.

The consequence of the independent behaviour of non-homologous chromosomes in meiosis is shown in Figure 10.22, which illustrates how the four different types of gametes (*TP*, *Tp*, *tP* and *tp*) can be formed from a plant that is heterozygous for height and flower colour (*TtPp*).

We can summarise the situation by saying that the alleles for height and flower colour segregate and assort independently because they are carried on separate chromosomes, which themselves segregate and assort independently in meiosis.

When expressed in terms of probability, transmission of the genes determining stem height and flower colour in the garden pea are independent events. If we consider the alleles for height on their own, the probability of any one F_2 plant being tall is $\frac{3}{4}$ and of it being short is $\frac{1}{4}$. This is shown in Figure 10.23; $\frac{9}{16}$ of the plants are tall and have purple flowers and $\frac{3}{16}$ are tall and have white flowers. Combining these numbers, we can see that a total of $\frac{12}{16}$ – that is, three-quarters – of the F_2 plants are tall.

Similarly, if we consider the flower colour alleles alone, the probability that an F_2 plant will be purple is $\frac{3}{4}$ and that it will be white is $\frac{1}{4}$. What, then, is the probability of an F_2 plant being both tall and purple? Assuming that the alleles are transmitted independently, and that the probability of being tall is $\frac{3}{4}$, the answer is $\frac{3}{4} \times \frac{3}{4} = \frac{9}{16}$. This means that the chance of any F_2 plant, chosen at random, being both tall and purple is 9 out of 16, which is slightly more than 50%. It also means that in a large random sample of F_2 plants, approximately 9 out of 16 can be expected to be tall and purple.

We can apply similar reasoning to the other possible combinations of characteristics. The probability of an F_2 plant being tall and white is $\frac{3}{4} \times \frac{1}{4} = \frac{3}{16}$, short and purple is $\frac{1}{4} \times \frac{3}{4} = \frac{3}{16}$, and short and white is $\frac{1}{4} \times \frac{1}{4} = \frac{1}{16}$. These numbers agree with those obtained by the Punnett square method (see Worked example 10.2) and with the results of Mendel's experiments (Figure 10.23). They can be explained by postulating that the two pairs of alleles are transmitted independently and assort freely.

WORKED EXAMPLE 10.2

A purebred fruit fly that has curly wings and red eyes is crossed with a purebred fruit fly that has straight wings and purple eyes (Figure 10.24). Their offspring all have curly wings and red eyes. Two of the F_1 generation flies are crossed. If the alleles for wing shape and eye colour assort independently, predict the phenotypes of the F_2 generation and the proportions of each phenotype.

a Assign the alleles. (1 mark)
b Draw the Punnett square and enter the haploid gametes. (2 marks)
c Determine the genotypes of all the possible offspring. (4 marks)
d Determine the corresponding phenotypes for the genotypes. (4 marks)

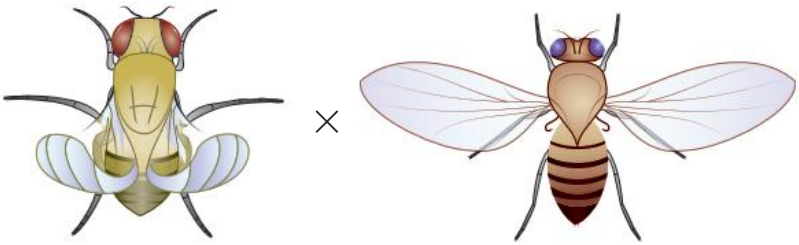


Figure 10.24
Purebreeding fruit flies with curly wings and red eyes are crossed with purebreeding fruit flies with straight wings and purple eyes.

Answer

a C = curly wing
c = straight wing
R = red eyes
r = purple eyes

Logic

The P generation flies are purebreeding, so they are homozygous for wing shape (curly or straight) and eye colour (red or purple). 1 mark

It follows that all the F_1 generation must be heterozygous with respect to both wing shape and eye colour.

All the F_1 generation have curly wings and red eyes. This indicates that curly wings are dominant to straight wings and red eyes are dominant to purple eyes.

b

		Female gametes			
		$\frac{1}{4}CR$	$\frac{1}{4}Cr$	$\frac{1}{4}cR$	$\frac{1}{4}cr$
Male gametes	$\frac{1}{4}CR$				
	$\frac{1}{4}Cr$				
	$\frac{1}{4}cR$				
	$\frac{1}{4}cr$				

The F_1 cross is between heterozygous fruit flies – that is, $CcRr \times CcRr$. For each individual, half the gametes will receive the C allele and half will receive the c allele; half will receive the R allele and half will receive the r allele. 2 marks

The alleles for each trait (Cc and Rr) assort independently of each other, so four equally likely combinations of alleles are present in the gametes of the F_1 generation: $\frac{1}{4}CR$, $\frac{1}{4}Cr$, $\frac{1}{4}cR$ and $\frac{1}{4}cr$.

c

		Female gametes			
		$\frac{1}{4}CR$	$\frac{1}{4}Cr$	$\frac{1}{4}cR$	$\frac{1}{4}cr$
Male gametes	$\frac{1}{4}CR$	$\frac{1}{16}CCRR$	$\frac{1}{16}CCRr$	$\frac{1}{16}CcRR$	$\frac{1}{16}CcRr$
	$\frac{1}{4}Cr$	$\frac{1}{16}CCRr$	$\frac{1}{16}CCrr$	$\frac{1}{16}CcRr$	$\frac{1}{16}Ccrr$
	$\frac{1}{4}cR$	$\frac{1}{16}CcRR$	$\frac{1}{16}CcRr$	$\frac{1}{16}ccRR$	$\frac{1}{16}ccRr$
	$\frac{1}{4}cr$	$\frac{1}{16}CcRr$	$\frac{1}{16}Ccrr$	$\frac{1}{16}ccRr$	$\frac{1}{16}ccrr$

As with the monohybrid cross, each square is filled with the product of the intersecting female and male gametes. For example, $\frac{1}{16}$ $CCRR$ is entered into the first vacant square, which represents the product of $\frac{1}{4}$ CR (female) and $\frac{1}{4}$ CR (male). The next vacant square to the right is filled with $\frac{1}{16}$ $CCRr$, which is the product of $\frac{1}{4}Cr$ (female) and $\frac{1}{4}CR$ (male). Continue working through until all 16 squares are filled. 4 marks

d

		Female gametes			
		$\frac{1}{4}CR$	$\frac{1}{4}Cr$	$\frac{1}{4}cR$	$\frac{1}{4}cr$
Male gametes	$\frac{1}{4}CR$	$\frac{1}{16}CCRR$	$\frac{1}{16}CCRr$	$\frac{1}{16}CcRR$	$\frac{1}{16}CcRr$
	$\frac{1}{4}Cr$	$\frac{1}{16}CCRr$	$\frac{1}{16}CCrr$	$\frac{1}{16}CcRr$	$\frac{1}{16}Ccrr$
	$\frac{1}{4}cR$	$\frac{1}{16}CcRR$	$\frac{1}{16}CcRr$	$\frac{1}{16}ccRR$	$\frac{1}{16}ccRr$
	$\frac{1}{4}cr$	$\frac{1}{16}CcRr$	$\frac{1}{16}Ccrr$	$\frac{1}{16}ccRr$	$\frac{1}{16}ccrr$

The dihybrid cross gives a 9:3:3:1 ratio of fruit flies with curly wings, red eyes : curly wings, purple eyes : straight wings, red eyes : straight wings, purple eyes.

Nine of the 16 squares show offspring with at least one *C* and one *R* allele, and these offspring will have both dominant phenotypes, curly wings and red eyes. Three of the 16 squares show offspring with at least one *C* allele for curly wing shape and two *rr* alleles for purple eye colour. Three of the 16 squares show offspring with two *cc* alleles for straight wings and at least one *R* allele for red eyes. Just one of the 16 squares shows offspring with the genotype *ccrr* for both recessive phenotypes, straight wings and purple eyes. 4 marks

Try these yourself

1 A purebred fruit fly that has curly wings and long legs is crossed with a purebred fruit fly that has straight wings and short legs. Their offspring all have curly wings and long legs. Two of the F_1 generation flies are crossed. If the alleles for wing shape and leg length assort independently, predict the phenotypes of the F_2 generation and the proportions of each phenotype.

2 A purebred pea plant bearing yellow, wrinkled peas was crossed with a purebred pea plant bearing green, round peas. All the F_1 offspring have yellow, round peas. If two of the F_1 pea plants are crossed, predict the possible combinations of pea phenotypes with respect to colour and shape and the proportions in which they are likely to occur.

RECALL

- Inheritance for two unlinked autosomal genes can be analysed with a dihybrid cross.
- In a dihybrid cross between two parents purebred for two independently assorting characteristics, the F_1 offspring are heterozygous for both traits and show the combination of dominant phenotypes. In a subsequent cross between F_1 individuals, the F_2 offspring are predicted to show four combinations of phenotypes, dominant–dominant : dominant–recessive : recessive–dominant : recessive–recessive in the ratio of 9:3:3:1.
- During the production of gametes, the two copies of genes segregate so that offspring acquire one allele from each parent. Alleles of a gene separate independently from alleles of another gene. Hence, the inheritance pattern of one trait will not affect the inheritance pattern of another.

RECAP 10.8

1 Define 'dihybrid cross'.
2 Explain how independent assortment works.
3 Explain the origin of the 9:3:3:1 phenotypic ratio in a dihybrid cross.

Linked dihybrid crosses

Mendel's predicted outcomes of dihybrid crosses were based on the study of genes that were located on different chromosomes. However, the same expected outcomes are not realised if the genes being studied are located on the same chromosome. Genes that

are located on the same chromosome are said to be **linked** and they are transmitted together; they do not show independent assortment.

To illustrate this idea, two characteristics of the fruit fly *Drosophila melanogaster* will be used. The vestigial-wing characteristic of *Drosophila* has two phenotypes: normal long wings (*V*) is dominant to vestigial wings (*v*). *Drosophila* also vary in their body width, as most have a broad abdomen but some have a narrow abdomen. Broad abdomen (*A*) is dominant to narrow abdomen (*a*). If these genes were on separate chromosomes and showed independent assortment, the predicted outcomes would be as shown in Figure 10.25.

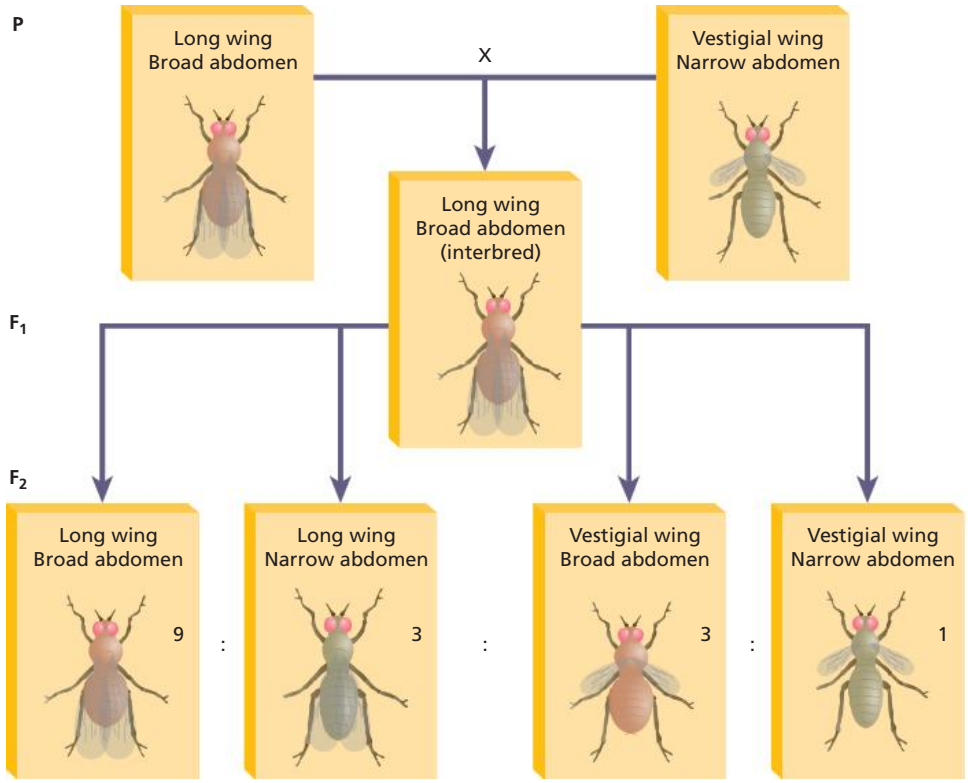


Figure 10.25
Predicted outcomes for a dihybrid cross of fruit flies when characteristics are on separate chromosomes

In reality, however, when these parental flies are crossed, all F_1 offspring are long-winged with broad abdomens as predicted, but the F_2 outcome is different – three-quarters of the flies have long wings and broad abdomens and one-quarter have vestigial wings and narrow abdomens. This does not agree with the 9:3:3:1 ratio predicted. This outcome can only be explained if the genes for wing length and abdomen width are transmitted on the same chromosome, as shown in Figure 10.26.

Such genes are linked, and the general phenomenon is known as linkage. It does not, however, follow that the alleles of linked genes can never be separated. If we looked at a very large number of F_2 flies in the example cited above, we would find that a few show independent assortment, so that a few long-winged narrow flies and vestigial-winged broad flies appear in the F_2 generation.

If, in a breeding experiment, the transmission of two (or more) characteristics shows independent assortment, then it is very likely that the genes are carried on different chromosomes. If, however, little or no independent assortment is shown, we can conclude that the genes are located on the same chromosome. An individual chromosome may contain as many as several thousand genes controlling a wide variety of characteristics. Genes linked together on the same chromosome constitute a **linkage group**.

Genotypes for linked genes are often written in a special way. As shown in Figure 10.26, a fly with normal wings and broad abdomen can produce a gamete with both these alleles. This gamete is written as *VA*. A gamete containing both recessive alleles is written as *va*. F_1 offspring would have the genotype: $\frac{VA}{va}$

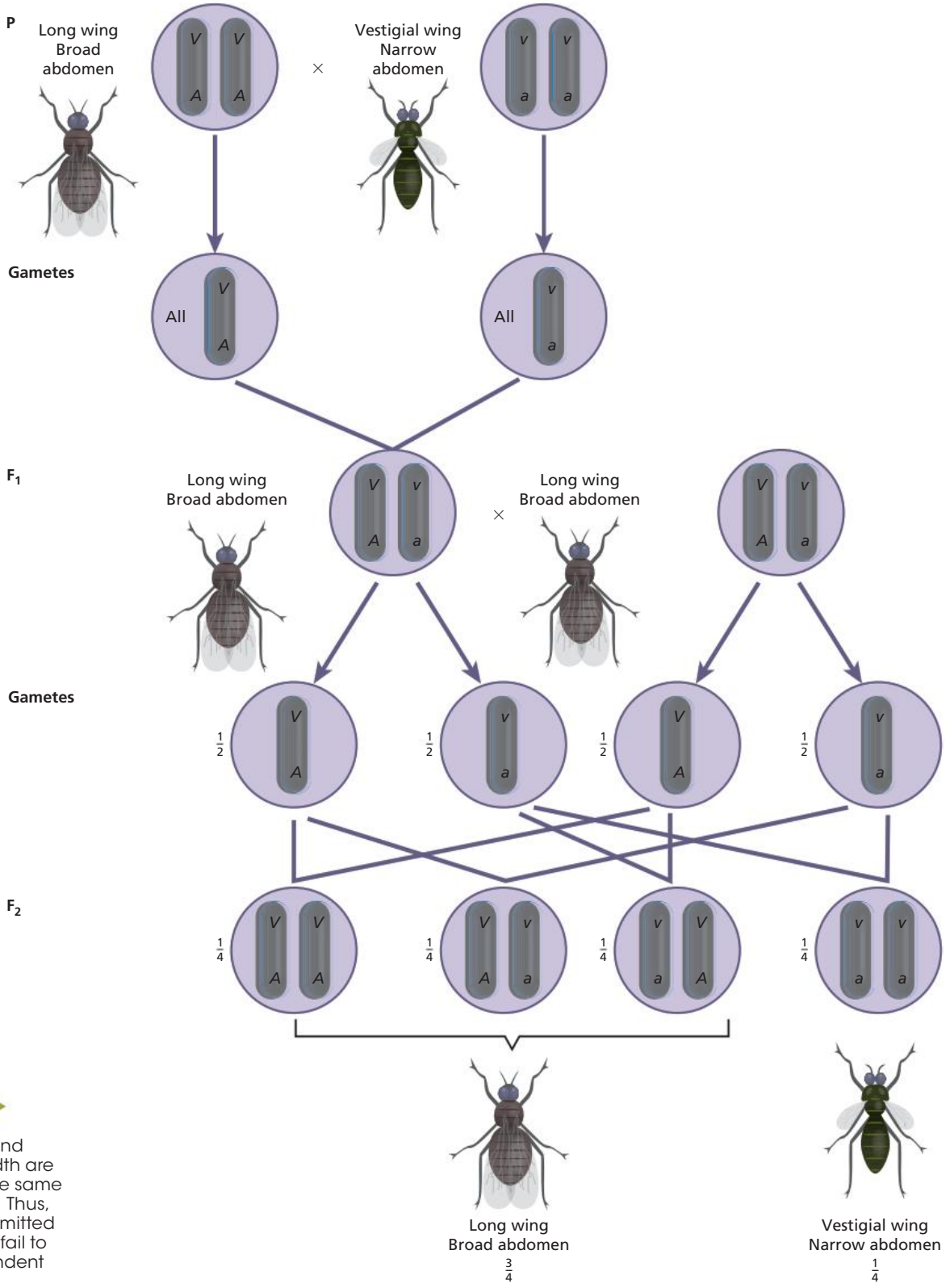
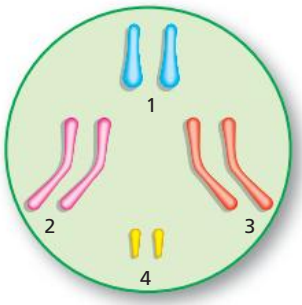


Figure 10.26 ▶
The genes for wing length and abdomen width are located on the same chromosome. Thus, they are transmitted together and fail to show independent assortment.

After studying linkage groups in many species, scientists have concluded that the number of linkage groups in a species is the same as the number of haploid chromosomes. It has also been suggested that the number of genes in a linkage group is directly proportional to the size of the chromosome. In *Drosophila melanogaster*, therefore, four linkage groups are found: two are large (i.e. with many genes); one is medium; and one is small, with only a few genes (Figure 10.27). Humans are found to have 23 linkage groups corresponding to the 23 pairs of chromosomes found in human cells.



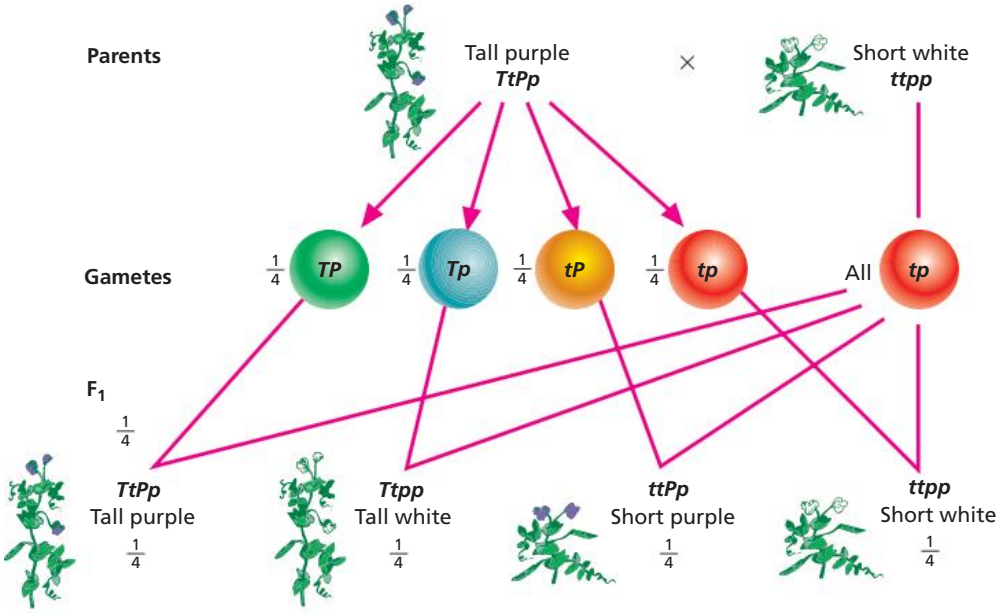
▲ **Figure 10.27**
The fruit fly, *Drosophila melanogaster*, has four pairs of chromosomes, which are distinguished from each other by their size. There are also four linkage groups, whose sizes differ from each other in the same way as chromosomes. The medium-sized pair of chromosomes are the sex chromosomes.

Test crosses and dihybrid ratios

It is clear from the Punnett square in Figure 10.23 and Worked example 10.2 that the same phenotype may result from several different genotypes. For example, a tall purple plant may have one of four possible genotypes: *TTPP* (homozygous for both genes), *TTPp* (homozygous tall, heterozygous for colour), *TtPP* (heterozygous for height, homozygous purple) or *TtPp* (heterozygous for both genes).

The easiest way of establishing the genotype of a tall purple plant is to cross it with a short white one (*ttpp*) – that is, to perform a test cross. If the plant with the unknown genotype is homozygous for both characteristics, all the offspring from the test cross will be tall and purple.

Now consider the outcome if the unknown plant happens to be heterozygous for both genes. In this case, it will produce four types of gametes: *TP*, *Tp*, *tP* and *tp*. The short white plant, however, produces only one type of gamete: *tp*. The fusion of the gametes is shown in Figure 10.28, from which it is clear that four types of offspring should be produced in approximately equal numbers: tall purple, tall white, short purple and short white. Mendel carried out this experiment and this is precisely what he found; he obtained 47 tall purple, 40 tall white, 38 short purple and 41 short white plants.



◀ **Figure 10.28**
In a test cross of a pea plant that is heterozygous for both height and flower colour with a homozygous recessive plant, four possible types of offspring may result.

Punnet square to show fusion of gametes in test cross

		Gametes			
		¼ TP	¼ Tp	¼ tP	¼ tp
Gametes	tp	¼ TtPp Tall purple	¼ Ttpp Tall white	¼ ttPp Short purple	¼ ttpp Short white

There are two other possible genotypes for a tall purple plant: *TTPp* and *TtPP*. If *TTPp* was test crossed with a short white plant (*TTPp* × *ttpp*), then tall purple (*TtPp*) and tall white (*Ttpp*) plants would be expected in equal numbers. If *TtPP* was similarly test crossed with a short white plant (*TtPP* × *ttpp*), then tall purple (*TtPp*) and short purple (*ttPp*) plants would also be expected in equal numbers.

Crossing over

Earlier it was noted that in the F_2 generation of the cross between long-winged, broad-abdomen flies and vestigial-winged, narrow-abdomen flies a number of unexpected long-winged, narrow-abdomen flies and vestigial-winged, broad-abdomen flies appeared. This is not theoretically possible if genes on the same chromosome stay linked together. How do new gene combinations arise?

Figure 10.29 ▶
Crossing over occurs in prophase I of meiosis. It disrupts part of a linkage group, resulting in new gene combinations.

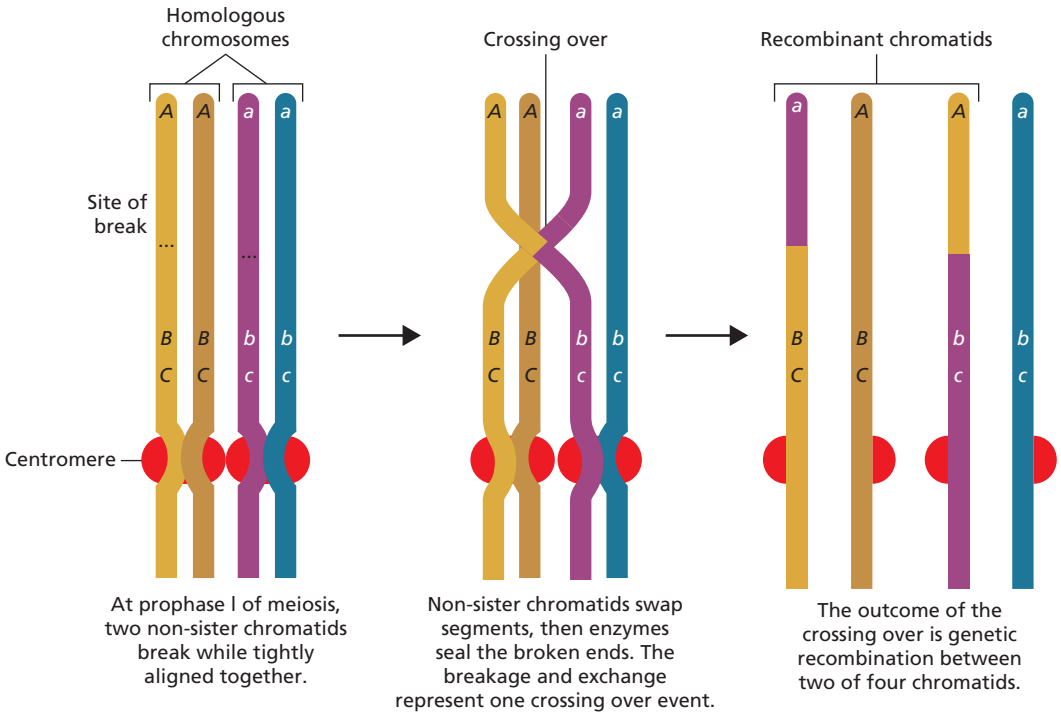
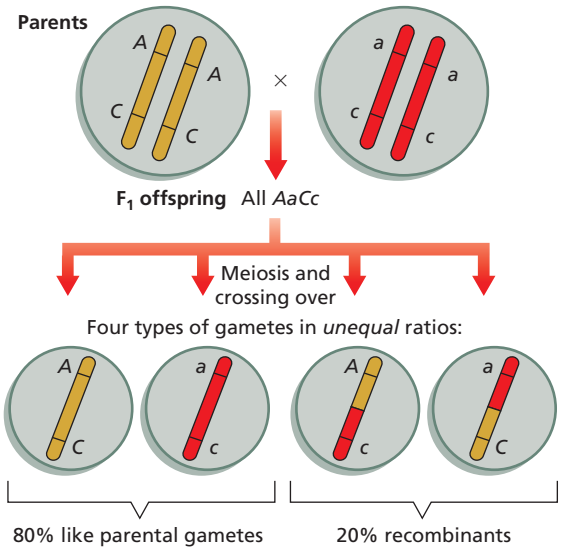


Figure 10.30 ▼
Incomplete linkage owing to crossing over results in recombinant offspring.



Genes on the same chromosome do not always stay linked together. Sometimes the chromosomes exchange sections, a process called **crossing over**. Figure 10.29 illustrates this with a pair of hypothetical homologous chromosomes with genes ABC and abc. Crossing over between linked genes results in **recombinant offspring** (Figure 10.30) and creates new combinations of genes in the gametes that are not found in either parent, contributing to genetic diversity. Thus crossing over helps to preserve genetic variability within a species by allowing for virtually limitless combinations of genes in the transmission from parent to offspring.

RECALL

- Genes linked on the same chromosome are transmitted together; they do not show independent assortment.
- A test cross is performed to determine whether an unknown dominant phenotype is homozygous or heterozygous by crossing it with a homozygous recessive phenotype.
- Crosses involving linked genes usually produce a small proportion of offspring with new combinations (recombinants) in addition to the parental combinations. This can be explained by crossing over during meiosis.

RECAP 10.9

1 Explain what is meant when genes are said to belong to a linkage group.

2 Describe the types of phenotypic ratios in a dihybrid genetic cross between two heterozygotes that would lead you to suspect that linkage was involved.

3 Explain how crossing over happens.

EXPERIMENT 10.1

A DIHYBRID CROSS IN MAIZE

The popular edible grain, corn (*Zea mays*), also known as maize, is a member of the grass family (*Poaceae*). It was first domesticated in Central America and later transferred to Europe following Columbus' expeditions there in the late 15th century. Today, there are dozens of varieties of domesticated corn (Figure 10.31), which have been generated by **selective breeding**, also known as **artificial selection**. This approach to cultivating new varieties depends upon crossing individuals with desirable phenotypes.

Corn is a useful organism for investigating patterns of inheritance because the offspring of the same parents are represented as kernels on a single cob. This means that examining a single cob provides data on several hundred offspring of the same parents. Each kernel is made up of an embryo surrounded by nutritive tissue called the endosperm and an outer covering called the aleurone layer (Figure 10.32).



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Figure 10.31 ▲
Some examples of different corn varieties

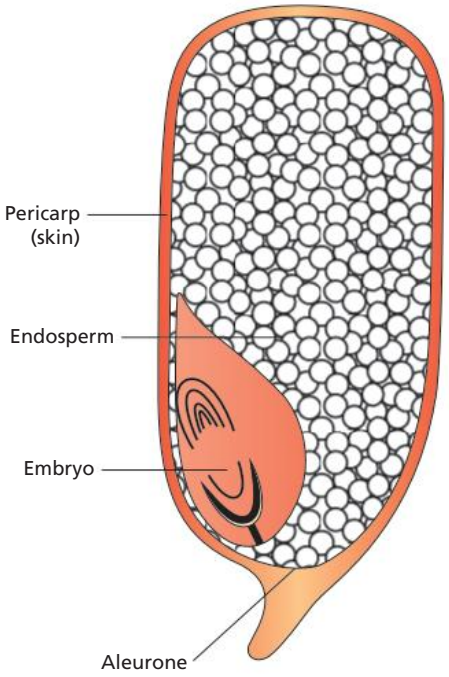


Figure 10.32 ▲
The structure of a corn kernel

Kernel colour is determined by the presence or absence of a pigment called anthocyanin in the aleurone layer. When the pigment is present the kernels are purple and referred to as 'coloured', and when it is absent the kernels appear yellow and are called 'colourless'.

Kernel shape may be described as smooth or wrinkled. The difference between the two is largely due to the ratio of sugar to starch in the contents of the endosperm. An endosperm high in sugar dries out quickly, causing the kernels to collapse and become wrinkled. An endosperm high in starch will tend to retain water and cause a kernel to remain smooth.

In this investigation, you will examine these traits of corn kernels (colour and shape) to determine their inheritance patterns over three generations.

Aim

To predict the phenotypic ratios of F_2 offspring arising from a dihybrid cross in *Zea mays* (corn) and test the prediction against observed data

Materials

- dihybrid maize model, boxed (produced by Carolina Biological Supply Company, sourced locally through Australian suppliers)

Note: Alleles are assigned in the model. Ideally, these should be removed or obscured so that alleles are assigned during the investigation.

- maize ear: segregation for dihybrid cross (Carolina Biological Supply Company)

Procedure

Part A: Predict the outcome of the dihybrid cross

A cross was set up between two purebred corn plants (P) to produce an F_1 generation. Representatives of the F_1 generation were subsequently self-pollinated to give the F_2 generation. A model of the two crosses is shown in the box.

1. Examine the model and determine the dominant and recessive phenotypes for the two independently assorting characteristics in corn: colour and shape. Copy Table A and enter your observations.
2. Assign alleles corresponding to each of the dominant and recessive phenotypes and enter them into Table A.
3. Copy and complete the first Punnett square (Table B) to show the genotype(s) of the F_1 generation kernels.
4. Copy and complete the second Punnett square (Table C) to show the predicted genotype(s) of the F_2 generation corn kernels.
5. Use the genotype in Table C to determine the corresponding phenotype of each possible zygote formed. List these possible phenotypes under Table C in your results section.
6. Use the phenotype data from your list to calculate the ratio of the predicted phenotypes of the corn kernels and record your results as Table D.

Part B: Gather experimental data and compare with predicted ratios

You are presented with the maize ear from the F_2 generation.

1. Identify the four different phenotypes with respect to kernel shape and kernel colour. Copy Table E and record the phenotypes in the top row.
2. Select and mark five columns of kernels with a pin (at the flat end of the cob). Count the number of kernels of each phenotype for each row and enter the data into Table E.
3. Calculate the total number of kernels for each phenotype and enter these into the 'Totals' row of Table E.
4. Identify which of the phenotypes in Table E is represented by the smallest total number of individuals. Divide the total number of each phenotype by the smallest total number and round off to the nearest whole number. Enter these values in the 'Simplified ratio' row of the table to generate a ratio for the observed phenotypes.

Results

Copy and complete each of the tables, following the instructions given in the procedure.

Table A Corn kernel phenotypes and their corresponding alleles

Characteristic	Colour		Shape	
Phenotypes	Dominant phenotype	Recessive phenotype	Dominant phenotype	Recessive phenotype

Table B Punnett square representing the cross between two purebred P corn plants to give the F_1 generation

		Female gamete
Male gamete		

Table C Punnett square representing the cross between F_1 corn plants to give the F_2 generation

		Female gametes			
Male gametes					

Possible phenotypes:

Table D Ratio of expected phenotypes for the F_2 corn kernels

Phenotype				
Ratio				

Table E Observed data for F_2 generation corn

	Phenotype 1:	Phenotype 2:	Phenotype 3:	Phenotype 4:
Column 1 Number of kernels				
Column 2 Number of kernels				
Column 3 Number of kernels				
Column 4 Number of kernels				
Column 5 Number of kernels				
Totals				
Simplified ratio				

Analysis of results

1 How many different genotypes are represented in your Punnett square (Table C)?

2 How many different phenotypes are represented (Table D)?

Discussion

1 Compare your expected and observed phenotypic ratios. Explain any discrepancies between the two ratios.

2 What could be done to improve the accuracy of the observed phenotypic ratio?

3 Consider the coloured smooth corn kernels of the F_2 generation. What kind of experiment could be done to determine their genotypes?

4 Discuss how corn from the F_2 generation could be crossed to regenerate purebred lines of coloured smooth and colourless wrinkled corn.

Polygenic inheritance

So far, we have only dealt with cases where a characteristic is controlled by the alleles of one gene. Sometimes, however, a single characteristic is controlled by the alleles of two or more genes interacting with one another. A characteristic controlled by more than one gene is known as a polygenic characteristic, and its transmission is called **polygenic inheritance**.

An example of polygenic inheritance is human height. Unlike Mendel's pea plants, which were either tall or short, humans have a range of heights with a smooth gradation from one extreme to another. This can be seen when you line up for your school photographs each year. Whether it is a form or level group photograph, most students are different from each other in height. According to the Australian Bureau of Statistics' Health Survey of 2011–12, the average adult height in Australia is 161.8 cm for women and 175.6 cm for men. In the past 40 years, many genes contributing to height have been identified by association with short stature or overgrowth. More recently, studies of the human genome have identified many more, with the total now exceeding 200 genes.

Clearly, height is a complex polygenic trait, the outcome of many genes, the majority of which have just a modest effect. Some genes, however, have a great influence. For example, short stature can be caused by mutations that abolish the contribution of a single gene, such as the gene encoding the growth hormone, GH1. On the other hand, because GH1 is produced by the pituitary gland in the brain, cancers of the pituitary gland can overstimulate production of GH1, leading to gigantism, with patients attaining heights of up to 2.5 m.

When a trait shows a range of phenotypes, this is called **continuous variation**. Traits that show continuous variation are controlled by two or more genes (**polygenes**). The greater the number of genes and the greater the influence of environmental factors (e.g. nutrition and standard of medical care), the greater the expected distribution of all phenotypes for the trait.

In contrast to continuous variation, **discontinuous variation** occurs when only one gene is involved and results in a small number of phenotypes, such as pea plants with either purple flowers or white flowers, but no colours other than these.

RECALL

- A characteristic that is influenced by the presence of two or more genes, such as height in humans, is known as a polygenic characteristic and its transmission is called polygenic inheritance.
- Polygenic characteristics generally show continuous variation.
- Characteristics such as height in Mendel's pea plants, which are caused by single genes, show discontinuous variation.

RECAP 10.10

1 Define 'polygenic inheritance'.

2 Explain how polygenic traits are different from traits determined by one gene.

3 Distinguish between multiallelic and polygenic.

4 Explain why some phenotypes, such as height, can show continuous variation, yet others show discontinuous variation.

Sex-linked inheritance

As we have seen in the previous chapter, male and female haploid sex cells fuse to produce a diploid zygote in the process of fertilisation. In humans there is a 50% chance that, in fertilisation, a sperm cell bearing a Y chromosome will fuse with an egg cell, resulting in a male (XY), and a 50% chance that a sperm cell carrying an X chromosome will fuse with an egg cell, resulting in a female (XX).

The X and Y chromosomes, or sex chromosomes, can be divided into homologous and differential regions. The homologous regions are those regions that the two chromosomes share in common. The differential regions are unique to each chromosome. In males, genes found in the differential regions are **hemizygous**, meaning that there is only a single copy of each of them.

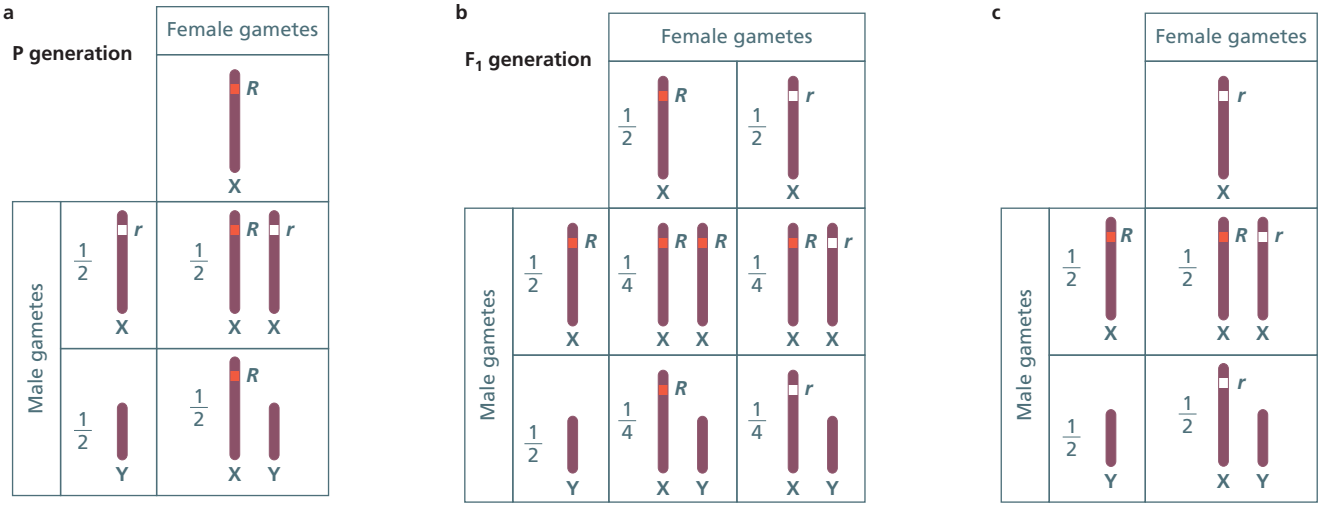
Genes within the differential regions of the sex chromosomes show inheritance patterns that can be described as **sex-linked**. Sex-linked inheritance can be detected as phenotypes that segregate differently between males and females.

X-linked recessive

In fruit flies, if a male with white eyes is crossed with a female with red eyes, all the F_1 fruit flies have red eyes, indicating that red is dominant to white. If males and females of the F_1 generation are mated, $\frac{3}{4}$ of the F_2 fruit flies have red eyes and $\frac{1}{4}$ have white eyes. So far, this seems like a typical Mendelian ratio for a monohybrid cross but there is a twist. All the white-eyed flies are male. Alternatively, if the initial cross is between a red-eyed male and white-eyed female, all the F_1 males have white eyes and all the F_1 females have red eyes. How can these observations be explained?

It makes sense if the gene for eye colour is carried on the X chromosome. In the first cross between the white-eyed male and the red-eyed female, the male is hemizygous for the white allele. The female is homozygous dominant with the red allele. In the F_1 generation, all the females are heterozygous for the red phenotype. The males, however, can only inherit one X chromosome, from their mother, and so are hemizygous with the allele for red eyes. In the F_2 generation, all the females have at least one allele for red eyes because they inherited one of their X chromosomes from their red-eyed father. On the other hand, males inherit only one X chromosome from their heterozygous mother: half get the red allele, half get the white allele.

In the alternative cross between a red-eyed male and a white-eyed female, all the F_1 females inherit an X chromosome with a red allele from their hemizygous father. All the F_1 males inherit their X chromosome with a white allele from their homozygous mother. Figure 10.33 summarises these crosses.



▼ **Figure 10.33** White eye colour in fruit flies is an X-linked recessive phenotype. The Punnet squares show (**a**) the P generation and (**b**) the F_1 generation of a monohybrid cross between a white-eyed male and a red-eyed female, and (**c**) a monohybrid cross between a red-eyed male and a white-eyed female.

When a recessive phenotype under investigation is determined by an allele on the X chromosome, it is said to be an **X-linked** recessive phenotype. Males who have the recessive allele on their X chromosome will always express the phenotype, as they only have one X chromosome. Females will only express the phenotype when both X chromosomes have the affected allele. A heterozygous female will be a **carrier**.

To express the phenotype, males only need one copy of the affected allele, while females must have two. Consequently, males show X-linked recessive phenotypes much more often than females do. Red–green colour blindness and haemophilia are two recessive conditions in humans that are transmitted to offspring through X-linked inheritance.

In this type of inheritance, a male with the phenotype cannot pass on the trait to his sons, as they inherit his Y chromosome only. His daughters will get the affected X chromosome but they will only show the phenotype if they inherit another affected X chromosome from their mother. As with autosomal recessive phenotype, some generations may not have any members showing the phenotype.

X-linked dominant

This type of inheritance is similar to sex-linked recessive inheritance except that heterozygous females will always show the phenotype and any affected individuals must have a parent with the phenotype. Males showing the phenotype will not pass the affected allele on to their sons (as they must inherit their father's Y chromosome) but they will pass it on to all their daughters, who will also show the phenotype. A heterozygous female is expected to pass on the allele to 50% of her offspring regardless of their sex.

Y-linked

If a trait is carried on the Y chromosome it is said to be **Y-linked**. The most conspicuous phenotype associated with genes of the Y chromosomes is male gender. 'Maleness' in humans is determined by the SRY gene carried on the Y chromosome. Other Y-linked genes are relevant to testis development and sperm production. By definition, inheritance of the Y chromosome is along the male line from father to sons.

RECALL

- Sex-linked genes are found on the sex chromosomes. X-linked genes are on the X chromosome and Y-linked genes are on the Y chromosome.
- Alleles carried on the X and Y chromosomes show different inheritance patterns for males and females. X-linked recessive and Y-linked phenotypes are more common in males because they are hemizygous for the sex chromosomes.

RECAP 10.11

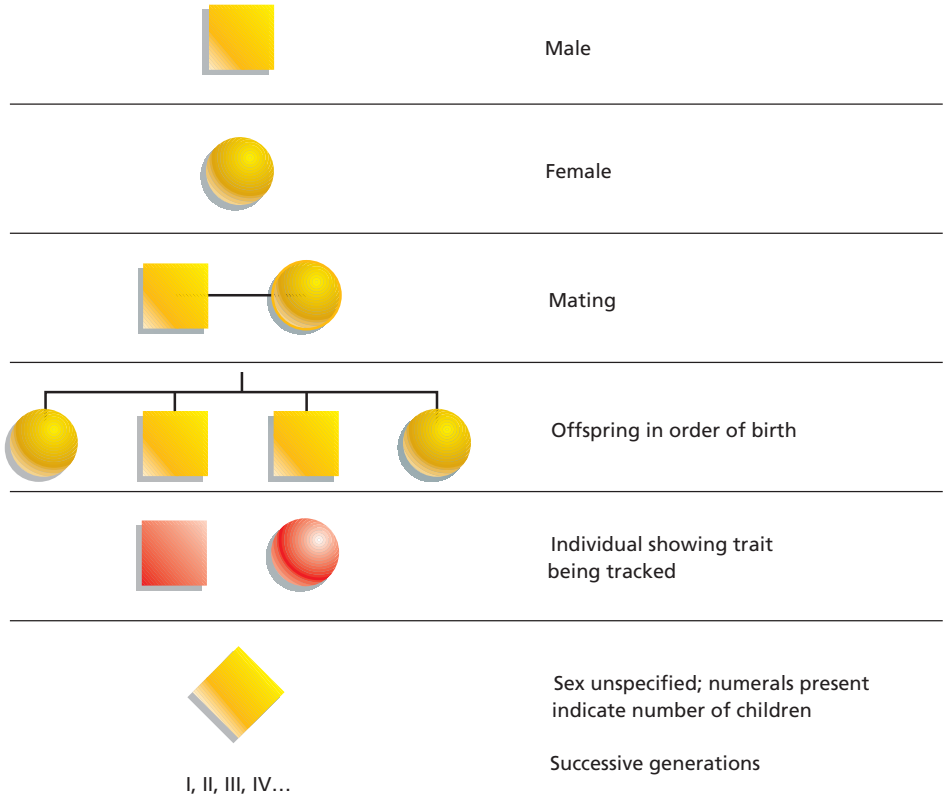
1. Define 'sex-linked', 'X-linked' and 'Y-linked' inheritance.
2. Define 'carrier'. Explain why males cannot be carriers of a sex-linked disease.
3. Explain why a father with an X-linked condition is not able to pass on the characteristic to his sons.
4. Explain why colour blindness is less common in women than in men.

Pedigree analysis

One way of finding out the type of inheritance of a characteristic is to follow the inheritance pattern over two or more generations. This technique is called **pedigree analysis**. Pedigree analysis of traits can easily be carried out in species such as pea plants and fruit flies because their generation times are short, they are easily manipulated and they can be grown in controlled conditions in a small area.

Humans, on the other hand, have long generation times, often as long as the geneticist studying them, and they are not easily manipulated; for instance, there is no experimental design element when humans select a mate, the number of offspring born to humans is often small and they reproduce if and when they want to. They live in a variable environment that cannot be experimentally controlled.

To study patterns of inheritance in humans, geneticists use all the available information, which can then be represented in pedigree charts. These pedigree charts show the inheritance of a particular trait over a number of generations. Studying more individuals in a pedigree and many pedigrees for the same trait makes the genetic analysis of the trait under investigation more accurate. Figure 10.34 shows examples and explanations of the symbols used in pedigree charts.



◀ **Figure 10.34**
Symbols used in constructing pedigree charts. When studying the pedigree of a family, geneticists use their knowledge of patterns of gene transmissions to determine whether the responsible allele of the characteristic under investigation, often a disorder or abnormality, is located on an autosome or sex chromosome and whether the trait is dominant or recessive.

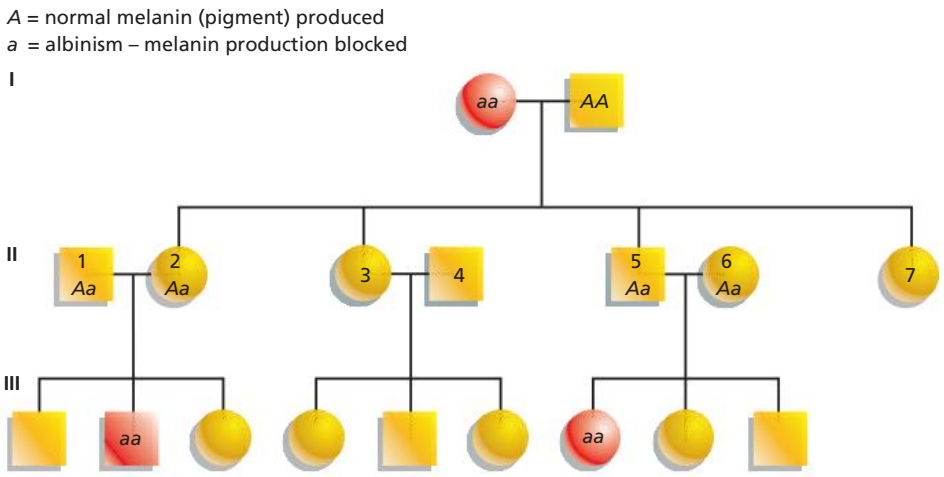
Pedigree analysis can be used in a clinical setting, as it may reveal inheritance patterns that allow predictions about the transmission of genes to future children. Pedigree analysis may occasionally be affected by the presence of mutations that arise spontaneously.

Autosomal recessive inheritance

Genetic disorders can be inherited from parents in a number of ways. For an individual to express an autosomal recessive trait, they must carry two copies of the allele for the recessive trait. The affected individual must receive one copy of each allele from each parent. If the parents are heterozygous, they will not express the trait but will still be

able to pass on an affected allele. In this case they are said to be a carrier of the trait. It is expected that 25% of their children will express the trait and 50% will be heterozygotes – that is, they will carry one allele for the recessive trait but it will not be expressed. If both parents are affected, all offspring will be affected. A family pedigree may have some generations where no expression of the trait occurs. Figure 10.35 shows an example of autosomal recessive inheritance with genotypes assigned to some individuals.

Figure 10.35 ▶
Pedigree showing individuals with the autosomal trait of albinism



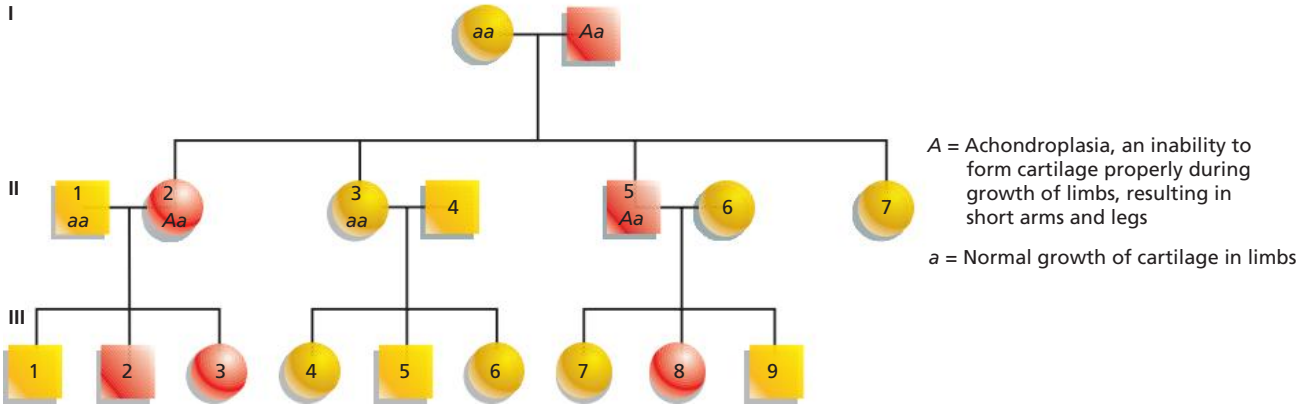
Autosomal dominant inheritance

An autosomal dominant trait is expressed when at least one copy of the allele is present in an individual. This means that each individual with the trait must have at least one parent with the trait and that it often appears in each generation.

If one parent is homozygous recessive and therefore does not show the trait, and the other is heterozygous and therefore does show the trait, then any child has a 50% chance of being heterozygous and showing the trait and a 50% chance of being homozygous recessive and not showing the trait.

Figure 10.36 ▼
Pedigree showing individuals with the autosomal dominant trait, achondroplasia

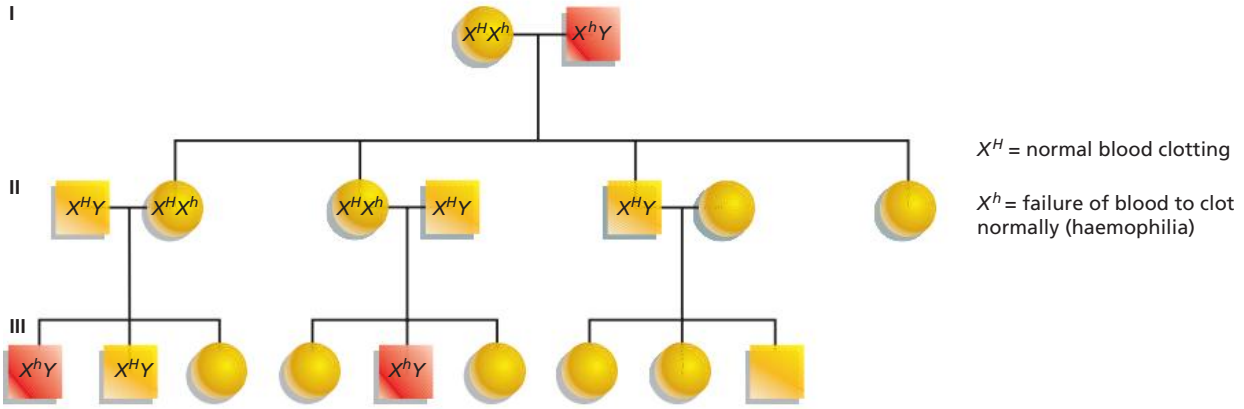
Figure 10.36 shows a human pedigree of a family with achondroplasia, a form of dwarfism, an autosomal dominant condition that affects about 1 in 10 000 humans. The homozygous dominant condition leads to stillbirth but heterozygotes reproduce normally.



Some alleles for dominant traits cause serious genetic disorders, such as progeria, which is a rare genetic disease producing premature ageing. Why do these diseases remain in populations? Some, such as progeria, occur spontaneously by mutations; others, such as Huntington disease, do not appear until later in life, often after 40 years of age, when most people have already had children and passed on the disease.

X-linked recessive inheritance

When an allele for a recessive trait under investigation is on the X chromosome, it is said to be a sex- (or X)-linked recessive trait. Males who have this allele on their X chromosome will always express the trait as they only have one X chromosome, but females will only express the trait when both X chromosomes have the affected allele. A heterozygous female will be a carrier. This type of inheritance is usually detected in a pedigree when more males than females express the trait. Another way to detect this is in the pattern of inheritance of a male with the trait and his children. His sons cannot inherit the trait from their father as they inherit his Y chromosome only, but his daughters will get the affected X chromosome and, if another affected X chromosome is inherited from their mother, they will show the trait. As with autosomal recessive traits, some generations may not have any members showing the trait. Figure 10.37 illustrates a pedigree of a family with haemophilia, a recessive sex-linked disease in which the blood does not clot normally.



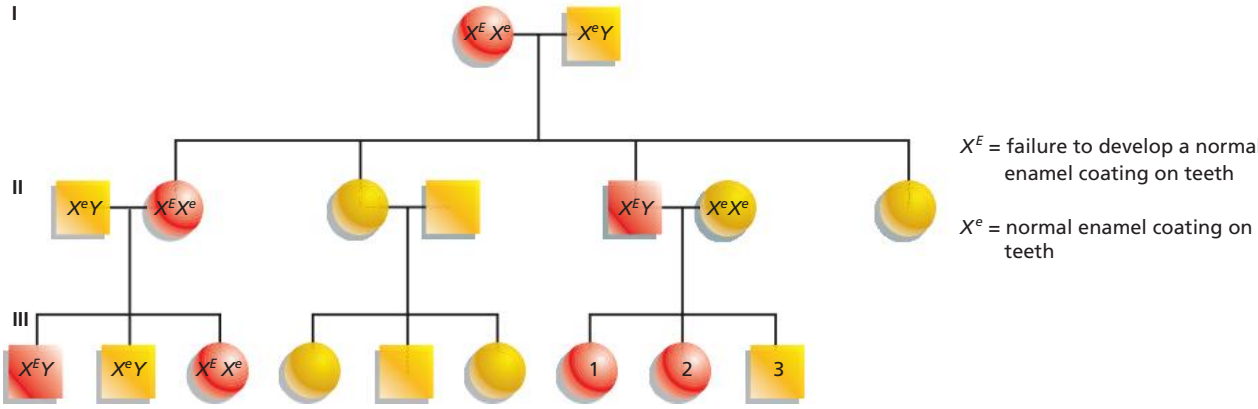
X^H = normal blood clotting

X^h = failure of blood to clot normally (haemophilia)

▼ **Figure 10.37** Pedigree showing individuals with the sex-linked recessive trait, haemophilia

X-linked dominant inheritance

This type of inheritance is similar to sex-linked recessive inheritance except that heterozygous females will always show the trait and any individuals must have a parent with the trait. Males showing the trait will not pass the affected allele on to their sons (as they must inherit their father's Y chromosome) but they will pass it on to all their daughters, who will also show the trait. A heterozygous female is expected to pass on the allele to 50% of her offspring regardless of their sex. Figure 10.38 illustrates the pedigree chart of a family with faulty enamel trait, which is apparent when the normal protective enamel coating of teeth fails to develop.



X^E = failure to develop a normal enamel coating on teeth

X^e = normal enamel coating on teeth

▼ **Figure 10.38** Pedigree showing individuals with the sex-linked dominant trait of abnormal teeth enamel coating

RECALL

- Sex-linked inheritance is detectable by unequal phenotypic ratios between males and females.
- X-linked recessive phenotypes are more common in males than in females.
- X-linked dominant phenotypes show up in all affected females and males.
- Y-linked phenotypes are exclusively male.

RECAP 10.12

1 Suggest what can be done to improve the accuracy of pedigree charts.

2 Describe features of a pedigree that indicate that a trait is inherited as a dominant trait rather than a recessive trait.

3 The family pedigree shown in Figure 10.39 is an example of a sex-linked dominant type of inheritance.

- **a** Assign allele symbols for the faulty enamel gene and explain why you chose those symbols.
- **b** Name the genotype of a male with faulty enamel trait.
- **c** List the genotypes that females with the trait can have. Name the genotype that normal females have.
- **d** Name the genotype of individual III 5.
- **e** Explain whether individual III 1 inherited the faulty enamel allele from her mother or from her father.

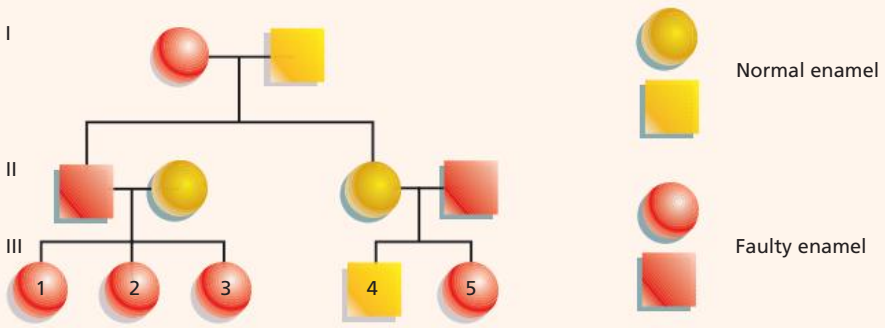


Figure 10.39 ▶
Pedigree of family with faulty enamel

Investigation of an issue: Making the punishment fit the crime gene

'Not guilty by reason of insanity' is a legitimate defence in criminal court. So how about 'not guilty by reason of genotype'? Judgement in criminal law has long recognised that some offenders have more control over their actions than others. For example, a youth raised in an abusive environment will receive a more lenient sentence than an adult with a secure upbringing for committing the same crime.

It is a biological principle that people's characteristics are the product of their genes and the environment. Children don't choose their environment; nor do they choose their genes. If environment is a legal consideration, why not also genes?

A gene implicated in criminal behaviour is the MAOA gene located on the X chromosome. The gene codes for monoamine oxidase A, an enzyme that breaks down a neurotransmitter (monoamine) in the brain. A particular allele of this gene, MAOA-L (long form of the gene) results in reduced expression of the enzyme. The MAOA-L allele is associated with impulsive aggression and is relatively more common in male prisoners than in the general population. Evidence is mounting that males with the MAOA-L form of the gene are more vulnerable to the effects of childhood abuse (Baum 2013).

The idea that an offender could blame their actions on 'crime' genes is gaining some traction. In 2009, for example, an Italian court reduced a convicted murderer's jail term by one year primarily on the

evidence that he tested positive for MAOA-L (Baum 2013). The notion is upsetting for some, however, who regard it as an insult to victims of crime by absolving a perpetrator's guilt on the basis of biology (McCay 2013). Such outcomes also bring into sharp focus the purpose of punishment. Law breakers who have the 'crime' gene and a troubled upbringing may still be dangerous. Should judges condemn offenders with MAOA-L to harsher sentences to discourage future crime? Should such high-risk offenders be locked up for extended periods to protect the public?

Over to you: Evaluating the application of genetic testing for the 'crime' gene

A routine genetic test is available for MAOA, so there is no technical limitation to detecting whether an individual has MAOA-L. An international law conference has invited you to submit a report on the use of the 'crime' gene in criminal law. Your report should be 850–1000 words, and may be in the form of a digital presentation, an oral communication or a written report.

The report is divided into three parts. Part 1 is an analysis of the science behind the testing and interpretation of the 'crime' gene. Part 2 addresses the ethical implications of using the 'crime' gene for making legal decisions. Part 3 is a presentation of your conclusions based on the outcomes of Parts 1 and 2.

Part 1: How feasible is it to genetically test individuals for their propensity to commit crime?

(350–400 words, for a scientific audience)
Respond to the following questions for your presentation.
Task 1: Draw on your understanding of inheritance to explain why MAOA-L apparently affects more males than females. Use a model to support your explanation.
Task 2: What kind of variation is implied by inheritance of the MAOA gene? Are you satisfied that this kind of variation best describes variation in human behaviour? Explain your reasoning.
Task 3: Use your response to Task 2 to evaluate the validity of the model of inheritance proposed in Task 1.
Task 4: Do you believe 'criminal behaviour' is a valid phenotype? Outline two reasons in support of your answer.
Task 5: Discuss how both the MAOA gene and the environment may affect an individual's potential to commit violent crime.

Part 2: How could information about an individual's 'crime' gene be used or misused?

(350–400 words)
Task 6: Consider a proposal to genetically test individuals for the 'crime' gene. Evaluate the application of this genetic test in criminal law by providing a comprehensive analysis of the ethical issues, using the following guiding principles:

- individual rights
- beneficence
- non-maleficence
- justice and equity.

In your analysis, consider the prospect of testing: all individuals, accused suspects, and convicted individuals. Consider the consequences for: individuals who have tested positive for MAOA-L, victims of crime, and the broader community.
Task 7: Consider a situation where two first-time offenders were convicted of the same type of crime. Would you argue that, if one of the offenders was shown to have a 'criminal' genotype, the punishment should be more lenient, the same or more severe, compared with the other convicted offender? Explain your reasoning.

Part 3: Conclusion

(150–200 words)
Task 8: Discuss at least two benefits and two concerns associated with using a convicted criminal's genotype as a basis for determining their sentence.
Task 9: Draw a conclusion about who should be tested for the 'crime gene' – the whole population, selected individuals or no one at all. Support your conclusion with reasons derived from your analyses in Parts 1 and 2.

References

Baum M. (2013) The Monoamine Oxidase A (MAOA) genetic predisposition to impulsive violence: Is it relevant to criminal trials? *Neuroethics* 6: 287–306.
McCay A. (2013) Evil gene would make punishment a tricky business. *The Age*: 22 April, online, http://www.theage.com.au/comment/evil-gene-would-make-punishment-a-tricky-business-20130422-2ia09.html

CONCEPT SUMMARY

Inheritance

Genotypes and phenotypes

Alleles
Forms of a gene, passed on to offspring

- Dominant
- Recessive
- Codominant
- Partially dominant
- Homozygous
- Heterozygous

Genotype
A specific combination of alleles for a particular gene locus

Environment
Factors that can influence the development of traits, e.g. nutrition, medical care, physiological or psychological stress

Epigenetics

- Specific modifications to DNA that change the activity of genes
- NOT modifications to the sequence of DNA
- Affected by environment

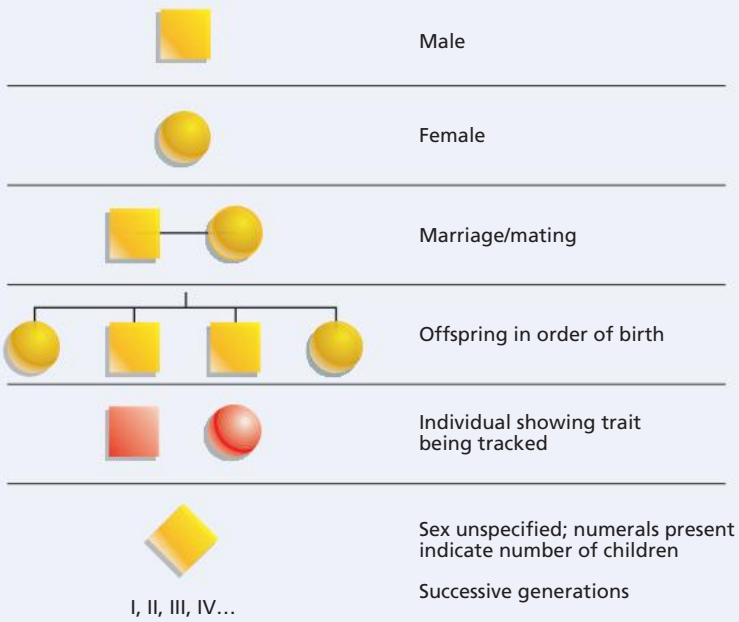
Phenotype
Actual form taken by a specific feature; specific traits or characteristics

Patterns of inheritance

- *Monogenic traits* are determined by a single gene.
- *Polygenic traits* are determined by multiple genes, such as melanin production and height in humans.
- *Autosomal dominant* traits are determined by an allele on an autosomal chromosome. They are always expressed when present.
- *Autosomal recessive* traits are determined by an allele on an autosomal chromosome. They are only expressed when homozygous.
- *X-linked* traits are determined by an allele on the X-chromosome. They can be recessive or dominant. There are different expression patterns in males and females.
- *Y-linked* traits are determined by an allele on the Y chromosome. Genes that determine male gender are Y-linked.

Pedigree charts

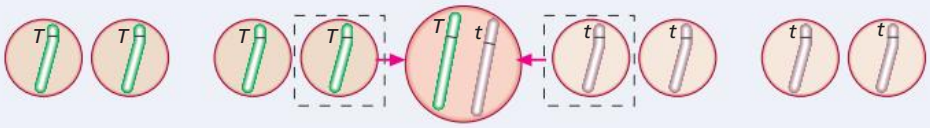
- Visual representations of the inheritance of a particular trait over a number of generations
- Help to determine the pattern of inheritance



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Monohybrid crosses

- Involves one pair of contrasting phenotypes
- Two homozygous parents with different phenotypes produce all heterozygous offspring



Monohybrid test crosses

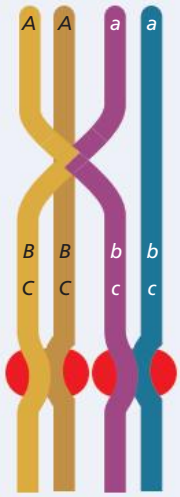
- Used to determine the genotype of an individual expressing a dominant phenotype
- Made between an organism exhibiting the dominant trait and another organism displaying a recessive trait

Linkage of traits

When genes are present on the same chromosome, they are more frequently inherited together (they are *linked*).

Crossing over

During meiosis, homologous chromosomes can cross over and exchange sections. This results in *recombined* offspring. Crossing over increases genetic variability within a species.



Genetic testing

- Can be used to determine the presence of specific alleles, such as alleles that cause genetic diseases
- Can be carried out on embryos in vitro or in utero
- Can be carried out on adults

Social and ethical implications

- The individual's right to choose: proper informed consent for testing, choice of abortion
- Confidentiality of results: employers, insurance agencies, other members of the family
- Stigmatisation
- Discrimination: employment, insurance, acceptance

GLOSSARY

allele one of different versions of the same gene (at the same locus) determined by small differences in the DNA sequence of the gene

artificial selection *see* selective breeding

carrier usually used in reference to disease; a healthy, heterozygous organism carrying an allele for a recessive phenotype; the organism may transmit the recessive allele and resulting phenotype to its offspring or to others

co-dominant a state in which both alleles of a heterozygous individual are fully expressed in the phenotype

continuous variation variation in a characteristic that shows a smooth gradation of different phenotypes

crossing over the process of chromatids breaking and re-joining during prophase I of meiosis

dihybrid cross a cross between two organisms that are heterozygous at two gene loci

dihybrid inheritance inheritance of two pairs of contrasting characteristics

discontinuous variation a variation in a characteristic that shows two or just a few clearly distinct phenotypes

DNA methylation the attachment of a methyl group to nucleotides or histone proteins

dominant a phenotype that requires only one copy of its allele in an individual to be expressed

epigenetics the study of chemical modifications to gene function that are not due to DNA sequence changes; DNA methylation is an example

epigenome chemical compounds that modify the genome

first filial generation (F_1) the first generation of offspring produced from a cross between two purebreeding parents (P)

gene a unit of heredity that transmits information from one generation to the next; a segment of DNA that codes for polypeptide

genotype a specific combination of alleles for a particular gene locus belonging to an individual or cell

hemizygous describes a gene that occurs only as a single copy in a diploid organism or cell

heredity the study of inheritance; the genetic transmission of characteristics from one generation to another

heterozygous a genotype with two different alleles for a single gene locus

homozygous a genotype with two identical alleles for a single gene locus

homozygous lethal phenotype a phenotype that arises from a homozygous recessive genotype, leading to the premature death of an organism

incomplete dominance the state in which a heterozygous individual has a phenotype that is intermediate between those of the corresponding homozygous individuals; also known as partial dominance

independent assortment when alleles of gene pairs redistribute independently into different combinations in gametes during meiosis

inheritance the genetic acquisition of characteristics by offspring from their parents

linkage group genes that are inherited together; all the genes of a given chromosome are linked

linked refers to genes (or their alleles) that are inherited together more frequently because they are located on the same chromosome

Mendelian genetics explanation of patterns of inheritance based on the discoveries of Gregor Mendel and his statistical analysis and breeding experiments on pea plants

monohybrid cross a cross between two organisms that are heterozygous at one gene locus

multiallellic when three or more alleles of a gene exist among members of a population

parental generation (P) two individual organisms that represent the start of a breeding experiment; their offspring are the F_1 generation

partial dominance *see* incomplete dominance

pedigree analysis a way of finding out the type of inheritance of a characteristic by following the inheritance pattern over two or more generations

phenotype the actual form of a specific feature in a particular individual based on their genotype; can be used in reference to particular traits or characteristics or to the overall form of an individual

polygene a gene for which the alleles have an additive effect on a phenotype; many polygenes together contribute to continuous variation in a phenotype

polygenic inheritance transmission between generations of characteristics that are controlled by more than one gene

Punnett square a grid used to graphically predict the outcome of a cross or breeding experiment

purebreeding a line of organisms that always produce offspring with the same phenotype when crossed with each other

recessive a phenotype that requires two copies of its allele in an individual to be expressed

recombinant offspring offspring with combinations of alleles that are not found in either parent

second filial generation (F_2) offspring of the F_1 generation; the second generation produced from a cross between two homozygous parents (P)

selective breeding a process by which humans domesticate animals or plants by purposely choosing individuals with the most desirable characteristics as parents for each successive generation of breeding

sex-linked refers to the inheritance pattern shown by a gene located on a sex chromosome

test cross a cross using an organism with a recessive phenotype to determine the genotype of an organism with a dominant phenotype

trait a heritable characteristic; phenotype

X-linked related to a gene located on the X chromosome

Y-linked related to a gene located on the Y chromosome

CHAPTER REVIEW QUESTIONS

Remembering

1 Describe the relationship between the following terms:
   - **a** gene and allele
   - **b** genotype and allele
   - **c** genotype and phenotype.

2 Match each item in the first column with a description in the second column. Each item can only be used once.

Hemizygous	Only one copy of the allele is required for the phenotype to be observed.
Heterozygous	Two different alleles are both fully expressed in the phenotype.
Homozygous	The phenotype is intermediate between each of those determined by two different alleles.
Recessive	Two copies of the same allele are present for a particular gene locus.
Dominant	There is only one copy of the gene in a diploid organism.
Co-dominant	Two different alleles are present for a particular gene locus.
Partially dominant	Two copies of the allele are required for the phenotype to be observed.

3 Explain why it is not possible to produce a purebreeding pink snapdragon.

4 Explain why genetic analysis of traits in humans is much harder to carry out than in organisms such as pea plants.

Understanding

5 Explain what 'purebreeding' means. Why was it important for Gregor Mendel to use purebred plants in his experiments?

6 Explain how organisms with the same genotype can have different phenotypes, and how organisms with the same phenotypes can have different genotypes.

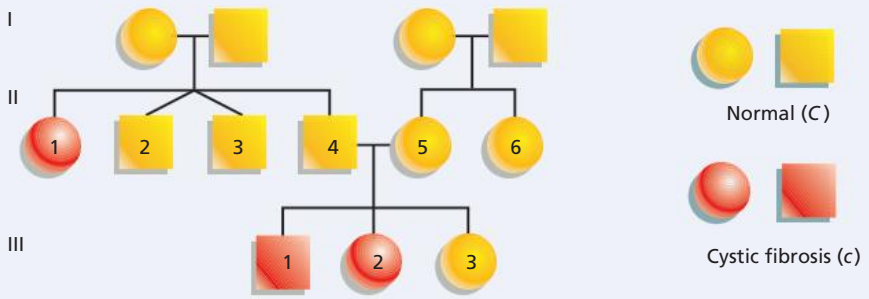
7 Distinguish between the effects of random assortment of alleles, and of linked alleles, on phenotype. Explain what accounts for these differences.

8 Explain how lethal phenotypes can persist in a population.

Applying

9 A child has blood group O, but both the mother and the father have blood group B. Explain how this is possible.

10 Cystic fibrosis is inherited as an autosomal recessive trait, as shown in Figure 10.40.



◀ **Figure 10.40** Pedigree of a family with cystic fibrosis

a Decide how many genotypes are possible for individual III 3, and name them.
b Identify whether individual II 4 is homozygous or heterozygous for this trait. Explain your answer.
c Discuss whether individuals II 2 and II 3, who are identical twins, would have exactly the same genotype for cystic fibrosis.

11 Describe and explain the occurrence of phenotypes that are:
a X-linked recessive
b X-linked dominant
c Y-linked.

12 Xolo is a miniature breed of hairless dog. The hairless phenotype is dominant to hairy.
a Assign the allele symbols for hairless and hairy and use a Punnett square to demonstrate the expected phenotypes for a litter of four pups born to two heterozygous Xolo parents.
b Experimental data show that litters from Xolo crosses typically include hairless and hairy pups in the ratio of approximately 2:1, and that hairless Xolo dogs are never purebreeding. Account for these observations.

13 Two purebred rabbits are mated: a doe with grey fur and black eyes is mated with a buck with white fur and red eyes. The litter contains only offspring with grey fur and black eyes.
a Assign the alleles and show the genotypes of the P and F_1 individuals.
b Draw a Punnett square to show a cross between individuals of the F_1 generation.
c Predict the ratio of phenotypes with respect to fur and eye colour in the F_2 generation.

14 The capacity to tolerate high salt concentration varies between individuals of a population of salmonid fish.
a Plot a graph of salinity tolerance versus number of individuals in the fish population to show what you would expect if the trait is under the control of multiple genes.
b Re-plot the graph to show what you would expect if the trait is under the control of one gene with two alleles: an allele for saline intolerance and another for high tolerance. Assume that the alleles occur in equal proportions in the population and that high tolerance is dominant to intolerance.

15 Ichthyosis is an inherited condition characterised by scaly skin. The condition affects around 1 in 6000 males but female cases are almost unknown.
a Suggest what might account for the differences in ichthyosis occurrence among males and females.
b Name which parent an affected male would have inherited the condition from.
c Predict the probability of the affected male passing the responsible gene on to his sons. Explain your reasoning.

16 The novel Xg blood group is an X-linked phenotype that is observed in approximately equal proportions in males and females.
a Explain how an X-linked phenotype could be observed in equal proportions in both sexes.
b Predict the probability of Xg sons being born to a heterozygous mother with Xg and a father without Xg. Predict the probability of daughters of this mother and father showing the Xg trait.
c Predict the probability of Xg sons being born to a mother without Xg and a father with Xg. Predict the probability of these parents having Xg daughters.

17 Two grey rats are mated. Half the offspring are grey, one-quarter are white and one-quarter are black.
a Assign the allele symbols for coat colour.
b Describe the genotypes of the parents and the offspring.
c Name the type of dominance shown.

18 There are four possible phenotypes for ABO blood groups in humans: A, B, AB and O. The most common of these, O, is a recessive phenotype. The four phenotypes are determined by three alleles, of which I^A and I^B are co-dominant and *i* is recessive to both.
a Write each possible genotype and the corresponding phenotype.
b If a woman is heterozygous with blood type A and a man is heterozygous with blood type B, predict their children's possible blood type(s) and the probability of each. Support your conclusions with a Punnett square.

19 In mice, coat colour is determined by an autosomal gene, and pink coat colour is dominant to brown. Dwarfism is caused by an X-linked recessive allele. If a brown female dwarf mouse mates with a purebreeding pink male of normal size, predict the phenotypic ratios in each gender in the F_1 and F_2 generations.

20 In cherry tomatoes, a tall vine is dominant to a dwarf vine, round-shaped fruit is dominant to pear-shaped fruit, and red fruit is dominant to yellow fruit. If you crossed a purebreeding tall, round, red-fruited plant with a short, pear-shaped, yellow-fruited plant, predict what you would expect to be the appearance of the F_1 generation. Assuming that the genes controlling these three characteristics are inherited independently, predict the possible combinations of genes in the gametes of the F_1 generation.

21 A particular gene in cats is crucial for normal development. An allele of this gene – Manx (*M*) – causes the spine of cats to develop abnormally. In the homozygous form (*MM*), cats die when they are still embryos. In the heterozygous form (*Mm*), cats are born with no tails. Suppose that two *Mm* cates mate.

- **a** Predict the probability of their kittens having tails.
- **b** Predict the probability of their kittens lacking a tail.
- **c** Explain how lethal alleles can remain in a population.

22 Explain why test crosses are important to commercial breeders.

Analysing

23 The snapdragon (*Antirrhinum majus*) can show a condition called 'aurea' in which the leaves appear a golden colour instead of green. A pair of aurea snapdragons with golden leaves was crossed and they produced 101 offspring, 67 with golden leaves and 34 with green leaves. Draw a Punnett square for the cross and use the data to explain how the ratio among F_2 offspring could have arisen.

24 A test cross of fruit flies with curly wings and red eyes produces offspring with red eyes, half of which have curly wings, half straight wings. Identify the genotype of the original red-eyed fruit fly with curly wings, and provide evidence to support your conclusion.

25 A male purebred fruit fly with the standard brown body is crossed with a female purebred with a yellow body. All the male offspring have yellow bodies, while all the female offspring have brown bodies.

- **a** Explain where the gene is located.
- **b** Predict the proportions of the phenotypes in the offspring produced by crossing the F_1 fruit flies.

26 Genetics is said to explain why offspring resemble their parents. Yet a child born to parents of whom one is blood group AB and the other blood group O can never have the same phenotype as either of its parents. Explain this apparent paradox.

Evaluating

27 Discuss the benefits and limitations of studying Mendelian inheritance patterns in humans.

28 Would you consider most phenotypes to be monogenic or polygenic? Discuss the observations you would cite in support of your point of view.

Creating

29 Draw four different pedigrees showing examples in which the only possible mode of inheritance can be:

- **a** autosomal dominant inheritance
- **b** autosomal recessive inheritance
- **c** sex-linked dominant inheritance
- **d** sex-linked recessive inheritance.



CHAPTER 11
INVESTIGATING AN ISSUE

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

KEY KNOWLEDGE

Investigation of an issue

- the 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 biological concepts specific to the investigation: definitions of key terms; use of appropriate biological terminology, conventions and representations.
- the use of data representations, models and theories in organising and explaining observed phenomena and biological concepts, and their limitations
- the nature of evidence and information: distinction between opinion, anecdote and evidence, weak and strong evidence, and scientific and non-scientific ideas; and validity, reliability and authority of data including sources of possible errors or bias
- the influence of social, economic, legal and ethical factors relevant to the selected biological issue.

KEY SCIENCE SKILLS

Conduct investigations to collect and record data

- systematically generate, collect, record and summarise both qualitative and quantitative data

Analyse and evaluate data, methods and scientific models

- process quantitative data using appropriate mathematical relationships and units
- organise, present and interpret data using schematic diagrams and flow charts, tables, bar charts, line graphs, ratios, percentages and calculations of mean
- take a qualitative approach when identifying and analysing experimental data with reference to accuracy, precision, reliability, validity, uncertainty and errors (random and systematic)
- explain the merit of replicating procedures and the effects of sample sizes in obtaining reliable data
- evaluate investigative procedures and possible sources of bias, and suggest improvements
- explain how models are used to organise and understand observed phenomena and concepts related to biology, identifying limitations of the models

Draw evidence-based conclusions

- determine to what extent evidence from an investigation supports the purpose of the investigation, and make recommendations, as appropriate, for modifying or extending the investigation
- draw conclusions consistent with evidence and relevant to the question under investigation
- identify, describe and explain the limitations of conclusions, including identification of further evidence as required
- critically evaluate various types of information related to biology from journal articles, mass media and opinions presented in the public domain
- discuss the implications of research findings and proposals

Communicate and explain scientific ideas

- use appropriate biological terminology, representations and conventions, including standard abbreviations, graphing conventions and units of measurement
- discuss relevant biological information, ideas, concepts, theories and models and the connections between them
- acknowledge sources of information and use standard scientific referencing conventions

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Issues in biology

It's 1953 and Professor Suzanne Cory is sitting in a lecture theatre at the University of Melbourne. She recalls her lecturer rushing into the theatre holding a journal aloft in his clenched fist, proclaiming, 'They've done it! They've done it! They've solved the structure of DNA!' Since this discovery, new DNA technologies have emerged that change the way we live (Figure 11.1). New ideas and technologies help us to solve problems related to health and the environment. They generate national income and inform policy, industry and economic decisions.

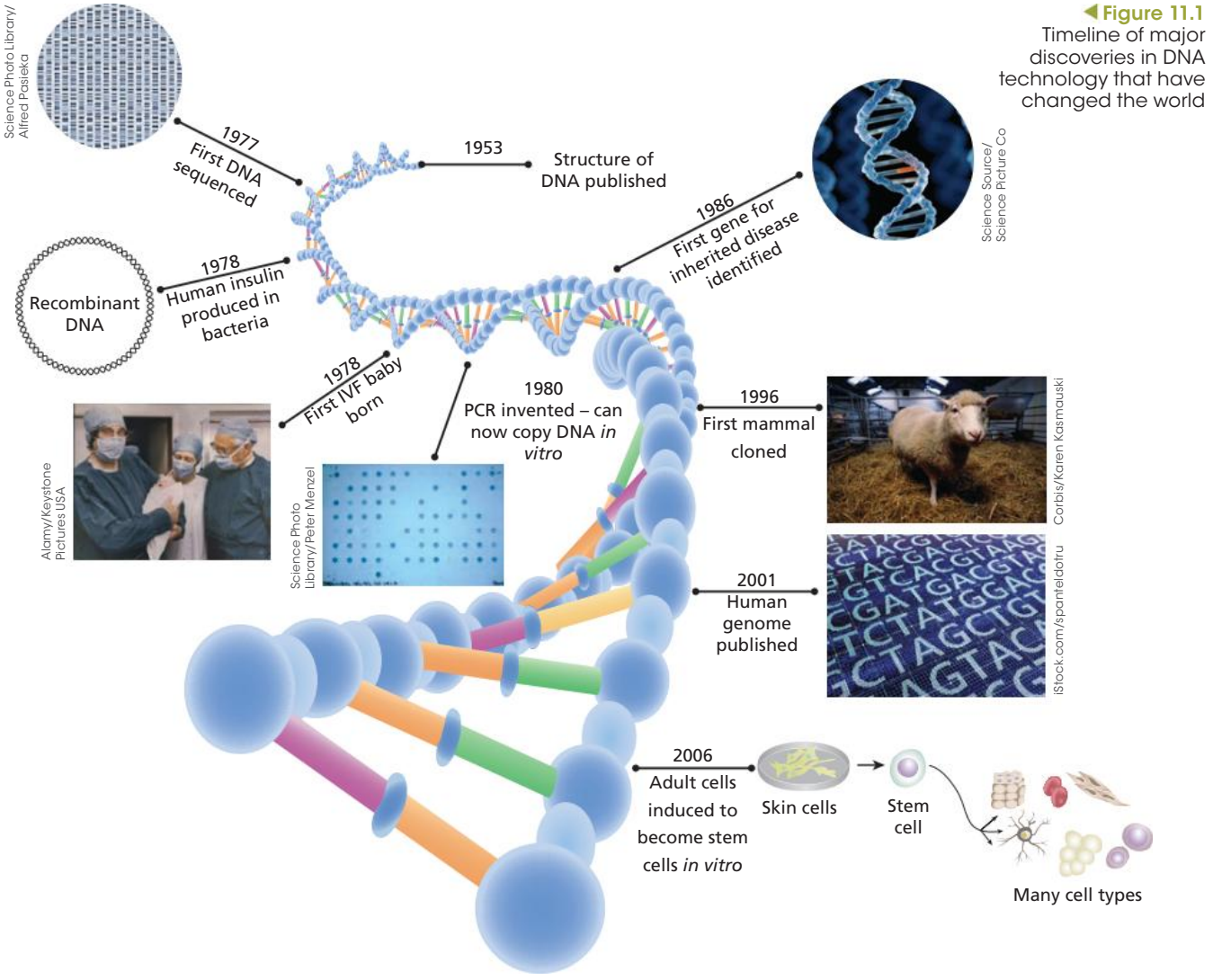


Figure 11.1 Timeline of major discoveries in DNA technology that have changed the world

However, while these discoveries provide benefits to society they can also raise **issues** – important social, economic, legal and ethical questions for debate and discussion. An issue is a problem, a matter of concern or interest, about which you may need to make a decision. It can be personal, such as: 'Will this dietary supplement help me lose weight?' Or it may require debate or discussion as it guides public policy, such as the debate around human surrogacy in assisted reproductive technologies. Issues arise when economics, health, environment, or human or animal welfare, security and safety might be at risk. Figure 11.2 reveals what leading Victorian biologists believe will be the big issues in their field over the next decade.



AAP Image/Dean Lewins/Menzel

Sir Gustav Nossal (Former Director of Walter and Eliza Hall Institute)

A major issue is the personalised treatment of cancer. Today, cancer chemotherapy is a blunderbuss affair with many side effects. Recently, the gene mutations of individual cancers have been scrutinised by sequencing the genes of the cancer cells themselves. This frequently identifies targets for very particular drugs. The trouble is that the DNA sequencing and subsequent gene analysis are still very expensive. Citizens together with doctors and scientists will have to determine whether the benefits justify the costs.



Courtesy Professor Sharon Lewin

Professor Sharon Lewin (Director of the Peter Doherty Institute)

With global travel and rapid changes in our environment, I expect we will see new and re-emerging infectious diseases in the future. I imagine that rapid advances in molecular sequencing, drug design and immunology will lead to improved tests, treatments, vaccines and ways to track outbreaks. The main challenge facing us as a global community is to ensure that we continue to invest in research and to address the social determinants that drive the spread of infectious diseases. Regardless of living in a high- or low-income country, this remains the responsibility of all.



Courtesy Professor Geoffrey Donnan

Professor Geoffrey Donnan (Director of the Florey Institute of Neuroscience and Mental Health)

Knowledge about the brain is increasing in an almost exponential fashion. The main drivers for this are extraordinary advances in imaging the living brain at a macro and micro level, and an understanding of the genetics of brain diseases. Over the next 10–15 years these approaches are likely to result in significant cures for disorders ranging from Alzheimer's disease to stroke. Such advances could never have been contemplated in past decades and this underscores the emergence of neuroscience as one of the most rapidly advancing areas in medicine.



Courtesy Professor Suzanne Cory

Professor Suzanne Cory (Former Director of Walter and Eliza Hall Institute)

Advances in understanding the genetic accidents driving individual cancers have led to the development of highly effective new drugs targeted to specific mutations. As a consequence, during treatment, unintended damage to normal cells is minimised. However, the development of a new cancer drug is still very costly – around $1 billion. Society may baulk at this cost, thereby preventing the development of effective treatment for many types of cancer. How should society and scientists approach this dilemma?



Fairfax Syndication/ Joe Armao

Professor Bob Williamson (Former Director of Murdoch Children's Research Institute)

Science is changing very quickly, and one of the few fields that has an infinite number of problems to solve during the coming twenty years is how the brain works. Why are we much more intelligent than monkeys or mice, when we share so many genes with them? Can we build a super-computer that can think like we do? Should we enhance our intelligence by changing genes in our babies that offer more and better abilities? Are there ethical issues in all this, and how do we solve them? So much to do, but a young scientist today will have fantastic tools to address these questions.



Courtesy Professor Megan Munsie

Associate Professor Megan Munsie (Stem Cells Australia)

Stem cells hold great promise in regenerative medicine over the next decade, for repair and replacement where new cells are manufactured outside the body and returned to the patient to restore function to damaged tissues or organs. Research may also reveal how to activate dormant stem cells found within organs. Imagine if the damage to the heart following a heart attack could be restored by coaxing heart stem cells to divide and replace the damaged muscle. We need to ensure that the public remains meaningfully informed about such advances. Scientists must share their work with the public and voice their concerns about advances that may place human health and wellbeing at risk.



Courtesy Professor Rob Shepherd

Professor Rob Shepherd (Director of the Bionics Institute)

A decade of research in medical bionics will produce improved hearing outcomes for users of the bionic ear, allow blind patients to read text, detect the onset of epileptic seizures and provide a level of independence for quadriplegic patients using brain–computer interfaces. Society will require a new generation of researchers and engineers to achieve these goals.



Courtesy Sylvia Metcalfe

Professor Sylvia Metcalfe (Murdoch Children's Research Institute)

Would you take a genetic test to find out if you are likely to develop particular diseases, how you might respond to medications, to discover your ancestral roots, to find out the right diet for you or how good an athlete you are? Some companies offer these tests to people without involving their doctor or health professionals to explain results. Also, the genetic information of people who elect to have these tests can be shared without explicit consent. This has raised concerns about privacy and confidentiality, genetic determinism, and equity issues. Now and in the future, society needs to work out how best to harness the information in our genes for the benefit of all while minimising the possible harms that might arise through misinformation and misuse.

Figure 11.2 ▲
Leading Victorian biologists share future advances and issues in medical biology that may impact society over the next 10 years.

Identifying an issue

Information on local, national and global issues that concern all members of society can be accessed through a variety of sources including journals (Figure 11.3), news items, documentaries and websites. As consumers and citizens we must critically evaluate available information to make informed decisions about issues and participate in debate. When we read, watch or listen to scientific reports we should use **critical thinking** skills and ask questions such as those found in Table 11.1 (on page 338) to clearly identify the issue or problem being discussed.



Courtesy University of Texas at Dallas

▲ **Figure 11.3**
Issues in Science and Technology is dedicated to discussion of public policy related to science, engineering and medicine.

Writing a problem statement to guide your investigation

Once you have identified an issue, it is good practice to write a problem statement that provides a clear description of the issue. This will help guide your investigation and keep you focused on investigating a particular question. A problem statement consists of three components:

- **Statement 1:** Give a brief background statement to provide context for the investigation. State the impact and significance (real or potential) of the problem as a justification for the investigation.
- **Statement 2:** Describe the problem or issue. Identify and describe the specific aspect of the issue that your investigation will address, and state why your investigation is necessary.

RECALL

- A problem statement is a clear and precise description of a particular issue or problem to be investigated, and why the investigation should take place.
- The problem statement is useful to justify and guide the research.

WORKED EXAMPLE 11.1

Identifying an issue to investigate, and writing a problem statement

Meat from cloned animals need not be labelled, EC says

By Bruno Waterfield, in Brussels, and Sarah Knapton for *The Telegraph*, 18 Dec 2013

The EU has decided against restricting or labelling the sale of meat or milk from the offspring of cloned animals

A row broke out last summer when it emerged that meat from the offspring of a cloned cow had been sold unwittingly without a licence being obtained.

Meat from the offspring of cloned animals will continue to be sold without labels in Britain after the European Commission refused to end the practice.

Shoppers in the UK have been unknowingly eating meat sourced from the young of animals whose DNA has been altered for the past two years despite calls for it to be clearly labelled. It is thought that hundreds of dairy cows from cloned parents have already been reared and slaughtered on British farms. Consumer groups claim more than 80 percent of people are opposed to eating food from clones or their offspring.

The EC yesterday proposed a temporary ban on the cloning of animals for food in the EU but said it will not take measures to restrict meat or milk from cows, sheep or pigs that are the descendants of cloned animals. More significantly for shoppers, the commission ruled out labelling food from the offspring of cloned animals claiming it would be unenforceable. 'This requires that parentage information for every food producing animal is conveyed through

the food production chain,' said the commission. 'This becomes more complicated and therefore costly with every generation between the clone and the animal, reproductive material and the food. For official controls, checking the accuracy of statements on labels would require in particular for food from offspring and descendant meticulous investigation into the accompanying documentation.' Because there are no restrictions on importing semen which has come from a cloned animal, it is likely that tens of thousands of pigs and cows in Europe are offspring of cloned stud animals from America.

In 2008, America's food safety authorities 'concluded that meat and milk from cow, pig, and goat clones and the offspring of any animal clones are as safe as food we eat every day'. The EU imports 300 000 to 500 000 tons of beef every year, much of it comes from the US and Argentina, which authorise cloning for commercial purposes, usually for producing semen for artificial insemination leading to herds composed of the offspring of clones.

The proposals for an EU directive will 'ban the use of the cloning technique for farm animals and the imports of these animal clones'.

'The marketing of food from animal clones will also be prohibited,' said the commission.

Animal welfare and consumer campaigners have expressed their disappointment with the failure to introduce an immediate ban. 'The proposals do not go far enough. As they do not ensure that a ban on the import and sale of animal clones, their offspring and food products from animal clones and their offspring as well as semen and embryos from animal clones is introduced immediately across the EU,' said Reineke Hameleers, the director of Eurogroup for Animals. 'We urge the EU to stand firm and prevent the sale and import of food from cloned animals and their offspring, respecting the wishes of Europe's citizens by properly amending the proposed legislation quickly.'

The questions in Table 11.1 provide a useful guide to identifying the issue reported in this article.

Table 11.1 Questions to consider as you identify an issue for investigation

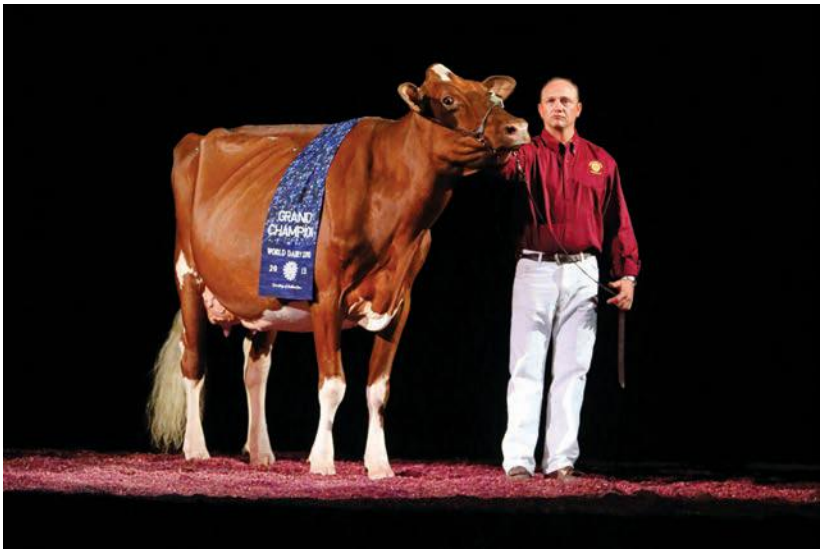
Question	Examples relating to cloning cattle in agriculture
What is the issue or problem under investigation? Is it short term or ongoing?	Animals are cloned for agricultural purposes. Products from cloned animals and their offspring are sold unlabelled. Some groups want to ban the practice of agricultural cloning entirely. This issue increases as more animals are cloned and their semen and embryos are sold worldwide.
Who is affected by this problem and how? There may be more than one set of stakeholders (affected groups) and they may be affected differently. This is the *impact* of the problem.	Consumers may want to choose whether they eat the products of clones. Dairy farmers want to have cattle with desirable traits to increase milk production. Animal welfare groups would like to ban cloning, on ethical grounds.
What is causing the issue?	Companies produce clones of phenotypically superior cattle and sell their offspring, semen and embryos to farmers around the world. Clones and their offspring are now being used in the manufacture of dairy products.
Where does the problem occur?	It is a worldwide issue.
When does it become a problem?	Legislation differs in different countries. Complying with new labelling laws that require tracking of clones and offspring across many generations is difficult and costly.
Why is it important that we fix the problem? What social, legal, economic or ethical benefits will follow? This is the *significance* of the problem.	It is important to maintain consumer trust in food manufacture while at the same time considering profit margins for farmers, associated environmental impact and animal welfare.
Proposal for addressing the problem. Would this revise existing knowledge or practices? Is research required? Is policy or law reform required? Do the public need better information?	We need to examine the practice of cloning for benefit and harm to the animal, consumers, farmers and the environment. The public should be well informed and there should be clear and equitable legislation across the industry.

After identifying the issue, write a problem statement to guide the investigation.

Statement 1
Agricultural practices for food production must consider animal welfare, environmental impact, consumer safety and profitability for producers. Cloning of dairy cattle and the sale of their offspring, semen or embryos is a means to improve yield as worldwide demand increases and puts pressure on existing agricultural land.

Statement 2
However, uncertainty exists around the practice of cloning with respect to animal welfare and the information provided to consumers about how their food is produced.

Statement 3
This investigation will evaluate and report current practices in order to educate consumer groups, animal welfare organisations and policy makers to guide legislation around cloning and marketing of products associated with clones and their offspring.



Nina Linton Photography

◀ Figure 11.4
The Grand Champion at the 2013 World Dairy Expo was a clone with outstanding milk yield. The cow from which she was cloned came second and her daughter came third.

Staying impartial as you conduct an investigation

When reading about, listening to or watching **scientific reports** you should always remain **objective**. Good investigators try to refute their own ideas to test whether their assumptions are misguided. They keep an open mind and modify their opinions if the evidence warrants this. Sometimes, if you have a certain belief already, you will tend to look for things that support it while ignoring ideas that do not. This is known as **confirmation bias**. You may also experience wishful thinking, which can interfere with making rational judgements. This is known as **cognitive bias**. As shown in Figure 11.5 on page 340, a number of factors can influence how you make decisions.

When you start an investigation, record your immediate feelings and opinions relating to an issue. As you investigate an issue you may find that your original opinion was based on misinformation or an incomplete understanding of the issue. As lifelong learners, it is powerful to recognise when our opinions shift and why. Such experiences can be useful to share with an audience at a later date.

Be aware of how ideas are being presented. In his book titled *Influence: The psychology of persuasion*, Robert Cialdini, a professor of psychology, reveals the six main elements involved in the science of persuasion that are used to win support.

- Authority – people will believe knowledgeable experts.
- Liking – you are more likely to agree with someone you like.

- Consensus – you are more likely to do what others are already doing or saying; you will follow a trend. Percentages may be used to sway you to the majority opinion.
- Reciprocity – you may feel obliged to support an opinion to repay a personal or public service.
- Scarcity – often when there is less of something it means we are more likely to want it; you may support the minority group in order to be different or because you feel they need support.
- Consistency – often you will be asked for a small commitment, and over time the commitment increases.

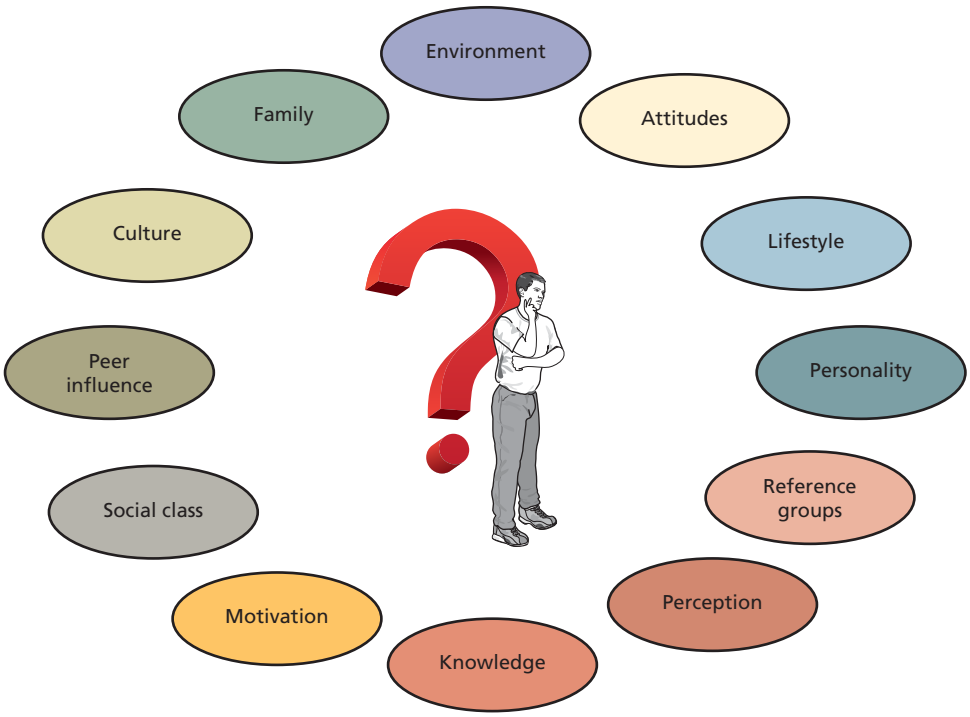


Figure 11.5 ▶ Factors that can influence how we make decisions

WORKED EXAMPLE 11.2

Identify factors that could influence decision making when investigating the issue of cloning

Examples

- **Cognitive bias**: Animal welfare advocates, and those who oppose their arguments, would need to recognise that bias may interfere with objectivity.
- **Confirmation bias**: Having a fear or distrust of biotechnology could interfere with objectivity.
- **Other factors**: A farmer or relatives of farmers may identify strongly with the need to increase productivity.
- **My initial thoughts**: There does not seem to be much discussion about dairy cattle cloning in the media. I'm unsure about the procedure and its effect on animals, and so this will need investigation.

Questions that I need to investigate

1. What is cloning and does it affect animal welfare? Who is conducting the cloning? How much is being done?
2. Is this practice contributing to a significant difference in productivity in farmers' herds? If so, is it equally accessible for small and large farms?
3. Is consumption of products manufactured using clones and their offspring safe? What are consumer attitudes to cloning, and to labelling of marketed food, and why? What cloning and labelling legislation exists in different countries, including Australia?

ACTIVITY 11.1

IDENTIFY AN ISSUE TO INVESTIGATE

Step 1: Locate a media report related to genetics or reproductive biology that raises social, economic, legal and/or ethical questions. You may consider the areas of human cloning, genetic modification of organisms, the use of forensic DNA data banks, assisted reproductive technologies, or prenatal and predictive genetic testing as possibilities.

Step 2: Use the guiding questions in Table 11.1 to identify the issue discussed in the report.

Step 3: Write a problem statement to help guide your investigation.

Step 4: Recognise any factors, such as those on page 340, that could influence your decision making. This will help you to stay impartial as you investigate the issue.

Step 5: Record your initial thoughts regarding this issue. Keep note of when your thoughts change and when they are supported.

Step 6: Make a list of questions that need further investigation.

Understanding the biology

As we accumulate knowledge we can pick up **misconceptions** in our scientific thinking. Misconceptions arise through misinterpreting science, exposure to reporting that contains scientific error, social and cultural beliefs, and revisions to scientific knowledge as new evidence is found. To minimise error, check your scientific understanding using a variety of sources.

Specialist language used in biology can sometimes be difficult to grasp, leading to misunderstanding of concepts. If you encounter complex words, try to break them down to identify their origin. Let's use the term *enucleated egg cell* as an example. The first word can be broken into the Latin 'e' meaning 'out of' and the Latin 'nucleus' meaning kernel. An enucleated egg cell has had the nucleus taken out of it. Let's explore the term *somatic cell nuclear transfer*. Somatic is from the Greek 'soma' meaning 'body'. This terminology then refers to transferring the nucleus of a body cell. In the process of cloning it is transferred into an enucleated egg cell. Imagery can help you to understand meaning. As you conduct an investigation, keep a glossary of the biological terminology that you encounter and include **annotated diagrams** where possible.

Representations such as metaphors, demonstrations, diagrams, animations, tables, graphs, graphic organisers and models can help you understand and describe **scientific concepts**. They can be useful for organising your thoughts and refining your knowledge. It is important to use correct scientific terminology when reporting on your findings so that you are accurately discussing relevant scientific concepts in language that is standardised across the scientific world.

RECALL

- Scientists use definitions, diagrams and representations as tools to learn and to clearly explain biological terms and concepts.
- Scientists communicate in ways that are appropriate for their target audience.
- It is important to use accurate scientific terminology when communicating scientific concepts to a scientific audience.

WORKED EXAMPLE 11.3

Understanding the biological process of somatic cell nuclear transfer used in cloning technologies

Somatic cell nuclear transfer (SCNT) technology is used to generate clones of prize cattle (Figure 11.6).

In SCNT, the nucleus of a cow egg cell is removed. Next, the nucleus from a skin cell of a prize bull or cow is transferred to the enucleated egg cell. The resulting fused cell is stimulated to develop into an embryo. The embryo is then implanted into a surrogate cow where it develops to full term. The calf that is born is a clone of the original prize bull or cow.

At maturity, a cloned bull can be used as a source of semen to artificially inseminate a large number of fertile cows.

A cloned cow can be used in milk production and can be artificially inseminated to produce high-quality offspring. Her eggs can also be harvested and then fertilised by prize bull semen. The developing embryo can be split to produce many embryos. Semen and embryos are sent around the world to improve dairy herd genetics.

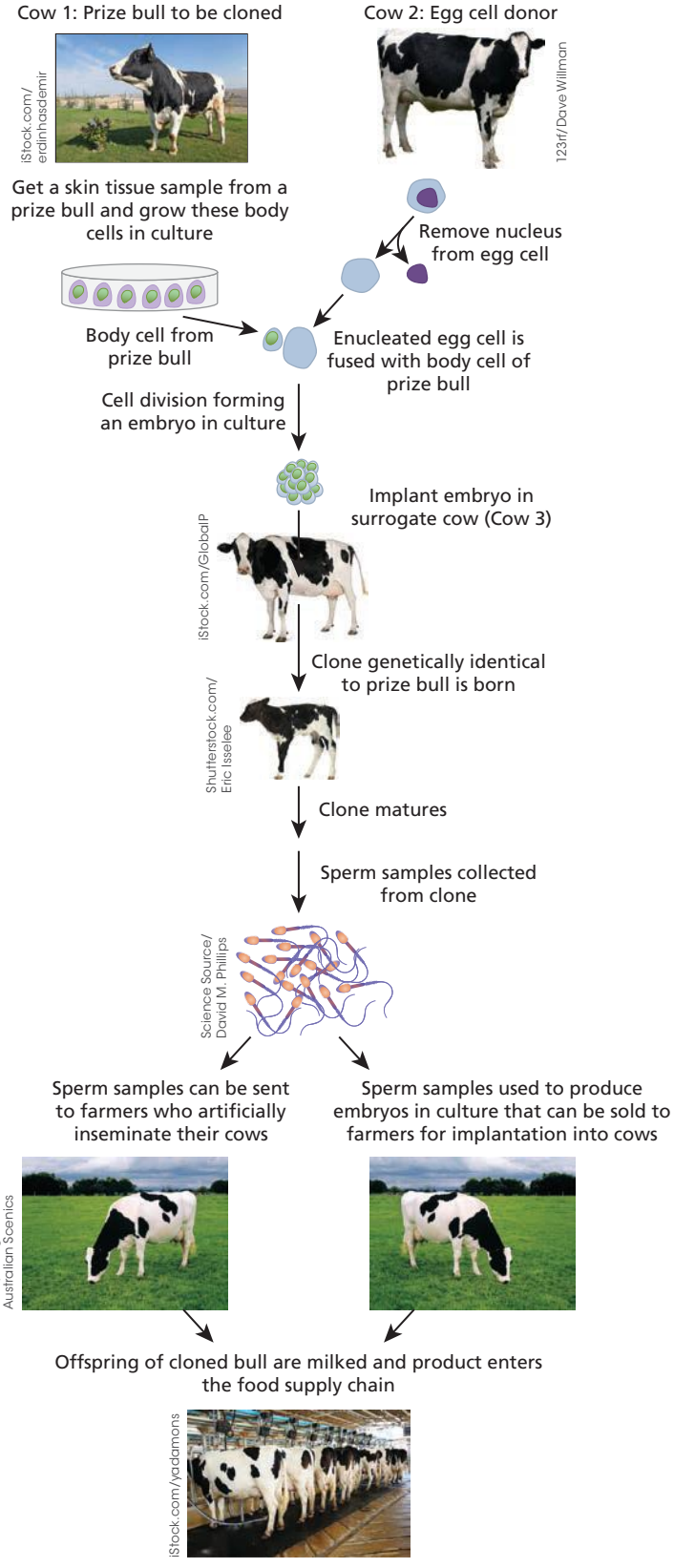


Figure 11.6 ▶
How the process of cloning contributes to improving the genetics of dairy herds around the world

ACTIVITY 11.2

ACCURATELY DESCRIBE THE BIOLOGICAL PROCESSES RELATED TO YOUR ISSUE

Step 1: Provide a description of the biological processes related to the issue that you identified in Activity 11.1.

Step 2: Construct a flow chart or animated diagram to support your description of the biology.

Step 3: Start a glossary to record definitions of biological terminology encountered in researching your issue.

Conducting research to investigate an issue

There are many aspects to investigating an issue (Figure 11.7). Investigators gather information from a wide variety of **sources** to help establish facts and recognise the variety of opinions on an issue. Record details about each source as you conduct your research. There are different methods you can follow to do this. Throughout this chapter and in the issues boxes for this book, we use the American Psychological Association (APA) citation method. This method has been adopted for referencing in many scientific disciplines. Table 11.2 provides an example of how to reference information using this method. As you progress in your research, build a **reference list** by arranging your sources in alphabetical order based on the surnames of the leading author/producer.



▲ **Figure 11.7**
Qualities in investigating biological issues

Table 11.2 How to reference information using the APA citation method

Source of information	Citation method
Books	Author names or name of organisation if authors not supplied. *Title of book*. Location. Publisher. Year of publication. (Include URL and date of access if electronically accessed.)
Journal, magazine and newspaper articles	Author names. (Year). Article title. *Journal title*, volume number (issue number), page numbers. (Include URL and date of access if electronically accessed.)
Websites	Author names or name of organisation (if provided). (Year published). *Title of work*. Date you retrieved the information, website URL.
Personal correspondence or interviews	Interviews should be cited in the text as 'personal communication' (including month, day, year) and not included in the reference list. Names, initials (of interviewer). Names, initials (of interviewee). (Date).
Television	Names, initials (of executive producer). (Date). Title (of television program). Country or city of production: production studio or network.
Film	Names (of producer), and names (of director). (Year). *Title of film* (for a film). Country of origin: studio name.

Recording ideas as you investigate science reports

As you read an article or watch media reports, record the important ideas being presented. You can do this by summarising, paraphrasing and quoting. In **summarising** you put the main ideas into your own words to capture a broad overview. In **paraphrasing** you re-write a particular passage in your own words and retain the original meaning, ensuring you maintain relationships between main ideas and supporting points. When **quoting** you match the source word for word, enclosing the text in quotation marks.

The credibility of reports is improved when authorities are cited to support arguments. Quotes and paraphrasing are used when you want to provide evidence from an **authority**. To avoid **plagiarism**, acknowledge the original source of the ideas, data and images used from an external source. Using the APA citation method, you provide the author (last name or organisation name) and year in parentheses, in the text. If you include a direct quote or idea you should also add the page number so the reader of the information can verify your source. For more detailed information on referencing, you can consult library websites and librarians.

WORKED EXAMPLE 11.4

Referencing data when communicating science

Source: Brisville A., Fecteau G., Boysen S., Desrochers A., Dorval P., Buczinski S., Lefebvre R., Hélie P., Blondin P. & Smith L. (2013) Neonatal morbidity and mortality of 31 calves derived from somatic cloning. *Journal of Veterinary Internal Medicine* 27(5): 1218–27.

The following passage includes a quote and paraphrasing to provide supportive evidence from the source above.

> Brisville et al. (2013) recommend 'close monitoring of cloned calves during the neonatal period to allow early identification of complications and timely intervention' (page 1226). The majority (68%) of the 31 somatic cell cloned calves delivered at their veterinary facility survived their first three months. Of these, many were treated for umbilical cord infections, hyperthermia, gastrointestinal problems and respiratory problems.

From this information, we can start to formulate a recommendation regarding cloning.

> To improve the survival outcomes for somatic cell cloned calves, facilities using cloning technology should be equipped with veterinary equipment and staff.

ACTIVITY 11.3

CITING EVIDENCE FROM AUTHORITIES TO SUPPORT CLAIMS AND ARGUMENTS

Step 1: Find two or three media reports and/or scientific articles that relate to a query you have about the issue you started to investigate in Activity 11.1.

Step 2: Using Table 11.2 as a guide, record these sources in a reference list.

Step 3: Summarise the main points in each article. Practise your skills in writing quotes and in paraphrasing the findings of the authors. Record the page number when you do this.

Step 4: Add to your glossary of definitions and representations of biology concepts as required.

RECALL

- During investigations, summarising, paraphrasing and quoting are used to record evidence from authorities.
- The source of the evidence is recorded in the body of reports and in a reference list, to avoid plagiarism.

Evaluating scientific reports

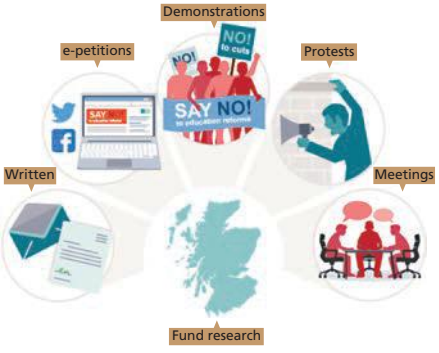
To determine whether the opinions and evidence presented in reports are trustworthy, we **evaluate** scientific reports to check for **bias** and misinformation. An unbiased article will present alternative views and address them in a fair manner. A biased article may employ extreme or exaggerated language, and the arguments used will often appeal more to emotion than to reason. Biased reporting lacks objectivity by presenting only one side of an issue or providing an over-simplified perspective.

Evaluate who produced the report and why

Research the author and publisher or producer of the work to determine whether they endorse religious or political views or have a vested economic interest that could affect their objectivity. Are they associated with a particular **pressure group** such as Greenpeace, the Australian Conservation Foundation, the Australian Christian Lobby or the Victorian Farmers Federation? Pressure groups exist to allow citizens to participate in law and reform by providing them with a voice (Figure 11.8). They contribute to the circulation of democratic ideas by providing information to governments and the public on how to view issues. However, at times they may use methods that make it seem like they have more support than they really do. In this case, their influence does not reflect the attitudes of the broader public. Lists of pressure groups can be located on the Internet.



Greenpeace/Rex Wyler





AAP Image/David Crosling

▲ Figure 11.8
Pressure groups use a number of methods to allow citizens to participate in law and reform and to represent public interests.

Does the author or publisher belong to a **professional association** such as the Australian Medical Association or the Australian Academy of Science? Professional associations exist to raise public awareness by providing reliable information through various means such as publishing journals and websites, or providing expertise to investigators. Associations regulate membership by ensuring that all practising members are qualified. This keeps the standards of the profession high. The expertise of authors or interviewees should be revealed by indicating their qualifications.

When using websites you can generally find information about the author or sponsors of the site by navigating to the 'about this site' link from the homepage. The URL address can also provide information about the country and the type of group providing information. For example, '.com.au' is commercial Australia; '.edu.uk' is educational United Kingdom; '.gov' is government; and '.org' is organisation. Determine the purpose of the site. Has it been constructed to sell a product, to inform the public or to sway public opinion? Is the information current or is the website updated regularly? If you can't find dates, check whether links embedded in the site still work. If they don't, the information on the site may no longer be reliable. Also, if the links only lead to websites that support the views of the author, the work may be biased.

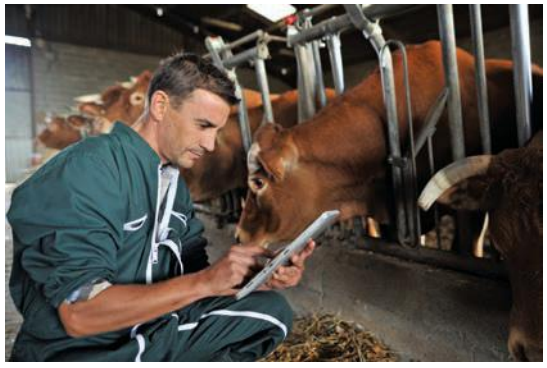
Evaluate how the scientific evidence is produced

Science reports should support their arguments and claims using scientific **evidence**. This helps to avoid **dogmatism**, where conclusions are based on authority or doctrines rather than evidence. So how do we know if evidence is scientific? The scientific approach to gathering evidence relies on observation and experimentation. Qualitative and quantitative studies are carried out to explore a question and collect data.

Qualitative studies

Descriptive or **qualitative studies** provide information about what is happening in a population and are used to measure the prevalence and type of experience or opinions of groups. Usually a **survey** or **case study** is used to collect data to detect a problem and monitor the scope of the problem.

Figure 11.9 provides an example of a qualitative study used to canvas views of key leaders and the public about the use of animal cloning for food production. This exploratory research provided insights into priorities, values and opinions relating to cloning. In a qualitative study such as this, it is important to get a broad representation of public opinion in focus groups. The researcher must consider the **demographic** of the population they are sampling, such as gender, age, socioeconomic status, race, religion, employment and level of education. Results of qualitative studies often inform the design of survey questions for a larger quantitative study.


Shutterstock.com/Goodluz


Alamy/Tom Merton/OJO Images Ltd

Figure 11.9 ▶ A qualitative study designed to canvas opinions about the use of animal cloning for food production used in-depth interviews with key opinion leaders and focus groups to represent the opinions of the general public.

Quantitative studies

Analytical or **quantitative studies** try to quantify the relationship between two factors. These studies can be observational, such as **cohort studies** where groups that have had an experience are compared to groups that have not; or **cross-sectional surveys** that reveal the prevalence of a factor (Figure 11.10) or the accuracy of a diagnostic test.



◀ **Figure 11.10**
Design of a cross-sectional study used to determine consumers' awareness of and attitudes toward meat and milk from cloned cattle

The most reliable quantitative studies involve **randomised controlled trials**, where investigators control experiments so they can investigate the effects of one factor at a time. They change this one factor, the **independent variable**, while keeping all other possible variables constant. They measure the **dependent variable**, to determine whether it is affected by the experiment. In this way, cause-and-effect relationships can be measured to find out whether a particular factor is causing an observed response.

Read more about independent and dependent variables in Chapter 12, page 379.

Imagine that an intervention was designed to improve public knowledge concerning the use of cloning in the dairy industry. A randomly selected group were given the intervention (the treatment) while another randomly selected group were given a **placebo** intervention (the control). Figure 11.11 describes a randomised controlled trial designed to reduce researcher and participant bias.

Evaluate whether the evidence is valid and reliable

The best scientific studies produce **valid** and **reliable** information. To determine whether evidence is valid and reliable, we analyse the method used to conduct the study and check whether the conclusions align with those of other independent studies and scientific thought. The following guidelines can be applied to evaluate the validity and reliability of data in a scientific report.

Read more about positive and negative controls in Chapter 12, page 382.

Guidelines for evaluating the validity of evidence

- **Study outcomes**: Did the study actually test the question under investigation? Were the techniques and equipment used suitable and accurate?
- **Controls**: Were conditions held constant by controlling as many factors as possible that could affect the events being observed? Was a **negative control** used so the outcome of the treatment group could be compared to a group that wasn't treated? Was a **positive control** used to observe a positive state for comparison?

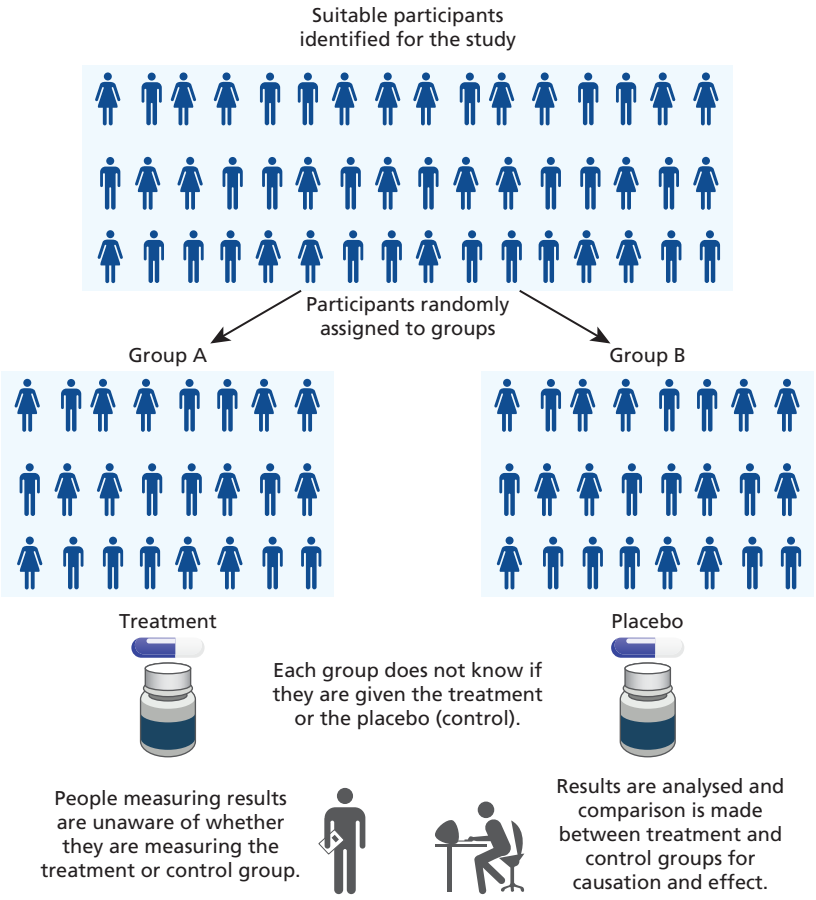


Figure 11.11 ▶
In this double-blind randomised controlled trial, bias is eliminated as neither the participants nor the researchers know who is in the control group and who is in the treatment group. This enhances the validity of data collected in the study.

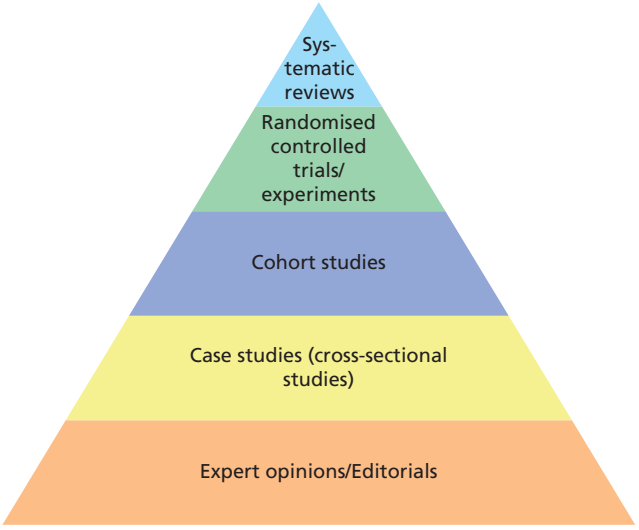


Figure 11.12 ▲
The risk of bias decreases and the validity of data increases as you move up this pyramid of evidence.

- **Randomisation**: How were the test subjects or treatments selected? Were individuals assigned randomly to treatment and control groups? To reduce false results, a **blind study** should be conducted so subjects do not know if they are in the treatment or control group. Data is even more valid when a **double-blind study** is carried out to eliminate researcher bias (Figure 11.11).

Figure 11.12 reveals the relative validity of different sources of evidence.

Guidelines for evaluating the reliability of evidence

- **Replication**: Was the treatment given to an adequate number of participants or conducted enough times to ensure that any measured outcome is not due to coincidence?
- **Reproducibility**: Has other independent research produced similar evidence?
- **Plausibility**: Are the results consistent with established ideas in science? The more the claim deviates from established science, the more evidence is required to support the claim.

When scientists publish the results of studies, they try to get their article published in the most reputable journal in their field of study. Journals are rated with an impact factor based on the number of times articles are cited from that journal. A high impact factor indicates that the journal is important in its field. *Nature* is a well-regarded journal with an impact factor of around 50. You can look up the impact factor for a journal by conducting an Internet search.

Reliable and contentious articles get cited most often and this is recorded in databases. Searching for highly cited articles is useful when starting to investigate an issue. Google scholar is a useful search engine when looking for highly cited articles.

When scientists conduct a study it isn't always possible to eliminate all sources of bias or scientific error. In such cases this should be communicated clearly in the scientific report. Remember to always check who conducted the study and why, and check who funded the study. If there is a possible conflict of interest, the authors should state this.

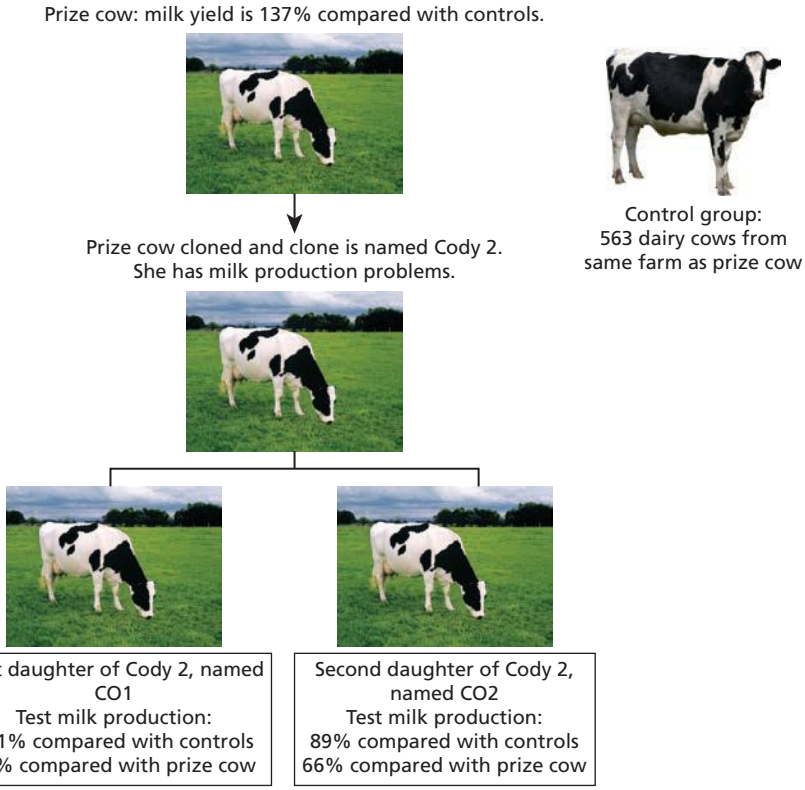
RECALL

- Strong evidence is obtained using the scientific approach, which distinguishes it from anecdote and opinion.
- Scientific evidence should be unbiased, valid and reliable.
- Analyse the authors of evidence for bias by looking into their motivation for producing the work.
- Analyse the validity of a study by determining whether the design was suitable for measuring the desired outcome, and that controls and randomisation were applied.
- Analyse the reliability of a study by determining whether replicates were used, whether similar evidence has been reported in other independent studies and whether the outcomes seem plausible.

WORKED EXAMPLE 11.5

Analysing a scientific report for bias, validity and reliability

This study was conducted to determine the milk-producing ability of the offspring of a cloned cow with reduced milk production. Figure 11.13 summarises the method and results of this study. The bias, validity and reliability of this study is scrutinised using the questions in Table 11.3 (on page 350) as a guide.



◀ **Figure 11.13** Diagram summarising the method and results of a study on milk production in the offspring of a clone

Table 11.3 Guidelines for analysing the bias, validity and reliability of a study

Measure of the bias, validity and reliability of a report	Illustrative example
Source of report	Takahashi M., Tsuchiya H., Hamano S., Inaba T., Kawate N. & Tamada H. (2013). Clinical study report on milk production in the offspring of a somatic cell cloned Holstein cow. *Journal of Reproduction and Development* 59(6): 595–8. This journal has an impact factor of 1.6, which is low.
Who produced the report and why?	A clone was born that had reduced milk production compared to the cow it was cloned from. Scientists wanted to determine whether the offspring of the clone would also have reduced milk production.
What type of report/study is it (see Figure 11.12)?	Cohort study
Has this report/study been cited by others?	No
What is being measured?	Milk production
Are controls used?	Yes. Production of milk was determined for 563 cows from the same farm as the prize cow.
Were treatment and control groups randomly selected?	No
Was the treatment replicated? If so, how many times?	Data for two offspring of the clone are provided
Have similar results been reproduced in other independent studies?	Other studies reveal that there is no significant difference between the milk production of clones and their offspring.
Is the reported result plausible?	Outcomes are consistent with studies of clone and clone offspring milk production.
Who funded the study?/Is there a conflict of interest?	Partly funded by the Japan Racing and Livestock Promotion foundation in the Japanese Research Association for Animal Embryo Transfer Technology.

There are some concerns with the validity and reliability of this study: validity as the study could not be randomised; and reliability because the number of replicates is very small and the journal has a low impact factor. However, its reliability is increased by the fact that other studies support the plausibility of these findings. Results from further studies about milk yield in clones and their offspring would be required. No immediate issues can be found relating to bias of the authors.

ACTIVITY 11.4

IS IT GOOD SCIENCE OR BAD SCIENCE?

Complete the following steps to analyse the sources that you collected for your investigation during Activities 11.1 and 11.2.

Step 1: Examine the study design for each source and make a representation of the study design and findings. This could be a diagram, flow chart or animation.

Step 2: Construct a table similar to Table 11.3 to evaluate the bias, validity and reliability of each of your sources.

Step 3: Write a paragraph providing your assessment of the evidence from each source. Provide reasons for your assessment in relation to bias, validity and reliability.

Using statistics to analyse data

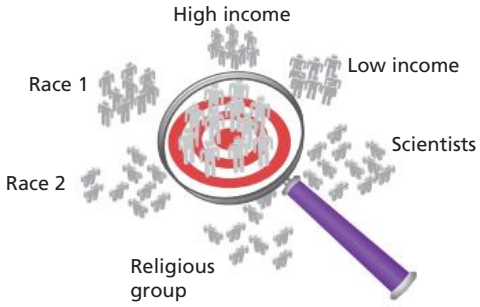
Statistics provides a powerful tool for analysing data to support or refute arguments. Often when conducting a study, financial, legal or operational constraints mean that you cannot sample a whole population, or that you can only repeat a study a limited number of times. Statistics are used to measure outcomes for full **populations** based on a representative **sample** of that population (Figure 11.14). Statistics are also used to predict expected outcomes based on the results of a replicated experiment.

Finding values of central tendency in a data set

A common statistical measure for a data set is to calculate values of central tendency including the mean, median and mode. These are all types of averages. Reports should clearly state the type of average calculated and what it reveals.

The **mean** value is used when a set of data does not have **outliers**. Outliers are results that are much lower or higher than the majority of results. The mean value is useful for comparing sets of data.

$$\text{Mean} = \frac{\text{sum of all values}}{\text{number of values}}$$



▲ **Figure 11.14** Investigations are conducted on a sample of the population representing demographics of the full population.

The **median** value is the middle number in a sorted list of numbers, and is especially useful when there are outliers in the data range. The following steps are used to determine the median:

Step 1: Arrange data from lowest to highest value.

Step 2: The median is the middle number. If there is an even number of values in the data set, select the two middle values, get the sum of these two values and divide the answer by 2.

The **mode** is used to reveal the most common value or the most popular result for non-numerical data. Sometimes there can be more than one answer for the mode.

It is useful to also provide the **range** of values encountered in a data set. This describes the variance in results and is calculated by taking the highest value and subtracting the lowest value.

Investigating the margin of error

When presenting data, the margin of error in any given measurement should be described. The **margin of error** reveals how well the sample represents the whole population. Let's explore this using the example of a survey on cloning, where a sample of the population was asked if they were aware of cloning practices in the dairy industry. If 30% of participants respond 'yes' and a margin of error of plus or minus 5% was cited, this tells us that if the survey was repeated 100 times, asking a different sample of people the question each time, then we can expect that those who say yes would remain within 5% of the original result. It could vary from 25% saying yes to 35% saying yes.

Increasing the number of people surveyed increases the sample size and reduces the margin of error. Similarly, increasing the number of times we repeat an experiment will reduce the margin of error, making the results more reliable. The margin of error does not

Table 11.4 The impact of sample size on margin of error

Sample size	Margin of error (%)
50	14
100	10
200	7
300	6
400	5
500	4
600	4
700	4
800	3
900	3
1000	3
1500	3
2000	2

depend on the size of the actual population. The industry standard is to have a margin of error of 5%. Table 11.4 provides an indication of how sample size affects the margin of error.

The margin of error is important when repeating a survey to monitor changes. Let's say that a public awareness campaign was established to inform people about the use of cloning in the dairy industry. The group who funded the education campaign wanted to know if the campaign had been effective. For change to be considered significant, the measured effect must exceed the margin of error. In the original survey, 30% ± 5% of participants were aware of cloning practices in the dairy industry. For the result of the intervention to be seen as positive, the second survey must show that more than 35% of the participants are aware of cloning practices in the dairy industry.

Looking for correlation and causation effects

Correlation is a statistical measure that indicates whether two or more factors fluctuate together (Figure 11.15). Factors are said to be positively correlated if they both increase together or if they both decrease together. They are said to be negatively correlated when one factor increases while the other decreases.

Sometimes changes in one condition or event bring about or cause a change in another condition or event. This is known as **causation** or cause and effect, where a factor (the cause) can change another factor (the effect). A valid experimental design is used to establish cause and effect claims.

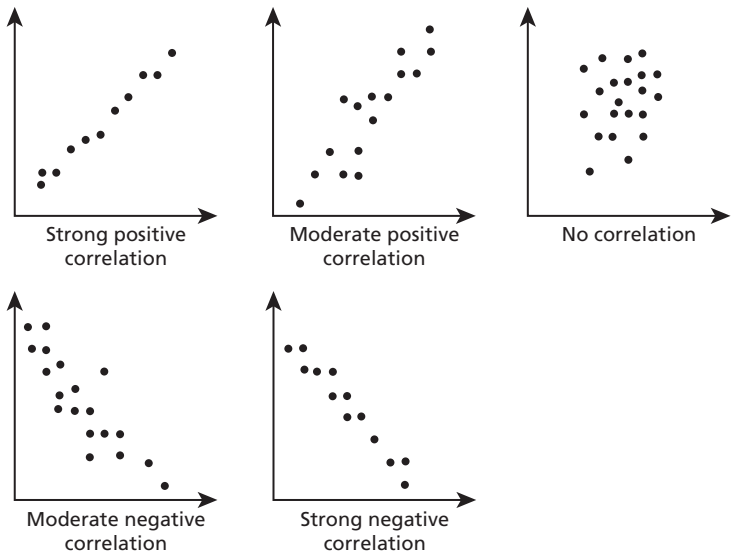


Figure 11.15 ▶ Graphs are useful when looking for correlation between factors.

Beware the misuse of statistics

When analysing arguments based on statistical evidence, beware of fraudsters. Statistics can be misused to play with data and misrepresent outcomes so they support an argument. Sometimes data are 'cherry picked' (used selectively) to prove a point. In this case the data are misrepresented, as only some data are presented while other data are omitted. Sometimes the population sample is too small to make confident claims. This is why it is important to draw on valid and reliable sources of data when conducting an investigation and to always interrogate the data yourself.

Statistics should be well presented, making clear for the audience how the data have been interpreted or how the data apply to the argument. Data should never be changed or manipulated to make them support your argument. Remember, another group may wish to replicate your findings to test the reliability of your data. Presenting unreliable data can damage your professional integrity permanently. Unexpected data that are valid and reliable are as important as expected data as they lead to new ideas and can change the direction of focus in a study.

RECALL

- Statistics are used to analyse data and measure expected outcomes for a full population based on a sample of the population.
- Increasing sample size and replicating procedures decreases the margin of error, making results more statistically reliable.
- Describe the statistics used to analyse data in reports, including measures of mean, median, mode, range, margin of error, correlation and causation.

ACTIVITY 11.5

USING STATISTICS TO ANALYSE A DATA SET

Consider the following hypothetical data set for 14 consumers who participated in a study relating to attitudes to cloning.

Participants were shown two statements:

Statement 1: 'I am willing to consume milk products from cloned animals.'

Statement 2: 'I trust the government to properly regulate the use of animal cloning.'

Participants were asked to rate the statements using a 5-point scale:

1 = strongly disagree, 2 = somewhat disagree, 3 = neither agree nor disagree, 4 = somewhat agree, 5 = strongly agree.

Their ages and responses are shown in Table 11.5.

Table 11.5 Consumer responses to two statements on cloning

Age	Response to Statement 1	Response to Statement 2
36	5	4
32	2	1
46	5	4
21	2	1
50	1	2
48	4	4
38	2	3
31	2	1
48	5	4
58	5	4
36	1	4
74	5	4
50	4	4
48	3	4

We can use statistics to analyse these results. Table 11.6 provides an example for calculating the mean, median and mode for age and results for statement 1.

Table 11.6 Measuring central tendency for age and responses of participants relating to willingness to consume milk products from cloned animals

	Measure of central tendency for age	Measure of central tendency for statement 1
Mean	$= \frac{\text{sum of all values}}{\text{number of values}}$ $= \frac{616}{14}$ $= 44$	$= \frac{\text{sum of all values}}{\text{number of values}}$ $= \frac{46}{14}$ $= 3.3$
Median	Arrange from lowest to highest value: 21, 31, 32, 36, 36, 38, 46, 48, 48, 48, 50, 50, 58, 74 Select middle value(s): 46 & 48 $\frac{(46 + 48)}{2}$ $= 47$	Arrange from lowest to highest value: 1, 1, 2, 2, 2, 2, 3, 4, 4, 5, 5, 5, 5, 5 Select middle value(s): 3 & 4 $\frac{(3 + 4)}{2}$ $= 3.5$
Mode	Arrange from lowest to highest value: 21, 31, 32, 36, 36, 38, 46, 48, 48, 48, 50, 50, 58, 74 Find the most common value: 48	Arrange from lowest to highest value: 1, 1, 2, 2, 2, 2, 3, 4, 4, 5, 5, 5, 5, 5 Find the most common value: 5

Questions

1. What is the range in ages for the sample population tested?
2. What is the margin of error for this sample size? (see Table 11.4)
3. Reflect on the values for mean, median and mode for the scores of statement 1. A report stated that the average response was 5. What message does this give to the audience? Is this an accurate reflection of responses in the data set? What type of pressure group might provide this average to support their cause or argument?
4. Calculate the mean, median and mode for the scores participants gave to statement 2. What is the most common response given by participants? Is this similar to the mean response?
5. Divide the audience into two groups based on age. Group 1 participants are under 40 years of age and group 2 participants are over 40 years of age.
   a. Calculate the mean, median and mode for each statement for group 1.
   b. Repeat this for group 2.
6. Provide the range of ages for each group in Question 5 and their range of responses to each statement.
7. Is there any correlation emerging between age and attitude to cloning? If so, write statements to indicate the statistical correlation.
8. Is there any correlation emerging between each statement?
9. Can you be confident of cause and effect for any observed correlation? Discuss this with reference to sample size, margin of error, study type and other contributing factors that could affect attitudes to cloning in a population. What further information might you need in order to establish cause and effect?

Presenting scientific data and concepts

A number of methods are used to present scientific data to an audience. There are accepted ways to represent scientific content, concepts and data that are recognised by the scientific community. These include tables, graphs, diagrams and models.

Presenting data using tables

Scientific tables are used when you want to show how a single factor is affected over space or time. For example, a table listing countries currently using cloning technologies would show the effects of space, while a table describing how the use of cloning technologies is increasing would show the effects of time. The first column lists the independent variable (the factor manipulated by the scientist) while the second column lists measurements of the dependent variable. Often tables will present data that have already been statistically analysed, keeping the data set small and easy to analyse. Tables should be numbered sequentially and have a clear title indicating what is measured and where the data came from.

WORKED EXAMPLE 11.6

Using tabulated data to support arguments

The following example illustrates how tabulated data are used to support arguments in reports.

A report on Trade and the Australian Dairy Industry released by Dairy Australia and the Australian Dairy Industry Council Inc. (2013) revealed that a mean 9.5 billion litres of milk is produced by Australian dairy farms annually. Of this, 40% is exported, generating $2.7 billion annually. Table 11.7 reveals that Australia's key markets are South-East Asia, Japan and other Asian countries including China.

In China the demand for dairy increased from 580 000 tonnes in 2007 to 1.6 million tonnes in 2012 (Table 11.8). Rising populations, increased wealth and changing diets in developing countries are contributing to an increased demand for dairy products. This offers an opportunity for dairy farmers and producers to increase production, thus increasing export revenue.

Table 11.7 Key dairy export markets and their value to the Australian economy in 2012. (Adapted from a 2013 report on Trade and the Australian Dairy Industry compiled by Dairy Australia and the Australian Dairy Industry Council Inc.)

Region	Value of Australian dairy exports ($A million)
South-East Asia	816
Japan	518
Other Asia	698
Europe	57
Middle East	347
Africa	54
Americas	105
Other	162

Table 11.8 Chinese imports of dairy products for 2007–12. (Adapted from Dairy 2013 situation and outlook report by Dairy Australia.)

Year	Dairy produce imported by China ('000 tonnes)
2007	580
2008	620
2009	910
2010	1 100
2011	1 300
2012	1 600

Using graphs to present data and support claims

A graph can be useful in providing an overall picture of data sets so we can explore patterns and trends. You can borrow or adapt graphs from reliable sources if you reference them, or you may choose to construct your own. Each graph should have a title that captures the trend being investigated. Graphs should be numbered sequentially and be as close to the relevant text as possible. Make specific reference to each graph using its figure number. Guide the audience in interpreting the graph. Let them know where the data came from and if the study was valid and reliable. What does the graph tell us? Make reference to specific points that support your interpretation of the data.

Bar graphs are used to display the frequency or other measures such as mean for discrete groups or categories. The *x* axis does not have a scale, as it represents the different categories. The *y* axis does have a scale and indicates the units of measurement. The lengths of the different bars are proportional to the size of the category they represent.

WORKED EXAMPLE 11.7

Referring to bar graphs in reports

A study by Liu et al. (2013) was conducted to determine whether the individual genetic characteristic of nuclear donor cells is an important factor in cloning success. Donor cells were collected from ear skin of five dairy cows, labelled F1 to F5. The results shown in Figure 11.16 reveal that the relative success rate of cloning is very low for all donor cell lines. However, the number of surviving offspring varied depending upon the animal from which the donor cell originated. Donor cells from animal F5 had a higher success rate than donor cells from animal F2.

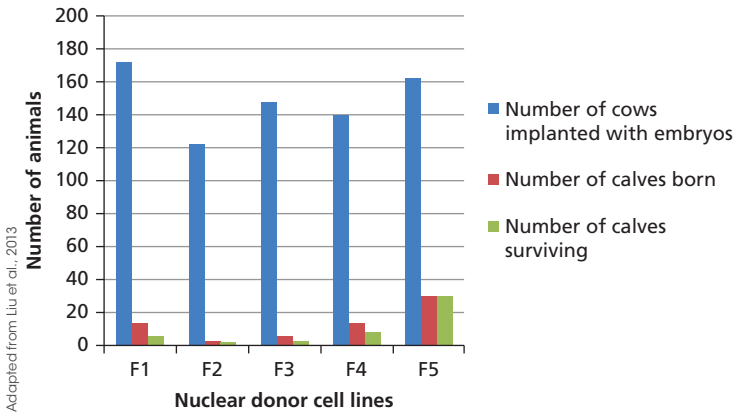
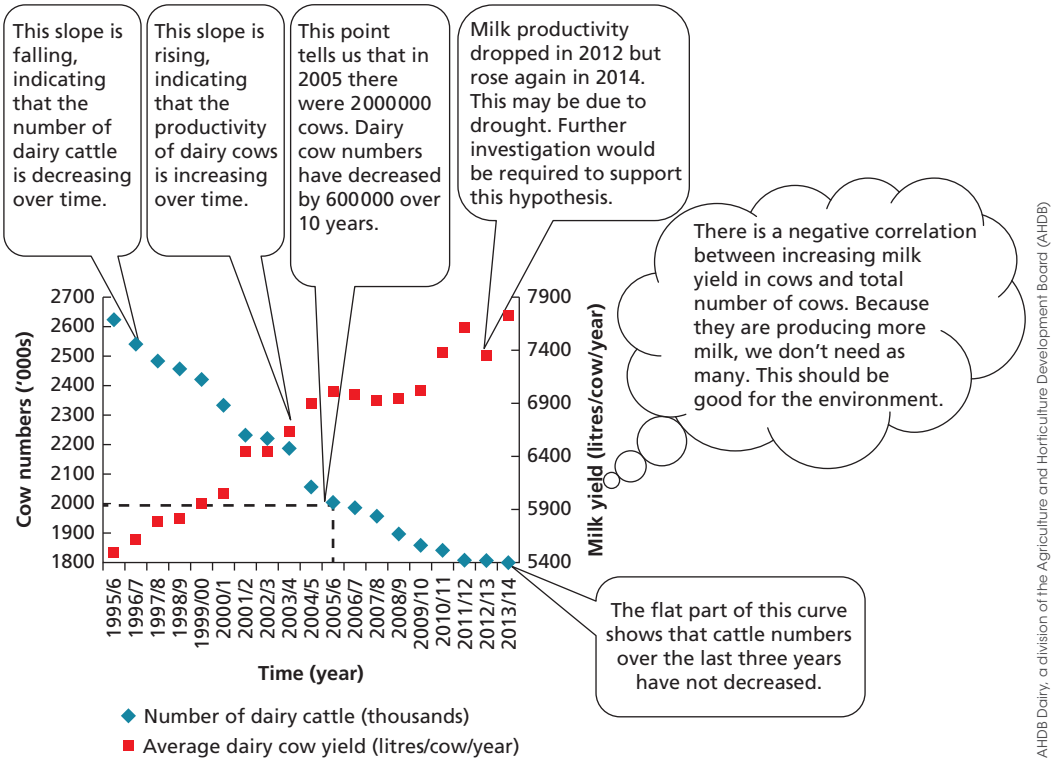


Figure 11.16 ▶ The relative cloning success rate for nuclear donor cell lines obtained from five dairy cows. (Adapted from Liu et al., 2013.)

Line graphs are used to show how a variable changes in response to a continuous variable such as time or distance. They are useful for identifying patterns and trends in the data. Several data series can be plotted on the same chart, and this is very useful when comparing trends in different data sets (Figure 11.17).



AHDB Dairy, a division of the Agriculture and Horticulture Development Board (AHDB)

Figure 11.17 Improving the milk yield genetics of dairy herds has contributed to reductions in dairy cow numbers in the UK. (Adapted from DairyCo organisation website, UK, based on data collected by the Department of Environment, Food and Rural Affairs.)

Scatter plots are used to show the relationship between pairs of numerical data, such as height and age. A scatter plot dot is added for each measure taken. You can then analyse the dots to look for patterns. Sometimes you can draw a line of best fit to reveal relationships and trends in the data. Line graphs and scatter plots are useful for detecting correlation between two factors (Figure 11.15).

Pie charts are used to show how the total data are distributed between the measured categories. They visually reveal proportions or percentages of each category for the whole data set.

WORKED EXAMPLE 11.8

Constructing and analysing pie charts

Brooks and Lusk (2011) conducted a cross-sectional survey of US consumers' attitudes towards farm and animal cloning. A total of 2256 participants were randomly selected to complete an online survey. This gives the data a margin of error of ± 2%. One survey question asked participants what they considered the relative importance of various objections to cloning. The results are shown in Table 11.9 on page 358.

Table 11.9 Relative importance of competing objections to farm animal cloning. (Adapted from Brooks & Lusk 2011.)

Statement that best represents objections to animal cloning	No. of participants selecting statement	%
Cloning will result in unhealthy farm animals.	115	5.1
Meat and milk from clones and their offspring are unsafe to eat.	95	4.2
Cloning is 'unnatural' because it is not a process that occurs in nature.	539	23.9
Cloning will lead to human cloning.	465	20.6
Cloning results in animals being viewed as 'objects' to be produced as opposed to being valuable in and of themselves.	336	14.9
Animal cloning is morally wrong.	296	13.1
Cloning will reduce genetic diversity to an unacceptable level.	237	10.5
The scientists and biotechnology companies who developed cloning technology cannot be trusted to look out for my best interests.	174	7.7

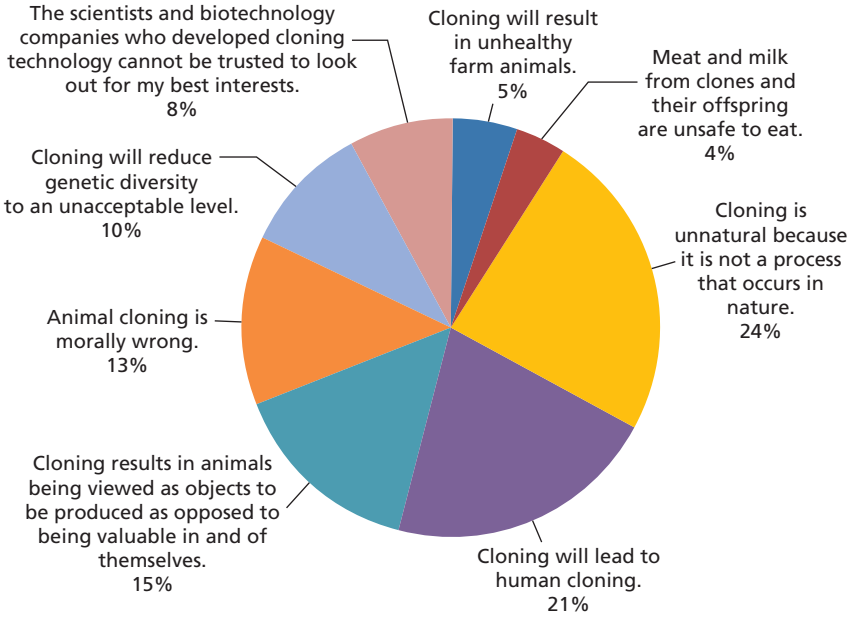
This information can be clearly represented to an audience using a pie chart. To construct a pie chart, determine the percentage of the total for each statement. This has been done in column 3 of Table 11.9. To calculate the percentage, take the number of responses for a particular category and divide by the total number of responses (in this case 2256). Then multiply the answer by 100.

Spreadsheet software such as Microsoft Excel can then be used to construct a pie chart. If using Excel, add the required data to a spreadsheet. Select this data and then choose 'pie chart' from the 'Insert' options. Take some time to explore what you can do with graph formatting options in this program.

Next you need to analyse the data in the chart for your audience.

Figure 11.18 shows the competing objections US citizens have to cloning. The strongest objection is that 'Cloning is unnatural because it is not a process that occurs in nature' (24%), followed by 'Animal cloning will lead to human cloning' (21%). While somatic nuclear transfer is not a natural process, clones do occur naturally in nature (identical twins are clones). It is possible that this objection could be mitigated through transparency and education programs. Two points of interest emerge when considering the lesser objections. First, only 5% of respondents rated 'Cloning will result in unhealthy farm animals' as their strongest objection. This is currently the major scientific obstacle to using cloning technology. Second, only 4% rated 'Milk and meat from offspring of clones are unsafe to eat' as their strongest objection. This has implications concerning labelling laws, which are costly and difficult to instigate and maintain.

Figure 11.18 ▶
Relative importance of competing objections to farm animal cloning



ACTIVITY 11.6

CONSTRUCTING AND ANALYSING LINE GRAPHS

The following tabulated data are taken from a review of trends and future prospects of livestock production by Philip Thornton (2010). You will use this data to construct and analyse a line graph.

Table 11.10 Past and projected trends in consumption of milk in developing and developed countries. (Adapted from Thornton 2010.)

Year	Annual consumption total in developed countries (metric tonnes)	Annual consumption total in developing countries (metric tonnes)
1980	228	114
1990	251	152
2000	265	222
2015	273	323
2030	284	452
2050	295	585

Follow these steps to construct line graphs for this data.

Step 1: Draw an *x* axis and *y* axis for your graph. Draw 10 equidistant increments on the *y* axis and 8 on the *x* axis.

Step 2: Label the *x* axis with the independent variable, in this case 'Year'. Label the *y* axis with the dependent variable, in this case 'Annual dairy consumption (metric tonnes)'. Always include units in brackets where possible.

Step 3: Work out a scale for the *y* axis. The scale is the number value for each increment on the axis of a graph. Typically the scale increases by increments of 1, 2, 5, 10, 25, 50 or 100, as it is easier to work with data using these figures. To calculate the most appropriate scale to use, determine the range of values for the variable represented by this axis (let's say the lowest value was 0 and the highest value was 585). Divide the range of variables by the number of increments. This yields a value of 5.85. Round up to the nearest ideal increment scale to use. In this case the scale would increase by 10 for each increment. Draw this on your graph.

Step 4: Give the *x* axis a scale. Be mindful that the start value for axes is not always zero, especially if the data begin at a much higher value. In this case start with the year 1980.

Step 5: Give your graph a title that clearly describes the content. Remember to always number tables and graphs so you can refer to them in reports and presentations.

Step 6: Plot the two separate data sets on your graph: the data for developed countries and the data for developing countries. When more than one data set is plotted on a graph, label each data set clearly using a key. You should also use different plot symbols or colours for each data set so it is clear which points belong to each data set.

Step 7: Reference the source of the data. Provide the dates for data collected if you conducted the study. Or cite secondhand data taken from another source.

Analyse the graph

To analyse the graph, start by looking at what the graph is showing and how it relates to the question under investigation. By reading the title and axes labels you can determine what was measured. Next you want to look for trends in the data. For line graphs look at the slope of the line. If it is going upwards, it is positive. If it is going downwards, it is negative. If one of the axes is a measure of time, you can calculate the rate of change by dividing the amount the line has risen or fallen by the time margin being measured. Often you will need to compare results of two groups at a particular time. Or you may compare trends in two groups if comparing slopes of graphs. Always include the units of measurement when you analyse graphs.

RECALL

- Tabulated data and graphs are used to organise and explain observed phenomena.
- Tables and graphs clearly demonstrate the importance and implications of findings and can be used to support arguments and claims in scientific reports.

Use of models in biology

Biological **models** are used to illustrate, explain and predict the structure and behaviour of biological objects and systems. They are representations that demonstrate aspects of function, mechanism or causality. They are substitutes for the real system or object that they are built to represent, making them easier to experiment with and learn from. This also means that they are not always 100% accurate. Science relies on construction, use, critique and revision of models to advance knowledge.

Constructing and using biological models

It can be useful to create a model to test and explain theories, to describe the structure and function of a biological object, to describe biological concepts, to represent biological systems or to predict the impact of one factor on another.

We can view chromosomes using microscopes but we have never actually seen the structure of DNA. Yet we can observe and manipulate physical models of DNA to help us understand how it functions as the genetic material of the cell. In 1953, Watson and Crick built a physical model to propose a theory for the molecular structure of DNA. How did they come up with this model? Upon viewing the results of a number of experiments, they had a conceptual model in their heads that explained these results. They built the physical model to test and subsequently present their theory, which was accepted by the science community.

Visualisation models can be used to link data with graphics, to help scientists construct theories, make predictions and explain phenomena. During the 1854 cholera outbreak in London, Dr John Snow recorded data on a map of London to track a cholera outbreak (Figure 11.19). This statistical map modelled the spread of the disease. He used it to convince authorities that cholera was transmitted through water. Three main observations supported his theory. First, there was a concentration of outbreaks around the Broad Street well. Second, workers from a nearby beer factory who drank beer instead of water did not get cholera. Third, a new outbreak started in a different part of town after a woman washed the nappy of an infected child in a well.

Mapping disease today uses computational models. Computational models can deal with vast amounts of data at any one time, making them powerful predictive models. Some predictive models help us to forecast the future state of a system, which is useful in the debate of issues. They can forecast the spread of disease, the effects of climate change, and the impact of change on an ecosystem or the economy. They help us to understand how actions might affect the future. Data collected through observation and experimentation are added to computer programs. Mathematical computation identifies and generalises patterns, so the behaviour of systems can be simulated. Computer programs can be used to compare sequences of DNA, predict protein structures and make model viruses to help us investigate disease.



Science Photo Library/British Library

◀ Figure 11.19
A reproduction of John Snow's map showing cases of cholera in red and pumps marked as Xs. The cluster of cholera cases around the Broad Street pump strongly suggests a link between the water and the disease.

Critiquing and revising biological models

Models are often made for a specific reason. Revisions are made using new data when they are used for a different purpose or when new evidence arises that does not fit the model.

The first food pyramid was published in Sweden in 1974 (Figure 11.20). It was a descriptive model advising on basic nutrition during a time when food was very expensive. It was triangular, so consumers could visualise suggested portions of each food type. It had three levels: basic foods at the base, including dairy and cereals; fruit and vegetables on the next level; and meat and fish at the top. The US Department of Agriculture released a new food pyramid in 1992. It was created to advise on eating habits based on knowledge gained from studying the relationship between diet and disease. It had six sections and recommended how many portions of each should be consumed. Critics of this model remark on two factors they believe were added due to pressure from lobby groups. First, dairy now had its own section, indicating that dairy is necessary in the diet. Many cultures in the past and vegans live without non-human dairy in their diet. Second, the recommended intake of cereals was 6–11 servings. The nutritionist designers who had recommended 3–4 serves believe this was increased due to pressure from the wheat and corn industry. Nutrition models continue to be revised in response to new experimental findings. The National Cancer Institute later used evidence to have the portion of fruit and vegetables raised from 2–3 to 5–7.

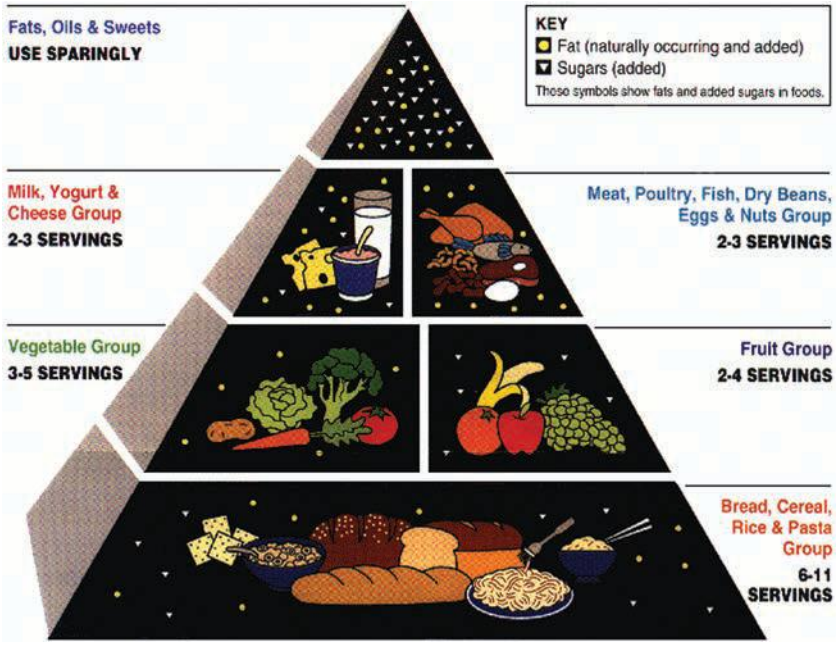
Figure 11.20 ▶
The food pyramid model has been modified over time. **(a)** The first food pyramid, published in Sweden in 1974. **(b)** Food pyramid released by the US Department of Agriculture in 1992, which critics claim was influenced by lobbyists in the dairy and wheat industries.

a



Coop - The Swedish Cooperative Union, The KF Group, archive and library/Leif Brandt

b



USDA, Center for Nutrition Policy and Promotion

RECALL

- Models are important simulations of biological objects and systems. They are used to advance scientific knowledge through testing hypotheses and predicting outcomes.
- Models are not always accurate because there may be data missing. As new discoveries are made, scientists refine models to suit the new information.
- Critiquing models improves their suitability for a particular use.

ACTIVITY 11.7

CONSTRUCTING A MODEL TO COMMUNICATE UNDERSTANDING

Methane emissions from cattle contribute to global warming. A study by Grainger et al. (2007) used respiration chambers to measure the methane emissions of 16 lactating dairy cows. They found that these cows released a mean value of 322 g of methane per day.

Using this information and the information in Figure 11.17 we can construct a model that illustrates the effect that improving milk yield genetics has on global warming.

The data in Table 11.11 were generated using Figure 11.17 to determine the number of dairy cattle in the UK and average milk yield per dairy cow. The total number of cows was then multiplied by the average methane emission per cow (322 g) to determine total methane emissions per day.

Table 11.11 Daily methane emissions by UK dairy cows

Year	Number of dairy cattle in the UK (`000s)	Milk yield per dairy cow (litres/cow/year)	Total methane emission (millions of grams/day)
1995	2600	1820	837
1997	2500	1950	805
1999	2450	2000	789
2001	2220	2180	715
2003	2200	2280	708
2005	2000	2380	644
2007	1980	2350	638
2009	1850	2380	596
2011	1800	2600	580
2013	1800	2650	580

Step 1: Construct a graph to model the effect of increasing milk yield per cow on total methane emissions. Be aware that dairy cattle produce milk only after calving and then for around 305 days. They do not produce milk 365 days a year. Your graph may require two *y* axes, one on the left and one on the right of your graph.

Step 2: Analyse and critique your model.

Step 3: Present your model to a family member or friend. Do they have any questions that the model does not answer?

Step 4: Make revisions to your model as required.

Using ethical principles to investigate issues in science

Prior to the 1970s, decisions about medicine and scientific research were largely left to doctors and scientists. Concerns emerged about research being conducted on minority groups such as prisoners, orphans and the mentally unwell, and on unaware citizens by the military. In response, the field of **bioethics** was established to address ethical questions concerning **morals**, **values** and social responsibility relating to research and practices in biology. A paper called the Declaration of Helsinki was released in 1964, providing **ethical principles** for the protection of human subjects of biomedical and behavioural research (Figure 11.21 on page 364). Table 11.12 outlines these ethical principles, which provide a framework for analysing issues in biology.

Figure 11.21 ▶
The declaration of Helsinki in 1964 provided the first ethical principles to guide medical research involving human subjects.



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Table 11.12 Ethical principles as a framework for analysing issues in biology

Guiding principle	Description	Considerations
Individual rights	Every individual has the right to autonomy – to be their own person and choose their own course of action	Are the individual rights of all individuals considered and respected? Is informed consent provided? Is there respect for privacy and confidentiality?
Beneficence	A duty to do more good than harm. To consider the welfare of the research participant	Who will benefit from this technology? How will they benefit (can include physical, psychological, economic or social)? How many will benefit?
Non-maleficence	The duty not to cause harm	Who might be harmed by this technology? How are they harmed (can include physical, psychological, economic or social)? How many are harmed? Is it possible to minimise the harm?
Justice and equity	Fair and equitable treatment for all	Can everyone have equal access? How can discrimination be avoided?

Some major ethical questions currently debated by science and society include the following:

- Who owns human biological samples? What rules should guide the use of human biological material for research and laboratory diagnosis?
- How do we monitor therapies being offered and the associated risk to patients?
- What does it mean to be human and when does human life begin?
- The clinical use of stem cells – how can we best monitor the validity of therapies being offered and assess the risks?
- Should we invest in anti-ageing research and assisted reproduction? How can we sustain a growing and ageing population?
- The use of animal models in research and industry – what kinds of experiments, what animals, and what considerations are there for the welfare of these animals?
- Genetic engineering – for what organisms (including humans) should this be used, and under what circumstances? What are the benefits and the risks?
- Who owns the results of scientific research? What regulations should we have for **patents** on biological materials?

Guidelines for making decisions on ethical issues

Decisions about the ethical application of biotechnology are often difficult because of conflicts between different individuals' values, beliefs and cultural experiences. Such decisions are informed by science but cannot be made purely by scientific study and observation. A number of frameworks have been developed to guide decision making for the application of biotechnology. These frameworks vary in their methods and underlying ethical approaches but they share a common purpose. They enable the decision maker to evaluate conflicting points of view in order to reach a judgement that is supported by logic and reason.

When investigating an ethical issue, use the following steps as a guide to making a decision:

Step 1: Identify the issue or decision to be made and who must make the decision.

Step 2: Describe the technology and practice that is causing the issue and why it raises moral dilemmas.

Step 3: Present the facts. What information is needed to make an informed decision about this issue?

Step 4: Present opinions. What is your opinion about the use of this technology and why? Has your opinion changed over the course of your investigation? If so, why? What opinions do others have about this technology?

Step 5: Determine which groups are affected by this issue. How are they affected and how many? Provide evidence for this. What values and priorities do these affected groups have?

Step 6: Are there alternative outcomes for this issue? What are the advantages and disadvantages for each affected group if we consider these alternatives? Are there any unacceptable outcomes? If so, why?

Step 7: Make your decision and compose your arguments to present to your audience.

RECALL

- New ideas and technologies in biology have social, economic, legal and ethical impacts. Decisions about the ethical application of biotechnology can be difficult, as different values and beliefs arise.
- The ethical principles of individual rights, beneficence, non-maleficence, justice and equity provide a framework for making ethical decisions in biology.

WORKED EXAMPLE 11.9

Evaluating an issue: The facts, stakeholders and alternatives on cloning of animals in agriculture and the labelling of products derived from cloned animals

Step 3: Present the facts. What information is needed to make an informed decision about this issue?

Is cloning unnatural?

The European Food Safety Authority (EFSA) reasoned that prize cattle and their cloned offspring are essentially like genetically identical twins, except that they were generated by technical intervention (2008). Gestation, birth and nurturing are in principle like those for offspring of sexually bred or artificially inseminated cattle.

Why is animal cloning used in agriculture?

In 2015 the US Food and Drug Administration (FDA) stated that commercial cloning has been standard practice in the United States since the late 2000s. The clones of animals with desirable traits are used primarily for their semen to sire offspring, rather than directly for food. Cloning extends the breeding line from a single animal beyond the original animal's normal reproductive life. Semen can be sent to dairy farms around the world to artificially inseminate cattle and improve herd genetics for a number of traits including increased milk yield, improved nutrition rate, increased resistance to mastitis and reduced methane output.

Is the health of the cloned animals compromised?

According to a report by the EFSA (2008), cloned calves have more health complications than typical calves. Worked example 11.4 discusses problems for newborn calves and the recommendation for specialist veterinary care. Beyond 6 months, the health of surviving clones is not significantly different from that of other cattle. The offspring of clones (derived from sperm or eggs of clones) are as healthy as normal cattle.

Does cloning result in increased milk yield?

See Worked example 11.5 for a study about a clone having poor milk yield but its offspring having milk yield similar to the prize cow. Cloning contributes to improved dairy herd genetics, which contributes to improved milk yields (Figure 11.17). However, the increased milk yields observed to date have been mostly attributed to other biotechnology techniques.

Is demand for dairy products increasing?

Refer to Worked example 11.6 for evidence that demand for dairy is increasing in developing countries, providing an opportunity for economic stimulus through increased exports if enough dairy can be supplied.

Are products from cloned animals safe to consume?

In 2008, the US FDA released a report declaring that products derived from cloned animals were no more harmful to consume than those from conventional farm animals. Its conclusion was based on a review of 'hundreds of reports' on the practice and products of cloning. In the same year, the EFSA (2008) reached the same conclusions. Food Standards Australia and New Zealand (2011) subsequently endorsed the views of the two international reports.

How easy is it to monitor and control the quality of products derived from cloned animals in product supply chains?

The EU argues that monitoring and control are unenforceable. The following proposals have been made to monitor for clone products: shortened supply chains, more extensive DNA testing, and enhanced use of computer tracking of animals and products. All add labour costs, require purchase of equipment, and affect import and export markets.

Step 5: Determine the stakeholders. What groups are affected by the technology? How are they affected? What values and priorities do these affected groups have?

Scientists and technology developers

These people research, develop, patent and market the technology for commercial application to maximise profits for their investment in research and development. Many believe this is a solution to the problem of emerging demand for foods outstripping supply.

Farmers and cattle breeders

Farmers are guardians of their animals' welfare, seeking to provide the best care and conditions for their livestock. They have an interest in delivering the best quality food, and in maintaining trust with the supply chain and the public. Their livelihoods depend upon sale of their product. Some invest in cloning technology to improve herd genetics and, therefore, productivity. There may be equity issues relating to the affordability of cloning technology. Some farmers are against the use of cloning technology and use other technologies or traditional methods to improve herd genetics.

The clones, their surrogates and their offspring

These are the animals whose health may be affected by cloning. Ideally, they should experience the highest standards of care. As their advocates, animal rights activists are the human representatives of this group.

Suppliers and retailers of food products

After the primary product leaves the farmer it travels along the supply chain to be processed, packaged and sold. Businesses along the supply chain depend upon a sustainable supply of products from the farmer. It can be argued that the supply chain owes it to consumers to provide transparent labelling of food products. Exposed cases of mislabelling destroy consumer trust, and businesses and farmers suffer lost sales.

Consumers

Consumers' health and wellbeing are linked to the foods they eat and the values they attach to those foods. They depend upon a continuous supply of food reaching the market. Their demands vary widely. Preferences can include the look and taste of the food, its nutritional content, and the practices that have brought the food to their table. Some people have religious or ethical beliefs that inform their diet. Advice about the origin and content of processed foods for sale enables consumers to make informed choices about what they buy and eat. Because of their buying power, consumers represent a powerful stakeholder group that shapes the actions of farmers and the supply chain.

Step 6: The following alternatives could be explored.

Alternative 1: Continue animal cloning but omit identification of products from cloned animals in food labelling.

Alternative 2: Ban animal cloning for agriculture.

Alternative 3: Continue cloning animals for agriculture and apply more stringent supply chain integrity and food labelling.

ACTIVITY 11.8

EVALUATING AN ISSUE TO ARRIVE AT A DECISION

Evaluate the issue that you identified in Activity 11.1. To do this, follow the steps that guide decision making concerning ethical issues. Steps 1 and 2 were completed in Activities 11.1 and 11.2. Build on this to make your decision by addressing steps 3–7 as detailed below.

Step 3: Present the facts. What information is needed to make an informed decision about this issue? Outline the scientific, financial and legal details that apply to the issue. Consider what scientific evidence is needed to confirm or refute the potential benefits or risks associated with the technology. Outline other information that would affect the decision, such as laws or costs of implementation. Gaps may remain because the relevant studies are inconclusive or relevant studies have not been done yet.

Step 4: Present opinions. These statements relate to the moral, cultural or social implications of the issue. Some of these may be integrated with facts, others may be emotional or philosophical. Form your own opinion. You may have an immediate 'gut' feeling about the issue, but your opinion may change as you explore and reprioritise diverse opinions and consider the facts. Your developing viewpoint will shape your final decision.

Step 5: Determine which groups are affected by this issue. Consider the facts and opinions and whose interests they represent. These groups of individuals are the *stakeholders* – those with a vested interest in the outcome of the decision. Demonstrate how each group is concerned with the decision. Connect each group with facts and opinions to support their claim as stakeholders. In some cases, stakeholders are a diverse group that may have conflicting values.

Step 6: Develop alternative outcomes and critically evaluate each one by taking account of the available facts, by prioritising opinions, and by analysing the effects on the stakeholders' interests using the guiding principles of personal rights, beneficence, non-maleficence and justice for all.

Step 7: Make your decision and develop a plan for how to present your arguments to your audience. For each argument, prepare the evidence that you will present, and remember to include competing opinions and analyse the evidence. Conclude by deciding which of the outcomes you would argue for and the reasons why. Your justification should reflect the guiding principles to maximise benefit and minimise harm for as many people as possible, as well as the values you would prioritise most.

Communicating your results

Once you have conducted the research, analysed the evidence, considered associated ethical dilemmas and made your decision about the issue under investigation, you need to think about the best way to present your arguments. Begin by deciding on your target audience.

Appropriateness for purpose and audience

Communicating ideas to an audience can only be done well when you have a clear outline of what you want to communicate and who you want to communicate with. Ask yourself: What do you hope to achieve through this communication? What is your message? Who do you want to persuade? Once this is decided, you need to consider the expertise of your audience, why they want the information, and their attitude towards you and the subject matter. Some examples of audiences include:

- experts in the field – have a shared understanding of scientific terminology relevant to their area of study, so it is not necessary to explain all biological terms. You may be adding new data to the field or providing a review of current knowledge.
- community members – will have mixed expertise, so it is important to explain biological terms and concepts clearly. Use narratives to provide context and to help your audience engage with the topic. Help them to distinguish between opinion, anecdotes and evidence.
- politicians and businesspeople – require clear reporting of data from valid and reliable studies explaining why these data should be used rather than data from less rigorous studies. Evidence and predictive models are used to support recommendations.



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Once you have identified your audience, try to see the issue from their perspective. It is always important to consider and respect those who may not share your opinion. In many instances this group is your target audience. How can you convince them to consider an alternative way of addressing the issue? Think about the information and evidence they may need to experience in order to connect with your arguments. Help your audience to recognise any cognitive bias and confirmation bias that they may have. Provide them with the range of opinions surrounding the issues and provide the authority behind these opinions. Explain how you made your decision through examining the evidence supporting competing ideas, by reflecting on values that inform your way of thinking, and by considering ethical perspectives.

Modes of communication

If using oral communication you have a captive audience that you can take on a journey of discovery, using logical arguments to articulate the issue. To keep your audience engaged you may decide to use props such as posters, images, interviews, film, animation or demonstrations to convey your message. Be certain that these elements don't distract the audience from your argument or confuse them unduly. Ask yourself whether the mode of communication is addressing the planned need. You can interact with the audience to clarify their understanding and to gauge how they feel about the issue under investigation.

Using written communication allows you to convince your audience using detailed evidence. They can choose to re-read components to reinforce their understanding. However, they can also be very selective about what they choose to read and what they choose to ignore. Keep this in mind when structuring your evidence. Written science communication can be in the form of a journal article, a media article, a blog or a poster.

More information on creating a scientific poster is provided in Chapter 12.

No matter which mode of communication you use, always consider the journey for your audience. When introducing the issue, capture their attention by providing a story that they can relate to. Give them some indication of your initial reaction to the issue and how you came to realise, as you conducted your research, that the decision was not an easy one. Let them know why the issue interested you and declare any bias you may have. Always respect your audience.

Retain your audience's attention by explaining scientific concepts and technologies clearly and succinctly. Build up your audience's knowledge in steps. If you begin with ideas and terminology that are too complex, your audience will be lost from the beginning and it will be difficult for you to reconnect with them. Using metaphors, diagrams, animations and models can help the audience to understand the science. Always clearly label or describe all components and remove any unwanted components that could distract the audience. Allow your audience enough time to digest a piece of information before moving on to a new piece of information. Stop and recap to remind the audience of the journey and describe how this understanding led to the next logical step in the argument.

Throughout this text, various skills in science communication have been introduced in the issues boxes in each chapter.

Checklist for investigating an issue

Identify an issue for investigation

1 Clearly identify an issue using the guiding questions in Table 11.1.
2 Write a problem statement to guide your investigation.
3 Record any bias or factors that may influence how you make decisions.
4 Record your initial thoughts and feelings, and make a list of questions that need further investigation. What do you need to know more about? What evidence do you need to collect?
5 Clearly explain the biology underpinning the issue.
6 Start a glossary of biological terminology and biological processes.

Conduct your research

7 Collect information from sources that will help you to answer the questions you composed in step 4. Use the Internet, books, journals and magazines to do this. Google scholar is useful when looking for scientific studies.
8 Start a reference list to record all sources. Table 11.2 provides guidance on using the APA citation method.
9 Summarise, paraphrase and quote ideas from each source. Remember to note the page number when you record a quote.
10 Evaluate science reports for bias, validity and reliability. Table 11.3 provides a guide for doing this. Clearly record your assessment of each source.
11 Collect evidence and present it as text, or in tables, graphs, diagrams or models.

Investigate the ethics

12 Use the ethical principles in Table 11.12 to identify any ethical dilemmas relating to the issue under investigation.
13 Follow the guidelines for making decisions on ethical issues, to arrive at the best alternative. Now you can plan your report.

Communicate your results

14 Identify your audience. It is a good idea to do this very early in your investigation.

15 Decide on the mode of communication that best suits this audience.

16 Prepare an outline to construct a clear argument for your audience. Indicate where evidence is required to support any claims you make. Include alternative views and an analysis of bias, validity and reliability of opinions.

Present data

17 If using evidence from scientific studies, use text or construct a flow chart or diagram to describe the study method.

18 Use tables and graphs to present and analyse data. You may take these directly from a study or construct your own.

19 Use statistics to strengthen your arguments, including measures of central tendency, margin of error, correlation and causation.

20 Follow the principles of effective science communication to prepare your report or presentation: accuracy of biological information; clarity of biological concepts, ideas and models; contextual clarity with reference to **importance** and implications of findings; **conciseness** and **coherence**.

21 Review your work. You could ask someone to review your work, or practise your presentation. Ask for constructive criticism.

CHAPTER GLOSSARY

annotated diagram a descriptive diagram with labelling to show specific parts, highlight sections or describe functions

authority an accepted source of information or advice, or an expert in a subject; quotations from such a source give credibility to ideas or an argument

bar graph a chart that uses bars to show comparisons between categories of data

beneficence an action done for the benefit of others; can be done by helping prevent or remove harm or by improving the situation of others

bias a preference for a particular outcome that interferes with ability to be impartial, unprejudiced or objective; as part of the scientific method, scientists try to remove all factors that could introduce bias

bioethics the application of ethics to the science and practice of biology

blind study an experiment where information about the test that could lead to bias in results is concealed from participants; if it is also concealed from those taking measurements, it is a double-blind study

case study an in-depth investigation of a person, group, event or community where data are gathered from a number of sources including interviews and observations

causation using controlled experiments to determine the cause of an effect or the reason for a phenomenon

cognitive bias thinking errors that can prevent us from understanding reality even when confronted with the evidence to form an accurate view; the scientific method helps to eliminate cognitive bias

coherence the quality of forming a logically consistent argument, theory or policy

cohort studies studies that observe what happens to a cohort (a group of people who are linked in some way) that are all experiencing a particular variable compared to a group that has not had the experience

conciseness giving a lot of information clearly and in few words; from the Latin 'to cut down'

confirmation bias the tendency to search for and interpret evidence that confirms your existing beliefs or theories; can interfere with objectivity

correlation a statistical measure of the relationship or connection observed between two factors

critical thinking the objective analysis and evaluation of an issue in order to form a judgement

cross-sectional survey a descriptive study of a situation at one particular time that is used to provide information; does not attempt to explain why, as variables are not manipulated by researchers

demographic the statistical data of a population relating to factors such as age, sex, socioeconomic status, etc.

dependent variable the variable being tested in a scientific experiment; measured in response to the researcher changing the independent variable; generally is recorded on the *y* axis of a graph.

dogmatism the tendency to state principles as undeniably true without considering the evidence or opinions of others

double-blind study *see* blind study

equity the quality of being just and fair

ethical principles universal standards of right and wrong that guide decision making and actions; include the goals of equity, beneficence, least harm, respect for autonomy and justice

evaluate assess the significance, worth or quality of a thing

evidence the available body of facts and information that is helpful in forming a conclusion or judgement as to whether a belief or idea is true or valid

importance a measure of the significance or value of an idea, study or authority; how influential the idea or study is

independent variable the variable that is varied by the researcher during an experiment; usually found in the first column of a table and recorded on the *x* axis of graphs

issues points or matters of discussion, debate or dispute; personal or social problems or difficulties that require resolution

justice the quality of being fair and reasonable using the principles of moral rightness and decency

line graph a graph where the relationship between two variables is represented by a line; used for continuous data to reveal how a factor changes over time or over space

margin of error the maximum difference expected between a true population parameter and the sample estimate for that parameter

mean a measure of central tendency; the sum of all values divided by the number of values

median a measure of central tendency revealing the middle value in a range of values; determined by arranging values in numerical order and choosing the central value

misconception a view or opinion that is incorrect because of faulty thinking or understanding

mode the most frequent response or value in a data set

model a systematic description of an object or phenomenon that shares important characteristics with the object or phenomenon; used in learning, in the formation of scientific theories, for making predictions and for forecasting

morals the judgement of the rightness or wrongness of human actions and character

negative control a control group in an experiment in which no response is expected; the opposite of a positive control, in which a known response is expected

non-maleficence the principle that we should act in ways that do not cause harm or inflict suffering upon others

objective impartial; not influenced by personal feelings or opinions when considering and representing facts to make judgements or arguments

outlier something that lies outside the main body or group; in statistics, a value that is much bigger or much smaller than most values in a set of data

paraphrasing using your own words to express someone else's ideas or results; the idea is clearly someone else's but the writing is your own; a citation is required

patent the exclusive right granted by a government to an inventor to manufacture, use or sell an invention for a certain number of years

pie chart a type of graph where a circle is divided into sectors that represent a proportion of the whole; each sector represents the relative size of each value

placebo a substance that has no therapeutic effect, used as a control in testing new drugs

plagiarism duplicating the work of another person without referencing them, thus claiming their work or ideas as your own

population a set of individuals, objects or data from which a statistical sample can be drawn

positive control *see* negative control

pressure group a group that tries to influence public policy in the interest of a particular cause

professional association a body of people engaged in the same profession that control entry to the profession, maintain standards and represent the profession in discussions with other bodies

qualitative study exploratory research used to define a problem or develop an approach to a problem; used to gain an understanding of underlying reasons, opinions and motivations, and so focus groups, in-depth interviews and observation are often used to collect information

quantitative study research used to investigate a specific question using observable phenomena; tries to understand how prevalent a phenomenon is by sampling a large population or repeating experiments and analysing results using statistics to achieve an unbiased result that can be generalised to a larger population

quoting to copy text or speech word for word and acknowledge the source

randomised controlled trial a quantitative study where selected participants are randomly allocated to be either in a treatment group or in a control group

range the difference between the highest and lowest value in a data set

references list a list of the sources of information referred to in a report or presentation

reliable describes evidence gained from studies where the test was replicated a number of times, yielding consistent results, when an independent researcher can replicate the experiment and get similar results, and when the results are plausible, that is, they align with other evidence in the field

sample in statistics, a group drawn from a larger group (the population) that is used to estimate the characteristics of the whole population

scatter plot a graph in which the values of two variables are plotted along two axes, the pattern of the resulting points revealing any correlation

scientific concept a scientific theory or law that is a well-substantiated explanation of some aspect of the natural world; often generated using the scientific method and repeatedly tested and supported through observation and experimentation

scientific report an account of an investigation of a scientific phenomenon or issue designed to convey information to a particular audience

scientific table a method of arranging data for interpretation by an audience; the data are often statistically analysed

source a person or report from which evidence and ideas originate

summarising using your own words to shorten a report so that it only includes the essential information; should provide a clear indication of the main points made in the report

survey a series of questions designed to query participants in a study in order to collect data for analysis

valid describes evidence gained from studies using suitable and accurate techniques and equipment, with appropriate control of variables and randomisation; measured by evaluating the design of a study used to determine cause and effect; controlled laboratory experiments have high validity; studies in difficult to control environments are less valid; randomisation increases validity.

values important and lasting beliefs or ideals shared by the members of a culture about what is good or bad and desirable or undesirable.



CHAPTER 12
SCIENTIFIC INVESTIGATIONS

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

KEY KNOWLEDGE

Practical investigation

- the biological concepts specific to the investigation and their significance, including definitions of key terms, and biological representations
- the characteristics of scientific research methodologies and techniques of primary qualitative and quantitative data collection relevant to the investigation: laboratory work (microscopy), fieldwork (quadrats, transects and field guides) and/or observational studies of animal behavior; precision, accuracy, reliability and validity of data; and minimisation of experimental bias
- ethics and issues of research including identification and application of relevant health, safety and bioethical guidelines
- methods of organising, analysing and evaluating primary data to identify patterns and relationships including sources of error and limitations of data and methodologies
- observations and experiments that are consistent with, or challenge, current biological models or theories
- the nature of evidence that supports or refutes a hypothesis, model or theory
- options, strategies or solutions to issues related to organism or species survival
- the key findings of the selected investigation and their relationship to cytological and/or ecological concepts
- the conventions of scientific report writing including biological terminology and representations, standard abbreviations and units of measurement.

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Performing practical investigations is your chance to experience what doing science is really like. Science is about finding things out through observation and experiment, which is what doing investigations is all about. This is why investigations are central to science, and why they are so much fun.

Sometimes an important advance in science begins when an observant person with an enquiring mind notices something that might be scientifically interesting. For example, after hearing from milkmaids that people who contracted cowpox (a relatively innocuous disease picked up after working with cattle) were protected from deadly smallpox, the British physician Edward Jenner effectively kick-started the science of vaccination. Jenner used samples from open cowpox sores on a dairymaid's hands to inoculate a young boy and protect him against smallpox. However, it would be another 50 years and a lot of carefully planned research before scientists truly began to understand the biological basis of immunity. This sort of early observation may begin a new field of research, which then proceeds by carefully planned investigation.

Scientific investigations can take years to complete and may involve collaboration among many scientists. They may require access to special equipment in Australia or overseas. They may cost a lot of money, sometimes millions of dollars, to complete. Hence scientists invest time in *planning* investigations before they begin. When scientists apply for grants to carry out investigations they need to show that they have carefully planned what they will do and how any money provided will be spent. Good planning is crucial to the success of the investigation.

Scientists then make careful *measurements and observations* and record their *results*. They *keep records* of all their experiments. This is a legal requirement. Typically, experimental results need to be kept for 5–7 years. There are also requirements on how and where data are stored.

Once data are collected they need to be *analysed*. This is done in various ways, but in the biological and biomedical sciences it typically involves constructing graphs and performing statistical tests to determine mathematical relationships within the data.

Finally, the results of the investigation must be *communicated*. Usually this involves publishing a scientific paper either in a journal or in conference proceedings, or presenting the findings in talks or posters at conferences. If the result is funded by a grant then a research report must be submitted to the agency providing the funding. If the results are really exciting, the scientists may write a media release. However the results are communicated, this step must happen for the investigation to be completed.

Planning your investigation

There are many things to consider when planning an investigation. You need to think about how much time you will have inside and outside class. You also need to think about the space and equipment you will need, and where you will go if you want to make measurements or observations outside.

You may be working in a group or on your own. Most scientists work in groups. If you can choose who you work with, think about this carefully. It is not always best to work with friends. Think about working with people who have skills that are different from your own.

Finally, and probably the first thing that most students think about, is the topic of the research. You will need to come up with a research question or hypothesis.

Choosing a research question

Obviously, it is a good idea to investigate something that you find interesting. If you are working in a group try to find something that is interesting to everyone in the group.

A good way to start is by brainstorming for ideas. This is useful whether you are working on your own or in a group. Write down as many ideas as you can think of. Don't be critical at this stage. Get everyone in the group to contribute, and accept all contributions uncritically. Write down every idea.



Alamy/Jim West

Figure 12.1 ▶ Brainstorm as many ideas as you can in your group.

After you have run out of ideas, it is time to start being critical. Decide which questions or ideas are the most interesting. Think about which of these it is actually possible to investigate given the time and equipment available. Make a shortlist, but keep the long list too, for the moment. Once you have your shortlist it is time to start refining your ideas.

Scientific terminology

Right from the beginning when you start thinking about your research question, it is important to use the correct scientific terminology. Using accurate scientific words to describe and communicate your ideas is essential for getting across their precise meaning. Such scientific language is difficult for non-scientists to understand and, when it comes to communicating your research to a more general audience, you will need to choose words and phrases that can be widely understood. However, now that you are embarking on scientific research of your own, you need to show that you can understand and describe the relevant biological concepts using the terminology that scientists use.

For every biological concept, there are certain key terms that should be used for scientific communication, instead of general language. For example, in Chapter 4, you learnt about environmental niches. You might choose to conduct an investigation into the abundance of a certain species in a newly urbanised area. In such a situation, the new environment may have changed from an *optimal niche* to a *marginal niche* for the species. This would be the scientifically precise terminology for describing the new environment, instead of saying it had changed to become a *worse home* for the species.

There may also be scientifically appropriate ways of representing biological concepts that you should be aware of when planning, conducting and reporting your research.

Researching and refining your question

Having come up with a list of ideas, using appropriate scientific terminology, the next step is to find out what is already known about the ideas on your list. Use the Internet, your textbooks and the library to find out. Make sure you *keep a record* of the information that you find as well as the *sources*. You should start a **logbook** at this stage. You can write in **references**, or attach printouts containing the source information to your logbook. This can save you a lot of time later! Many research students forget to do this when they first start reading about their topic and then have to search all over again. Referencing is discussed in more detail in Chapter 11 and later in this chapter.

Be critical of what you read. Do not assume that everything you read online or even in books is true. Try to find **reliable** sources of information. Textbooks and websites from universities and government research agencies are usually very reliable. Publications and web pages from professional associations, such as the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australian Academy of Science and equivalent international organisations are also good sources. Blogs and homepages of other students are not always reliable, although they are useful to give you ideas. Websites that are trying to sell you something should also be treated sceptically. Talk to your teacher about sources of information as well. They will be able to tell you if a website is reliable, and suggest sites that they know are suitable.

See Chapter 11 for more on evaluating the reliability of sources.

You may find examples of investigations that are similar to the one you are thinking of. It is a good idea to look at these, so you can learn from the experience of other researchers. However, in general, it is better not to try to replicate someone else's investigation exactly. If you do decide to replicate someone else's investigation, even a part of it, then you need to acknowledge and carefully reference their work. If you do not do so, it is **plagiarism**. This is a very serious form of academic misconduct. Talk to your teacher about how original your research needs to be, and how closely it can be based on someone else's work. It is much better to do this at the start than to be accused of cheating later on!

Finally, talk to your teacher about your ideas. They will be able to tell you whether your ideas are likely to be possible given the equipment available. They may have had students with similar ideas in the past and can make suggestions.

After you have researched your questions and ideas, you will hopefully be able to narrow the shortlist down to the one question that you want to tackle. If none of the questions or ideas looks possible (or still interesting), then you need to go back to the long list. You may need to read and gather more information on your topic of interest and then have another brainstorming session before you find an interesting, original and feasible research idea.

Proposing a research question or hypothesis

Once you have decided on what you will investigate, you need to turn it into a research question or a hypothesis. Make sure you check with your teacher about what kind of investigation or project you are supposed to be doing.

A good research question identifies the **variables** that will be investigated. Variables are factors or features that can vary or change during experiments, including factors that you vary on purpose, or factors that you measure as part of your investigation. Usually you will have one **dependent variable** (whose value depends on another variable) and one **independent variable** or **controlled variable** (whose value is changed by the investigator and will usually influence the dependent variable). For example, if a scientist is testing the effect of water temperature on seed germination, the controlled variable will be the temperature of water poured onto seeds and the dependent variable will be whether the seeds germinate. For a lengthy investigation you may have two or more independent variables (such as water temperature and time of seed exposure to the water). Variables are discussed in more detail later.

Research questions

A **research question** may be of the form 'What effect does a new fertiliser have on root growth?' The aim of your research is to then answer the question. It is important that you frame the question carefully. It needs to be specific enough that it guides the design of the investigation. A specific question rather than a vague one will make the design of your investigation much easier. Asking 'Does the new fertiliser increase root growth more than standard fertiliser?' tells you what you will be varying and what you will be measuring. It

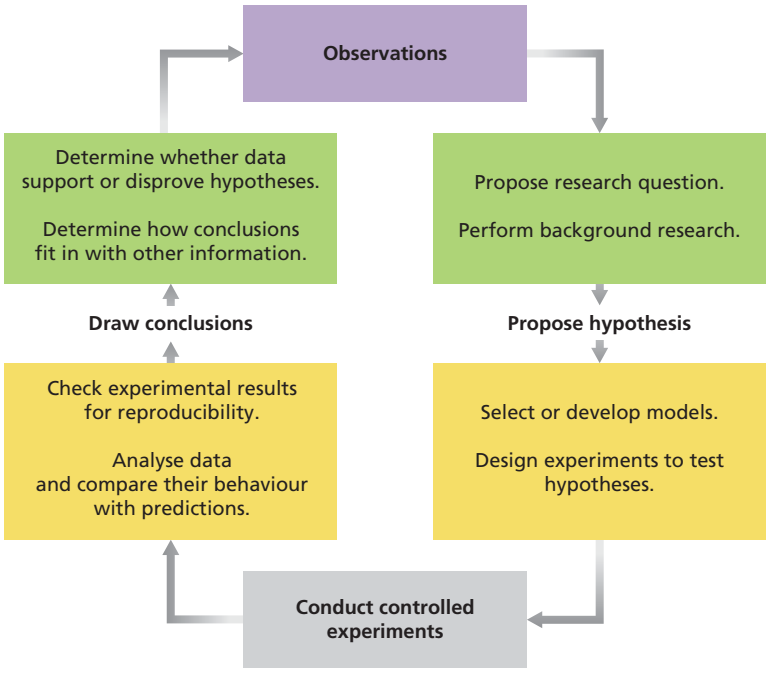


Figure 12.2 ▲
The scientific method. In this context, observations refer to the carefully considered overall conclusions of your study, based on reproducible and reliable results of controlled experiments.

also gives a criterion for judging whether your results have answered the question.

Asking 'How can we make roots grow the best?' is not a good question. This question does not say what will be varied, nor does it tell you when you have answered the question. 'Best' is a vague term. What you mean by 'best' may not be what someone else means.

Finally, a good research question should be answerable with the time and equipment available.

Hypotheses

A **hypothesis** is based on the research question, but is not posed as a question. Instead, a hypothesis is a tentative explanation or prediction, not yet confirmed by experiment, such as 'The new fertiliser makes roots grow longer in two weeks than standard fertiliser'. A hypothesis is often based on some existing **model** or **theory**. It is a prediction of what will happen in a specific situation based on that model.

A hypothesis should give you a prediction that you can test by performing an experiment. This means it should at least be **falsifiable** – that is, it should be able to be disproved. However, you will not generally be able to claim that you have *proved* your hypothesis. Rather, you may be able to say at the end of the study that your results *support* your hypothesis. Hence an aim for an experiment should not start with 'To prove …', as it is not possible to actually prove a hypothesis, only to disprove it.

If your experimental results disagree, then you may have disproved your hypothesis. This is not a bad thing. Often the most interesting discoveries in science start when a hypothesis based on an existing model is disproved. This means that the model it was based upon is either not a good model, or does not apply to the particular situation. You could then try to work out why the model does not apply, or try to formulate a better model. What to do when your hypothesis is not supported is discussed further in the analysis section.

Do not be surprised if you change or modify your hypothesis during the course of your investigation. In scientific research, the question you set out to answer is often only a starting point for more questions.

RECALL

- A research question is one that can be answered by performing experiments or making observations.
- A hypothesis is a prediction of the results of an experiment, which can be tested by performing experiments or making observations.

Designing your investigation

Once you have a specific research question or hypothesis, you need to design your investigation. It is fun to start making measurements or observations immediately, but it is also important to spend time learning how to use the equipment, and experimenting to find the best way to set up your investigation. You may also discover that you need different or more equipment. This may save time later.

It is also important not to get distracted and forget the purpose of your investigation. At the end of the process, you need good data that answers your question or tests your hypothesis. Having a plan ensures that you make the measurements you need. The longer the investigation, the more important it is that you have a clear plan. There are several things to consider.

- What data will you need to collect?
- What materials and equipment will you need?
- When and where will you collect the data?
- If you are working in a group, who will collect the data?
- Who will be responsible for record keeping?
- How will the data be analysed?

The data that you collect will always include secondary data, and will usually include primary data. **Secondary data** are data that have been collected by someone else.

You will already have collected some secondary data when you investigated your research topic to formulate your question or hypothesis. You will probably want to collect more secondary data. If your topic is not one for which you can collect primary data, then you will need to rely on secondary data. Remember that when you collect secondary data it is important to use reliable, reputable sources. These sources will need to be correctly acknowledged as part of the references section of your report or poster.

Primary data are data that you collect yourself. You can collect data by performing experiments or making observations in the field. You should be able to measure parameters that are relevant to the biological question being asked (e.g. rate of cell division, body temperature, enzyme activity, size of population). You will have had practice at measuring some or all of these things already. You need to decide which variables you will measure and which variables you will control. Consider which variables you can control, and which you cannot.

Consider how you will analyse the data. Will you need access to specific software such as a graphing or statistics package? If so, make sure that you know how to use it. If you are using software to draw graphs then you need to know how to produce a **scatter graph** and fit a **line of best fit** and add **error bars**. Note that a line of best fit is not the same as joining the dots. You should *never* join the dots, even though this is often the default setting in spreadsheet software. You should consult a reference guide, the 'help' menu for your software, or ask your teacher. Graphs are discussed in more detail later in this chapter.

See Chapter 11 for more on features of graphs.

Keep a record of your planning. This should go in your logbook. Writing down what you plan to do, and why, will help you stay focused during the investigation. If you are working in a group, a record of what each person agrees to do during the investigation will be very important.

Variables and measurements

Anything that can vary in an experiment is a variable. An independent or controlled variable is one whose properties you can control. For example, if you were doing an experiment to measure the activity of an enzyme at different pH levels, you would control the pH of the reaction and measure the rate of catalysis of the substrate. In this case the pH is the independent variable and the rate of catalysis, which varies with pH, is the dependent variable.

In the question 'Does the new fertiliser increase root growth more than standard fertiliser?', the type of fertiliser is the independent variable. The dependent variable is the root length (or change in root length). Other independent variables not mentioned in this question include soil composition, amount of water, light and temperature. These should all be kept constant, so they are not variables in the investigation. If it was a long investigation, the air pressure could be a second controlled variable. If you decide to have two independent variables, it is important to keep one constant while you vary the



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Figure 12.3 ▲
Keeping growing conditions as consistent as possible helps to control the independent variables.

other, if possible. Then you take multiple sets of measurements, keeping one variable at a fixed value for each set of data while you vary the other.

When variables have a numerical value, you make **quantitative measurements**. You measure the numerical value in the appropriate units. For example, you may measure root length in centimetres or weight of roots in grams.

Continuous variables may take any possible value, usually within some range. Length and time are continuous. In the root growth example, root length is a continuous variable, as it will likely change over time. A variable that may take only fixed values is called a **discrete variable**. Often these are whole numbers of things that cannot be broken into smaller parts, such as number of koalas or students. In the root growth example, the number of roots is a discrete variable.

Your measuring equipment will sometimes restrict you to only measuring discrete values. This is always the case with digital equipment. A set of digital scales that measures in grams gives you discrete values. It does not, however, mean that weight itself is a discrete variable. The weight of the roots is a continuous variable, but digital scales will only give you discrete measurements of the weight.

In some investigations you may use **qualitative measurements** or data. For example, a chemical reaction may lead to a colour change. You would usually describe the colour in words, such as 'pink' or 'green', rather than using a number. Sometimes you use a combination of qualitative and quantitative data. For example, you may describe the length of roots as reaching a maximum in centimetres (quantitative) but growing in a particular direction or pattern (qualitative). Once you have decided on the variables you will be measuring, you will be able to identify the equipment and other resources you will need.

Experimental controls

When planning your experiments, it is usually necessary to include experimental controls. These show that the experimental conditions are appropriate and that no unexpected independent variables are influencing the results. A **negative control** is a condition in which no independent variables are altered. Essentially, in the negative control condition, you expect little or no change in the dependent variable. If a substantial change is observed, it may indicate that an additional independent variable is acting in your study that needs to be identified and controlled in a repeated experiment. In a root growth experiment, the negative control may be a condition in which no fertiliser is added, which will give you a baseline of root growth in the absence of fertiliser.

A **positive control**, on the other hand, gives you some certainty that the experimental set-up will yield the expected results. For example, the standard fertiliser is a positive control as you can expect it to enhance root growth. If it does not increase growth, the growth conditions may be insufficient and you will need to reconsider your experimental set-up. Positive controls are not always included in experiments but they can be very valuable in assessing the reliability of data generated in your investigations.

Identifying the resources required

If you are going to collect primary data, make a list of all the equipment you need. Consider how precise the measurements will need to be. If your hypothesis predicts a temperature change of 0.1°C, but you can only measure to a precision of 0.5°C, then you will not be able to test your hypothesis. You may need to think carefully about how you measure some things. For example, in a root growth experiment, you may need to measure the dry weight of the roots, which means finding a consistent way to dry them.

Consider who will supply the materials and how much they might cost. Scientists generally have to work within tight budgets. Also, the equipment you plan to use must be safe. Will you need special protective equipment, such as lab coats, safety glasses or gloves? Risk assessment is discussed later in this chapter. Make sure you include any safety equipment needed in your equipment list.

When you have your list, talk to your teacher about what equipment is available. You might find that you need to modify your question or hypothesis at this stage.

Consider where you will perform your experiments or observations. Can you use normal classroom space, or do you need to be outside? If outside, what provisions can be made for ensuring that you can work without interference? Will you need to consider the convenience or safety of others? Talk to your teacher about what space is available.

Planning the experimental procedure

The most common problem that students have when doing research is time management. It is important to plan to have enough time to perform the experiments, *and* to analyse them, *and* to report on them. You also need to allow time to learn how to use the equipment if you have not used it before.

In any investigation you will need to collect reliable and precise data. You cannot do this if you do not know how to use the equipment. Always ask if you are unsure. Reading the user manual is also a good idea. It will usually specify the precision of the device, and let you know of any potential safety risks.

Whenever possible you should make repeat measurements, so allow time for this. This allows you to check that your measurements are valid. **Valid results** are affected only by a single independent variable, and only experiments with the correct negative and positive controls can produce valid data. If the results are similar each time, then your results are likely to be valid. If a result is not **repeatable** by you or **reproducible** by others, it is probably not a valid result. A result is repeatable if you or others make exactly the same measurement more than once and get the same result, within the limits of experimental uncertainty. A result is reproducible if another investigator, following your method, obtains data that leads them to the same conclusion as yours, even if there is some small variability between your results and theirs (for example, due to the different equipment used to take the measurements). If a result is not repeatable or reproducible, then a variable other than the one you are controlling is affecting its value. If this is the case, you need to determine what this other variable is, and control it if possible.

Think about how you can minimise uncertainties. Minimising uncertainty is not just about using the most precise equipment you can find; it is also about clever experimental technique. Important discoveries are possible using simple equipment and techniques.

Sometimes experiments simply don't work or can't be done for some reason such as equipment failure or unforeseen variables. For example, root growth will be affected if the plants contract a disease during the experiment. Try to think of all the things that could go wrong. If possible, come up with backup plans. Allowing plenty of time helps with this, as does starting your experiments as soon as possible.

Make sure you allow time for analysis. Ideally, do as much analysis as you can while you collect results. If you plot graphs as you take measurements, then you will be able to identify **outliers** early. An outlier is a data point that does not fit the pattern of the rest of the data. If you identify an outlier while you still have access to equipment and space,

Chapter 11 discusses statistical tests for dealing with outliers.

you can check the measurement and make sure that you didn't make a mistake or that the experiment hasn't been compromised by an uncontrolled variable.

With these things in mind, you may need to consider the number of **replicates** to include in your experiments. These are independent samples that allow you to take multiple measurements, increasing the reliability of your data. In the root growth example, having several plants grown in each experimental condition allows you to calculate an average value as well as the variation between values in your sample set. If the variation is small, it is likely that there is only one independent variable acting in your experiment, and your results are probably reliable. Read more on the statistical analysis of your results in the 'Analysing your data' section below.

After you have analysed your results, you need to write your report or communicate your findings in some other form. You need to plan ahead how this will be done. If you are working in a group, who will write which part of the report, and when? Who will proofread it? Who will be responsible for making sure all the parts fit together?

You may find a timeline useful. A timeline helps keep you on track, and reminds everyone of their responsibilities. If you are working in a group, get everyone to agree on it.

You can use the following table as a template.

Date and place	What will be done	By whom	By when	Outcomes

Minimising bias

Bias occurs when an experiment is not randomised, when there are errors with the equipment being used, or when the person making the measurements would like to get particular results. When an experiment is biased, the results are not valid and no conclusions can be drawn from the investigation. To minimise bias, first ensure that all equipment you are using has been calibrated and tested. Calibration ensures that the equipment gives the correct readings, using known standards. For example, scales can be calibrated using known weights. The equipment should be calibrated at the top and the bottom of its range at least.

Random assignment of subjects into experimental and control groups is an important part of the study design. For example, in a clinical trial of a new drug, patients are randomly assigned to be in the placebo (control) group or the drug treatment (experimental) group with a fairly equal representation in both groups of age, gender, nationality and other variables. Clinical trials are also designed as double-blind studies, in which neither the patient nor the nurse or doctor treating the patient knows which group they have been assigned to. These steps are essential for reducing bias.

For every step of your investigation, try to identify possible sources of bias, come up with ways of eliminating the bias, and incorporate these into your investigation design.

Risk assessment

You may be required to complete a risk assessment before you begin your investigation. Even if this is not a requirement, it is a good idea to think about it. You need to think about three things.

1 *What are the possible risks* to you, to other people, to the environment or to property?
2 *How likely is it* that there will be an injury or damage?
3 If there is an injury or damage to property or environment, *how serious are the consequences* likely to be?

A 'risk matrix', such as Table 12.1, can be used to assess the severity of a risk associated with an investigation. The consequences are listed across the top, from negligible to catastrophic. Negligible may be getting clothes dirty or a very minor injury such as a scratch. Marginal might be a bruise from falling off a bike, or a broken branch in a tree. Severe could be a more substantial injury or a broken window. Catastrophic would be a death or the release of a toxin into the environment. In general, you need to ensure that your investigation is low risk. You can use a risk matrix either for individual identified risks, or for the investigation overall. If there were multiple experiments in your study, then you would use a risk matrix for each one.

Table 12.1 Matrix for assessing severity of risk

Likelihood ↓	Consequences →			
	Negligible	Marginal	Severe	Catastrophic
Rare	Low risk	Low risk	Moderate risk	High risk
Unlikely	Low risk	Low risk	High risk	Extreme risk
Possible	Low risk	Moderate risk	Extreme risk	Extreme risk
Likely	Moderate risk	High risk	Extreme risk	Extreme risk
Certain	Moderate risk	High risk	Extreme risk	Extreme risk

All hazardous chemicals have an accompanying Safety Data Sheet (SDS, previously called a Material Safety Data Sheet or MSDS) that provides information on how the chemical affects health and safety. It gives guidance on safe handling and storage procedures for the chemical as well as emergency procedures for exposure, and considerations for the correct disposal of the chemical. The SDS for a chemical can usually be found by an Internet search or by looking on the manufacturer's website. It is important to read the SDS when assessing the risk associated with the use of the chemical, and deciding the precautions you should take in your experiments.

Once you have considered what the possible risks are, you need to think about what you will do about them. What will you do to minimise them, and what will you do to deal with the consequences if something does happen? This may be as simple as 'Always wear a lab coat, gloves and safety glasses.' You can use a risk assessment table similar to the one shown here.

What are the risks in doing this experiment?	How can you manage these risks to stay safe?
The fertiliser might be spilled on clothes or skin during application.	Wear a lab coat, gloves and safety glasses. Clean up spills immediately.

Safe use and disposal of biological material

When dealing with many biological materials, it is important to be aware of safe handling and disposal. For example, when growing known or unknown microbes on agar plates, it is important to use safe sterile techniques (discussed later in this chapter) and to wear a lab coat, gloves, safety glasses and, if required, a face mask. Treat all microbes on agar plates as potentially pathogenic and **autoclave** used plates before disposing of them.

Ethics

Ethics in research can be controversial. More than one scientist has lost their job for unethical research behaviour. Being ethical in your research has two aspects. The first is about being honest as a scientist. This means recording data accurately, and not ignoring,



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Figure 12.4 ▲
The use of animals for research purposes is governed by State and Federal laws.

hiding or changing any data that doesn't support your hypothesis. It means acknowledging and referencing sources of information including books, websites, articles and people who have helped you. It means not using other people's ideas or data without their knowledge and permission. Put simply, being ethical means showing integrity or 'doing the right thing'. A good rule is that if you wouldn't want someone to know what you are doing, you probably shouldn't be doing it. It is no different from behaving ethically in any other area of your life.

The other aspect of ethics is about treating animals, other people and the environment with care and respect. If your investigation will be using humans, you need to make sure you do not harm them, either physically or psychologically. If you are working with animals, you need to make a strong case for any investigation that harms or could potentially harm them. When scientists want to use humans or animals in their research, they need to be able to show that the benefits to the environment, other animals or humans significantly outweigh the negative effects on the animals or humans used.

The use and welfare of animals for the purposes of research is legislated by State and Federal laws, and respect for all animals (vertebrate and invertebrate) used in research is of the utmost importance. When using animals for research, scientist must adhere to the '3Rs'. These are:

- *replacement* of animal research with other types of research where possible
- *reduction* of the number of animals used in research
- *refinement* of experimental techniques to minimise pain and distress.

The National Institute of Health and Medical Research (NHMRC) has guidelines on the ethical use of humans and animals in experimentation. If you are planning to collect live specimens in the field, be aware of specific State laws that may pertain to native species (including plants).

Experimental technique

Once you have planned the experimental procedure, taking into account the minimisation of uncertainty, the risks involved and ethical considerations, it is time to begin the experiment.

In biology, a number of specialised techniques exist to ensure that the data collected are as reliable as possible. For example, in many laboratories, it is essential to use the **aseptic technique** to ensure that only the desired organisms grow in culture. Outside the lab, biological parameters can vary widely within populations and it is important to sample the population carefully to get an accurate representation of the population at large.

Aseptic technique

When dealing with cell culture (plant, animal and microbial), it is important to practise good aseptic (sterile) technique. This may mean working in a laminar flow hood – an enclosed workspace that prevents contamination of biological samples by maintaining positive pressure using filtered, sterile air. If a laminar flow hood is not available, a small sterile space can be created using a Bunsen burner, whose flame creates an updraft and kills airborne contaminants in the surrounding air.



Science Photo Library/Look At Sciences/Vincent Moncorge

◀ **Figure 12.5**
The use of a laminar flow hood can prevent contamination of biological samples.

Working in a sterile space must be combined with careful handling of all biological material and equipment, and regular decontamination, typically with a solution of 70–80% ethanol.

Alternatively, when preparing microbial cultures on agar, utensils used to transfer the microbes may first be held over a flame to sterilise them, then cooled in a sterile environment before use. Holding the Petri dish upside down as much as possible minimises the opportunity for airborne contaminants to land on the agar.

Using a microscope to make observations

Dutch scientist Anton van Leeuwenhoek changed our understanding of the biological world with his creation of a microscope that could observe bacteria, cells and other microscopic things. Since then, microscopes have become more powerful, widespread and easier to handle. You may choose to use a microscope as a way of making primary observations of microscopic objects as part of your scientific investigation.

Using the microscope

1 Use Figure 12.6 (page 386) to identify the parts of the microscope. If your microscope has a mirror, you will also need a light source. Check to see whether your microscope has an iris diaphragm or a wheel diaphragm.
2 To set up the microscope, move the nosepiece so the low-power objective clicks into position vertically in line with the body tube of the microscope. If you are using a mirror, use the concave side of the mirror, and move the mirror so light is reflected up through the stage.
3 Look through the eyepiece. If there are two adjustable eyepieces, move them together or apart so that the circles of light you see overlap, giving you a unified view. Adjust the iris or wheel diaphragm so that the circle of light first condenses, and then dilates so that it is just outside the visible field of view.

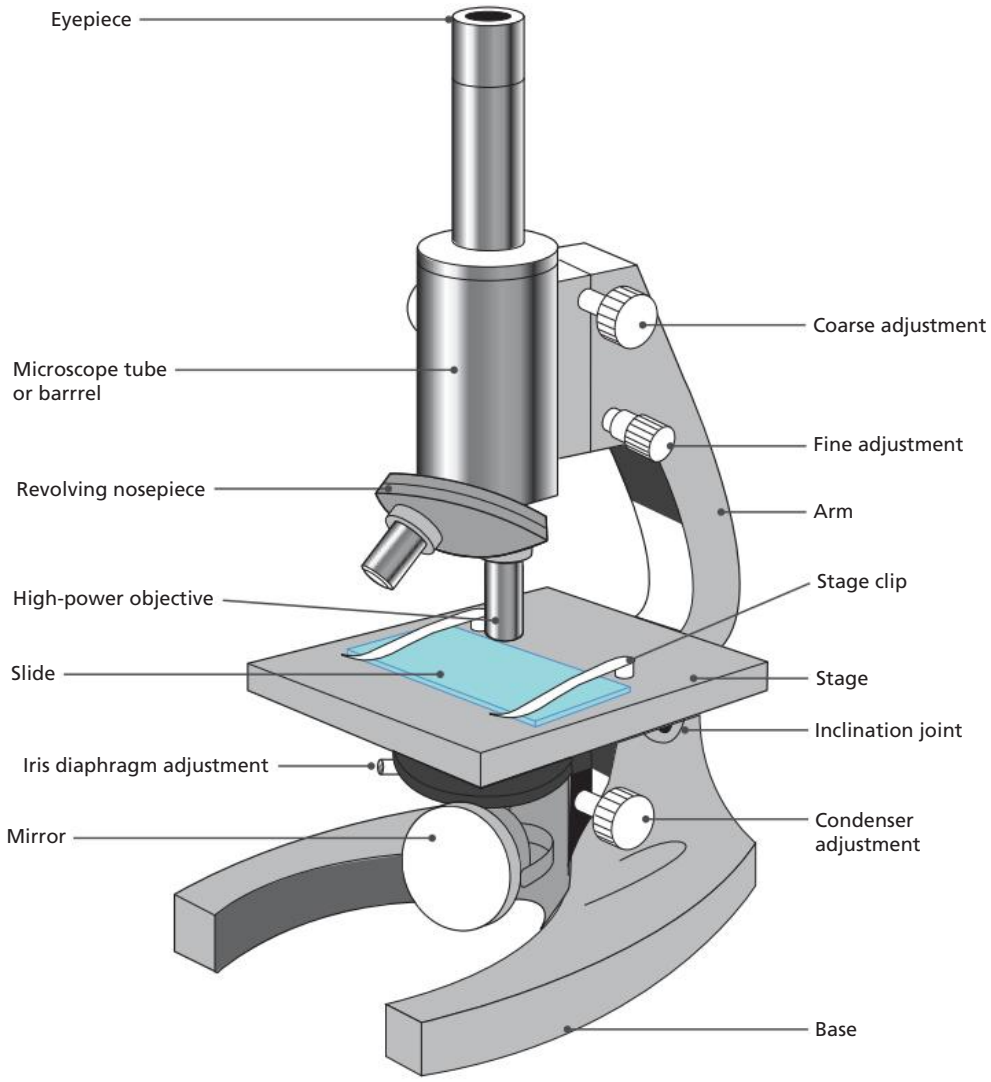


Figure 12.6 ▶
The parts of a monocular microscope

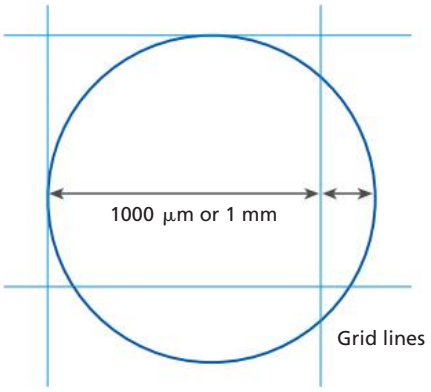


Figure 12.7 ▶
Estimate the field diameter using a mini-grid.

4 Now you need to find the size of the field of view. Place a mini-grid or a slide with a piece of graph paper (marked with millimetre gridlines) on the stage. Without looking down the eyepiece, lower the body tube until it is almost touching the slide, then look through the eyepiece and start to raise the body tube using the coarse adjustment focus knob, until the gridlines come into focus. The fine adjustment focus knob can help you focus more sharply.

5 Move the gridlines so that one sits at the left-most edge of the field of view. While using the low-power objective, you can estimate the diameter of the field of view (Figure 12.7). The eyepieces usually magnify 10× and the low-power objective 10×. This means that looking through the eyepiece and the low-power objective gives an overall magnification of $10 \times 10 = 100\times$. Use this information to calculate the size of the field of view.

6 Remove the grid and place a prepared microscope slide on the stage. Adjust the focus as before: *not* looking down the eyepiece, move the body tube down until it almost touches

the slide, then look down the eyepiece and move the body tube upwards first with the coarse adjustment knob, then the fine adjustment knob until you have a sharp focus.

7 Now rotate the objectives so that a higher-power objective clicks into line with the body tube. You may need to increase the light intensity if possible, and adjust the focus slightly.

8 Practise looking at some prepared slides first under low-power magnification and then under higher magnification. Can you distinguish different cellular features that you have learnt about? Can you estimate the size of cells, based on your calculation of the size of the field of view under low power and your observation or estimation of the number of cells that span the field of view? (See Figure 12.8, for example.) Practise drawing some cells and including scale bars on your diagrams.

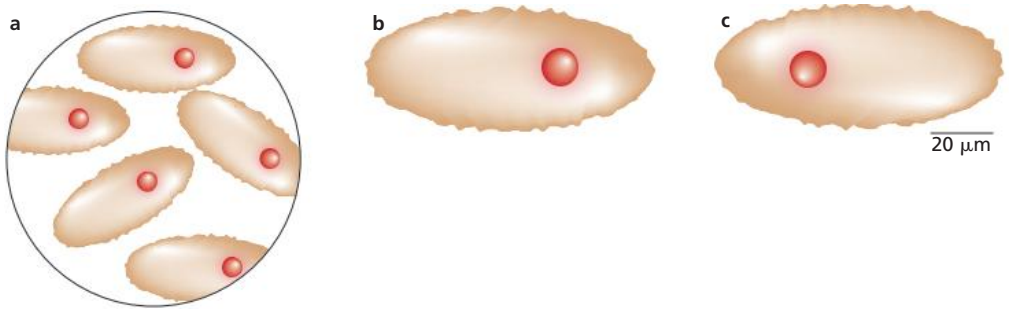


Figure 12.8 (**a**) Cells seen with the high power of a microscope. The field diameter of this microscope is 0.2 mm. (**b**) This cell is 100 µm long. (**c**) A cell with a scale bar

Note:

- The iris diaphragm or wheel diaphragm focuses the light from the light source onto the specimen on the stage.
- If you are going to visually represent anything you observe down the microscope, for example with a diagram or a photograph, it is essential to include a scale bar. This can be calculated from Step 5 above.
- Remember that the objectives have a scale of magnification (for example, 10×, 20× and 40×) but the overall magnification will be increased by ten times a factor 10 due to the eyepiece magnification of 10×.
- Scientists often stain samples so that they can more clearly distinguish features such as cell walls, organelles, starch granules and many other structures. Otherwise these features cannot be easily identified using a light microscope.
- Biological drawings of objects observed under a microscope should be made in pencil and have solid joined lines that outline features, with no shading or sketching. Features should be labelled with a ruled line and neat handwriting. A scale bar should be included (usually in the bottom right corner), and the diagram should have a title at the top. Images should fill the space available – ideally a whole page for each diagram – so that features are easily distinguishable for the viewer.

Field investigations

Depending on the type of investigation you are undertaking, your study may involve some field work, with data collection taking place in environments outside the lab. Field work in biological investigations usually involves identifying organisms, measuring populations or making observations of animal behaviour. It is important that any limitations in data collection be considered when planning your experiment. For example, it is not always possible to determine the population size of a species. Birds and insects are constantly on the move, and some animals move too fast to count or observe; however, there are still techniques that can be used to make estimates. It may be difficult to work out what actually makes up an individual organism. For example, how do you count individual plants of grass?

Identifying organisms

If your study involves observing or counting organisms in the field, it is important that you are able to accurately identify the organisms you have set out to study. To do this you might choose to use a field guide, which is a book that shows images and provides written descriptions of organisms. Field guides may be written to show particular types of organisms in a specific location, such as orchids in the Grampians National Park. The more specific the type of organism and the region they cover, the more detail field guides are likely to contain and therefore the more useful they are likely to be. A classification key is an alternative tool that can help you identify an organism. If you are working in a group with multiple members making field observations, it is important that they all use the same field guide or classification key.

Field guides and classification keys are discussed in Chapter 5.

Observational studies of animal behaviour

If your investigation involves animal behaviour as a dependent variable in your study, you will need to make direct observations in the field. While planning how you will collect your data, think carefully about how your observations will be recorded, who will make the observations and recordings, and how you will reduce variability in reporting of behaviours. For example, you may want to observe the range of animal behaviour in response to your independent variable and create a reference sheet for reporting of particular behaviours before you start collecting data. You may include a simple scale that is easy to follow and not ambiguous, such as a scale for animal movement consisting of *slow walking*, *fast walking*, *slow running* or *fast running*. The scale should use scientific terminology where possible.

Sampling populations

Taking accurate measurements in the field relies on measuring a large enough, representative sample of the population. Various standardised techniques have been developed to accurately sample populations and ecosystems. Different techniques are suitable for different types of studies and the method of sampling a population is an important component of the experimental design.

Making **direct observations** and recording sightings at particular intervals might be possible but it is time-consuming. It might even be dangerous, such as in the case of male fur seals in the breeding season on windswept shores. Satellite images have been used to determine percentage vegetation cover in relatively inaccessible regions. In aquatic ecosystems, plankton nets are used to 'sweep' or **sample** the organisms, and aircraft traverse areas to count kangaroos and other large mammals like musk ox in the Arctic and antelope on African savannahs.

Even when it is possible to count all members of a given population, it may not be necessary. Various sampling techniques can provide estimates of a population. A sample is a small group of organisms selected from the total population in a given area or volume. This sample represents the whole population.

When determining population numbers of nocturnal species, slight variations need to be employed. In New Zealand, scientists have been using spotlights with a red filter to determine the number of fish in a measured and netted area of a river. The filter reduces the impact on the fish and counting can be carried out reliably.

Choosing a particular site because it is easy to get to or is more interesting, or selecting a very small number of sample specimens, reduces the reliability of the data obtained. It does not give a true picture of the whole population. To represent the population as a whole reliably, the samples must be collected in an unbiased way.

Quadrats and transects

For organisms that are fixed or do not move very much, the **quadrat** method of sampling can be used to estimate distribution and abundance. A quadrat is a square, the size of which is determined according to the organism being studied, measured at ground level. It is most often used when measuring plant density, because plants are stationary. It is also a relevant method along shorelines when recording sedentary marine species that may be exposed as the tide varies. It can also be used to calculate density of a population.



CSIRO Division of Plant Industry

Figure 12.9
Quadrat sampling is often used to estimate plant population size.

If sufficient quadrats are chosen, and they are representative of the area under study, the results can be used to estimate total population size. For each quadrat:

- the number of individuals of each species is counted and recorded, *or*
- the relative numbers of each species is estimated using a scale from abundant (3) to absent (0), *or*
- percentage cover is estimated.

The totals of the quadrats are then averaged.

A simple mathematical calculation can give the total number or percentage cover for each species in the whole area. The density can also be calculated.

Estimating total population size of area under study

Average density of members of species (estimated) = Total number of individuals counted ÷ Area of each quadrat × Number of quadrats

WORKED EXAMPLE 12.1

If 35 individuals have been counted in 10 × 1 m^2 quadrats, what is the average density of that species? (3 marks)

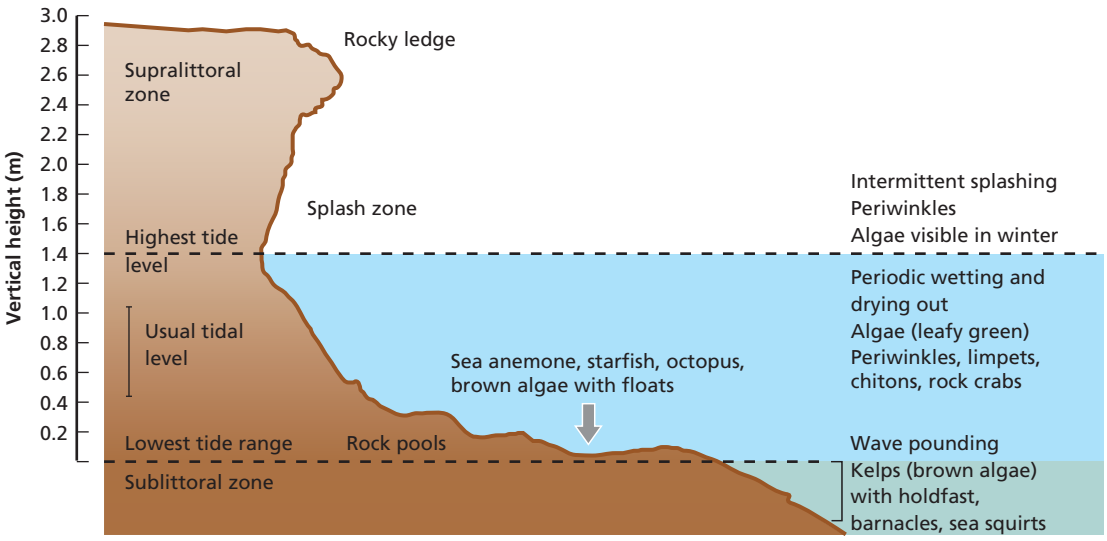
Answer	Logic	
Average density = 35 ÷ 1 m^2 × 10	Use formula shown in the box above. Enter values.	2 marks
= 3.5 individuals per m^2	Calculate answer.	1 mark

Try these yourself

1 Complete the following to determine the average density.

- **a** 65 individuals in 24 × 2 m^2 quadrats (3 marks)
- **b** 110 individuals in 12 × 5 m^2 quadrats. (3 marks)

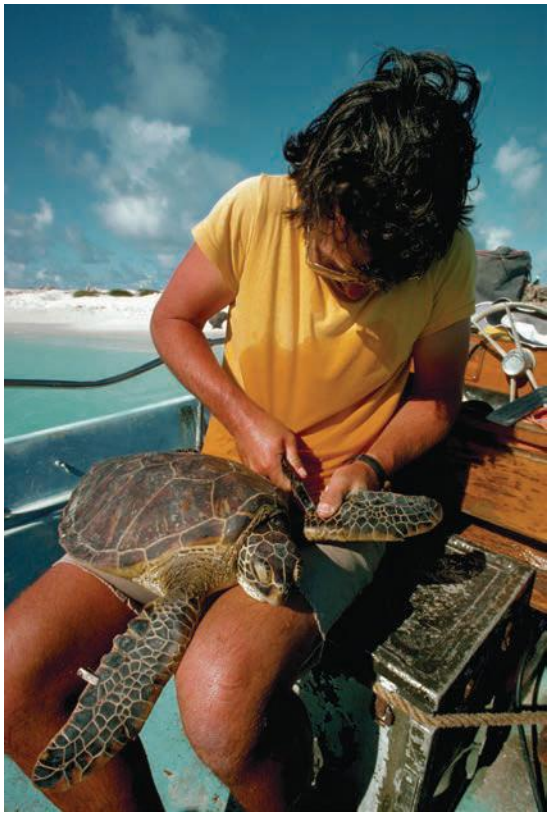
Figure 12.10 ▶
Transect profile of a marine rock platform



A **transect** ('trans' = across, 'sect' = section) is a line drawn through a community and the information gathered along it is used to determine the distribution of species within that community. Again, this is a useful method when species are fixed in place, such as plants and fungi. In order to improve the data collected, quadrats may also be placed at intervals along the transect line and thus data on density in specific locations may also be recorded.

When an area has been selected for study and the data needed have been nominated, the transect line is measured out. For example, it may be 10 metres long with regular segments (every metre), where information regarding changes in distribution is recorded as you move through a tidal zone towards land. It may also provide information on vertical features such as the canopy of the forest, as well as the species present. It may need to be a kilometre in length if studying changes in the distribution of organisms, because abiotic factors change with altitude along a mountainside.

Figure 12.11 ▼
Playing tag: tagging a turtle



Corbis/Jonathan Blair

The line transect method is best to use if environmental factors such as soil type, pH and salinity change along the distance to be sampled. Gradual changes like this are referred to as environmental gradients. Distribution of species can be correlated with changes in these abiotic factors. Vertical transects can show vertical distribution of species. Different conditions at different levels result in stratification – in forests, for example. Environmental factors change across a tidal mudflat or a marine rock platform. In these cases a profile can be drawn.

In order to gain a full picture of population distribution and specific abundance patterns in environments, a combination of methodologies is best. Data gathered using transects offer fairly accurate information regarding distribution of individuals and/or species, while quadrats offer a comprehensive picture of species abundance, but not distribution.

Capture–mark–recapture

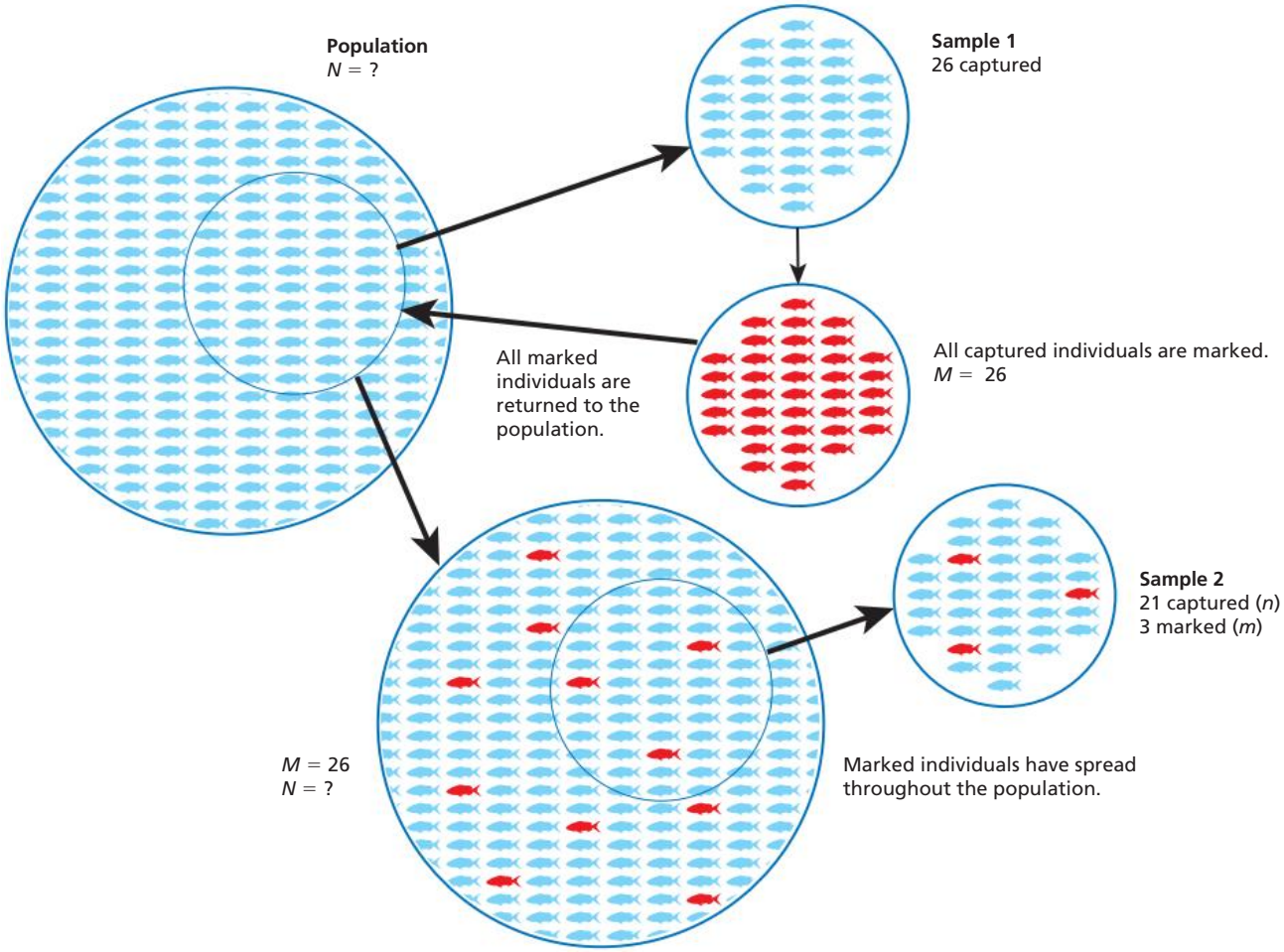
The **capture–mark–recapture** method is commonly used to sample mobile species. A random sample of individuals of a species is taken and an overall estimation of the abundance of the species is made.

Step 1: Capture Animals are caught randomly and in such a way that they are unhurt. Small animals are trapped in cages or pitfalls in the ground, birds are trapped in fine nets and some animals are caught easily when they 'freeze' in spotlights. Flying insects are attracted to light traps.

Step 2: Mark and release Each captured animal is marked so that the mark is not obvious to predators or harmful to the animal. Insects are usually marked with a blob of paint, while birds are tagged on the leg or wing. The animals are returned to their habitat and left to mix with unmarked individuals.

Step 3: Recapture Later, a random sample is taken and the number of marked individuals counted. The timing of recapture needs to be appropriate to again capture a random mixture of individuals, but without leaving it so long that many of the original marked individuals have died. From this information the total population can be estimated. The procedure has to be planned carefully so that the chances of each individual being caught are equal. Sometimes 'trap happy' individuals are sampled over and over.

▼ **Figure 12.12**
The capture–mark–recapture technique



WORKED EXAMPLE 12.2

In the first sample, 20 individuals were marked. In the second sample, 50 individuals were recaptured, and of these recaptured animals 10 were marked. What is the total population? (3 marks)

Total population (N) = no. marked in first sample (M) × total number of animals recaptured (n) ÷ number of recaptured animals that are marked (m)

Answer

$$N = \frac{M \times n}{m}$$

$$\text{Total population} = \frac{20 \times 50}{10}$$

$$= \frac{1000}{10}$$

$$= 100$$

100 individuals in the total population

Logic

Identify the formula — 2 marks

Substitute into the formula.

Calculate the answer — 1 mark

Try these yourself

1 In the first sample, 30 individuals were marked. In the second sample, 50 individuals were recaptured and 10 of these were marked. What is the total population? (3 marks)

2 In the first sample, 100 individuals were marked. In the second sample, 200 individuals were recaptured and 50 of these were marked. What is the total population? (3 marks)

Collecting your data

Once your experiment is underway, it is time to start collecting data. This is usually the fun part of any investigation. Don't forget that you have a question to answer or a hypothesis to test! To do this, you need to make sure that you think carefully about what you do and keep good records.

Record keeping

You will need to keep a record of what you do during your investigation. You do this in a logbook.

Scientists keep a logbook for each project that they work on. It is a record of what they did, why they did it, and what they found out. A logbook is a legal document for a working scientist. If someone's work is called into question, or if there are disputes over patents or ownership of data, then the logbook acts as important evidence. Every entry in a scientist's logbook is dated, records are kept in indelible form (pen, *not pencil*), and entries may even be signed. Scientists' logbooks include details of experiments such as methods and results. They include comments and ideas, thoughts about the experiments, and analysis. They frequently include printouts of data, photocopies of relevant information, photos and other items. The logbook is the primary source of information when a scientist writes up their work for publication. It is also important for assessment and for authentication purposes.

Some scientists keep their research records electronically, but most experimental scientists still keep a hardcopy logbook. There are several advantages to a hardcopy logbook over an electronic one. First, electronic records are easy to make changes to, and it is hard to track what was changed, when and by whom. Second, if you are working in a group, it can be hard to keep track of who has the most recent version of the file/s. Third, files can easily be deleted or corrupted. It takes much more care and discipline to

maintain a good electronic logbook than a good hardcopy. Remember that the purpose of a logbook is to record and maintain evidence of what you did. Electronic evidence is not as reliable as a signed hardcopy document.

You should talk to your teacher about what form of logbook records they require you to keep and any specific formatting requirements the logbook needs to adhere to.

If you are working in a group and all working in the same place at the same time, you may record tasks that another group member is performing in your own logbook (noting down in your book who did what) and the measurements being made. If you are working on your own, for example doing independent fieldwork, you will need to jot down what you do and the measurements you take as you go along.

Write down what you do as you do it. It is easy to forget what you did if you do not write it down immediately. An accurate record is important if you need to repeat any measurements or if you get unexpected results. The more detail you include, the easier it will be to prepare your report at the end of the study.

Include large, clear diagrams of any experimental set-up and include details of equipment used. You can also include photos of experiments.

Record the results of *all* measurements *immediately and directly into your logbook, in pen*. *Never* record data on bits of scrap paper instead of your logbook. Results must be recorded in indelible form. This means using a pen. Never write your results in pencil. Never use white-out or scribble over anything in your logbook. If you want to cross something out, just put a line through it. It is also a good idea to make a note explaining why it was crossed out.

RECALL

- Your logbook is a detailed record of what you did and what you found out during your investigation.
- Make an entry in the logbook every time you work on your investigation. At the start of each session you should record the date and the names of all the people with whom you are working at the time.

Conventions for presenting your data

When collecting your data and communicating your results to a scientific audience (including your classmates and teacher), ensure you use the correct scientific terminology and the key biological terms to describe your study and your findings. Be aware of any **standard abbreviations** that may be applicable (you might have come across these during your background reading in the planning phase of your study), and use only the **International System** or Système International d'Unités (SI) units of measurement or other units recognised for use with SI units.

Table 12.2 Some examples of SI units

SI unit	Measurement
kilogram (kg)	mass
metre (m)	length
second (s)	time
Kelvin (K) degree Celsius (°C)	temperature

There are also conventions of scientific writing to be aware of when reporting your findings. For instance:

- All unit names are written in small letters, except Celsius.
- The unit symbol should be in lower case unless it is derived from a proper name (e.g. Kelvin, Celsius).
- Non-standard abbreviations should never be used (e.g. 'sec' for seconds or 'kph' for kilometres per hour), and the unit symbol should not be altered to make it plural (e.g. 1 kg and 5 kg, not 5 kgs).
- A space should be left between the number and the unit symbol (e.g. 50 s not 50s).
- When writing large numbers, a space (not a comma) should be left between groups of three digits. This may be omitted in four-digit numbers (e.g. 12 250 for twelve thousand two hundred and fifty, 3000 for three thousand).
- Large numbers can be represented in scientific notation, such as 1.225×10^4 for twelve thousand two hundred and fifty.



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Figure 12.13 ▲
Plan exactly what you will measure to collect your data. Do you want to test the length of roots or the mass of roots? Where do the roots end? Will you use fresh weight or dry weight?

Performing experiments

If you have planned carefully and learned how to use the equipment, then hopefully your experiments will go smoothly.

The raw data should always be recorded directly in the logbook unless it is recorded using data loggers connected to a computer. In this case a printout of the data should be attached to the logbook, and the file name and location recorded. Make sure you measure and record everything you will need for your analysis. For example, if you are investigating root growth, you could record the amount of fertiliser used, the temperature and the starting length of the roots. It is much better to measure something and then discover that you didn't need to, than to start your analysis and realise that you didn't measure something that you do need.

Use appropriate units – for example, millimetres for length and grams for weight. If you are going to be collecting multiple data points, it is a good idea to draw a table to record them in. Label the columns in the table with the names and units of the variables. Do not put the units in the table cells. Note that the instruments you use will often restrict the accuracy of your measurements. For example, a ruler may only have markings down to 0.1 cm. Make a note of these restrictions, as they may affect the accuracy of your final results, especially if the changes measured are very small.

Plotting and analysing as you go can allow you to spot something interesting early on (provided you have not made a mistake). You then have a choice between revising your hypothesis or question to follow this new discovery, or continuing with your plan. Many research projects start with one question and end up answering a completely different one. These are often the most fun, because they involve something new and exciting.

Analysing your data

When you have collected all your data you will need to analyse it. Record all your analyses in your logbook. If this is done on a computer, record the file name and location and attach a printout of the analyses to your book. Many scientists have logbooks that are bulging with printouts.

The first step is organising your data. If you have more than a few data points, it is a good idea to display them in a table. You may have several tables for different experiments. You may also need to do some analysis of the data. For example, you may wish to show the change in root length over the course of the experiment in addition to the lengths at the beginning and end of the experiment. Will this be a simple difference (end length – start length) or will it be a fold change (end length / start length)?

Plotting graphs is a useful way to begin the analysis of your data. Graphs are a way of representing data so that trends and relationships can be visually identified. There are many different types of graphs that can be used to organise and display data. These are described in the next section. You will usually need to do some calculations with your data to be able to answer your question or test your hypothesis. Remember to keep units with all quantities, so that any derived values have the correct units. You will also need to calculate uncertainties on any derived quantities.

Identifying trends, patterns and relationships

You may be able to see a pattern simply by looking at a list of numbers in a table. However, the easiest way to identify a pattern in data or a relationship between variables might be to plot a graph.

A graph should be large and clear. The axes should be labelled with the names of the variables and their units. Choose a scale so that your data take up most of the plot area. This will often mean that the origin is not shown in your graph.

When you are looking for a relationship between variables, plot a scatter graph. This is a graph showing your data as points. Do not join them up as in a dot-to-dot picture. Usually the independent variable is plotted on the x axis and the dependent variable goes on the y axis, unless there is a good reason to do otherwise. For example, if you were measuring root growth in response to temperature, root growth (change in length) would be plotted on the y axis against temperature on the x axis.

To determine a relationship you need to have enough data points and the range of your data points should be as large as possible. A minimum of six data points (therefore, six replicates) is generally considered adequate if the relationship is expected to be linear, but always collect as many as you reasonably can, given the available time. For non-linear relationships you need more data points than this, so collect as many as possible.

A good graph to start with is simply a graph of the raw data. You will usually be able to tell by looking whether the relationship between the variables is linear. If it is, then fit a straight line using a graphing package. You can then use a **linear regression** tool to check how good the straight line fit is. This will give you an R^2 number, which is a measure of 'goodness of fit'. The closer R^2 is to 1 (or -1), the better the fit. If it is not *very* close to 1 or -1, then the relationship is not linear. An R^2 close to 1 means there is a positive relationship, or correlation, and so as you increase one variable the other increases as well. An R^2 of close to -1 means there is a negative correlation – that is, as one variable goes up, the other goes down, or vice versa.

If it is a linear relationship, then finding the equation for the line of best fit may be useful. *Never* force a line of best fit through the origin. Often the intercept gives you useful information. It may even indicate a systematic error, such as an error in calibration of your equipment.

When you plot your raw data you may find that one or two points are outliers. These are points that do not fit the pattern of the rest of the data. These points may be mistakes; for example, they may have been incorrectly recorded, or a mistake may have been made during measurement. They may also be telling you something important. For example, if they occur at extreme values of the independent variable then it might be that the behaviour of the system is linear in a certain range only. This is the case for many biological **assays**. You may choose to ignore outliers when fitting a line to your data, but you should be able to justify doing so.

When you extend a line of best fit beyond your measured points, this is called **extrapolation**. Any data that you read off a graph outside the range of your data points is extrapolated, and should be viewed with caution. You cannot say for sure that the system continues to behave in the same way beyond the bounds of your data.

Reading points other than data points from a line of best fit within the region in which you have data is called **interpolation**. You cannot be sure that this is exactly what you would find if you measured that point. However, if your line of best fit really represents the behaviour of the system, then you can use interpolated points in your analysis.

For example, an assay that measures the concentration of protein in a solution involves creation of a standard curve from which the concentration of samples can be interpolated (Figure 12.14 on page 398). Because the assay has a minimum level of detection (its **sensitivity limit**) and a maximum detection limit above which the assay is saturated, it is not possible to extrapolate outside the linear region of the standard curve.

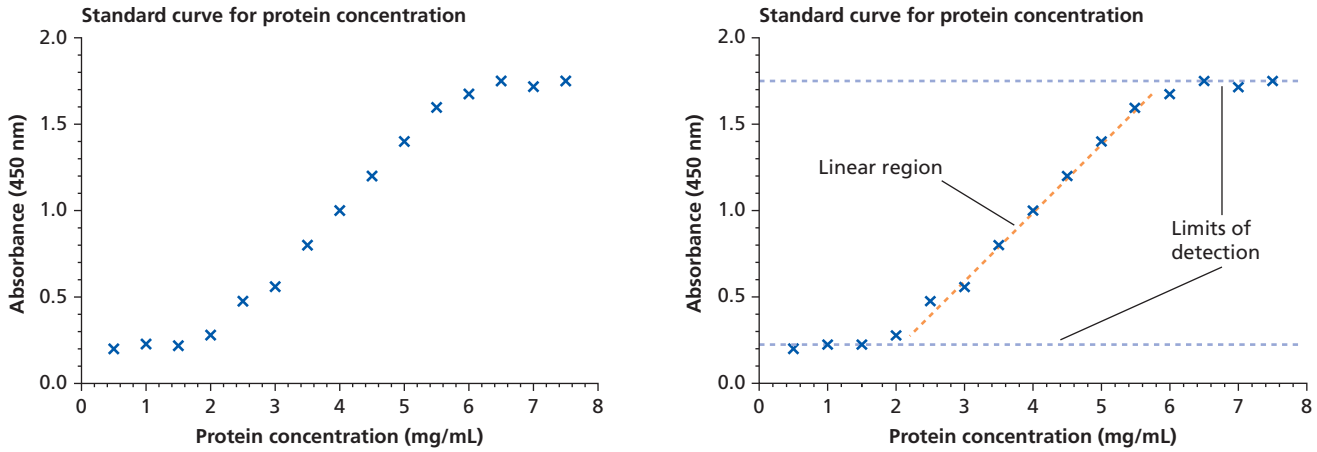


Figure 12.14 ▲
Standard curves can be used to interpolate and extrapolate values, but only within the limits of detection.

To measure samples whose concentration is higher than the detection limits for the assay, the samples must be diluted so their concentration lies within the range of the assay (the linear region of the standard curve).

In biological experiments, you are often comparing the effects of different independent variables on a single dependent variable. In the root growth example, you are comparing the effect of the new fertiliser with that of the standard fertiliser. In this case, you would typically plot a bar graph of the change in root length against the type of fertiliser used. If the data are taken from several different plants in each treatment group, you would plot the mean plus or minus one **standard deviation** (Figure 12.15). You might then use appropriate statistical analysis to determine whether there is a **significant difference** between the treatments. For data of this type, you might, for example, use a ***t*-test** to test for a significant difference between the two treatments. Graphing software typically has functions for calculating standard deviation and for statistical analysis of the data.

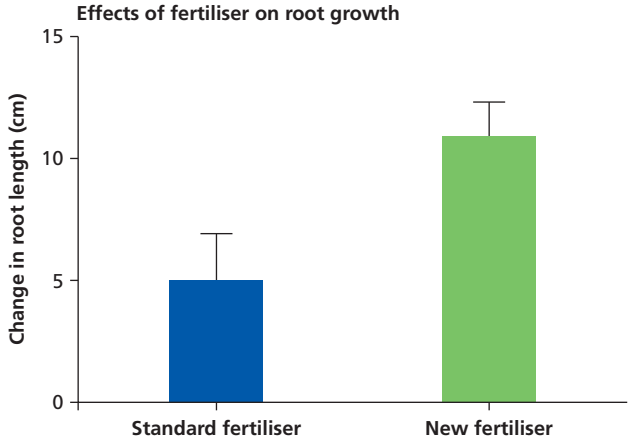


Figure 12.15 ▲
Bar graph of two data sets, with standard deviation

Interpreting your results

Once you have analysed your results you need to interpret them. This means being able to either answer your research question or state whether your results support your hypothesis. If you have performed statistical analysis, does this support your hypothesis? For example, if the new fertiliser induces statistically greater root growth than the standard fertiliser, with all other variables being equal, this would support the hypothesis that 'The new fertiliser makes roots grow longer in two weeks than standard fertiliser'. If there was no difference between the two, or if the new fertiliser induced significantly less root growth than the standard fertiliser, then this would argue against the hypothesis.

If your hypothesis is not supported

It is not enough to simply say, 'Our hypothesis is wrong'. If the hypothesis is wrong, *what* is wrong with it?

It may be that you have used a model that is too simple, or did not take into account all the other variables. For example, in the root growth experiments, it may be that the new fertiliser works best at a particular temperature, or over a longer time, or in

conjunction with certain soil conditions. Or perhaps it doesn't work with the type of plant you used. It may be that the experiment was simply too limited to fully test the hypothesis. Thus, you might conclude that further experiments are required to test these other variables.

Before you decide that the model is at fault, however, it is a good idea to check carefully that you have not made any mistakes or ignored any variables.

Think carefully about any factors that you did not take into account but which might have affected your experiment.

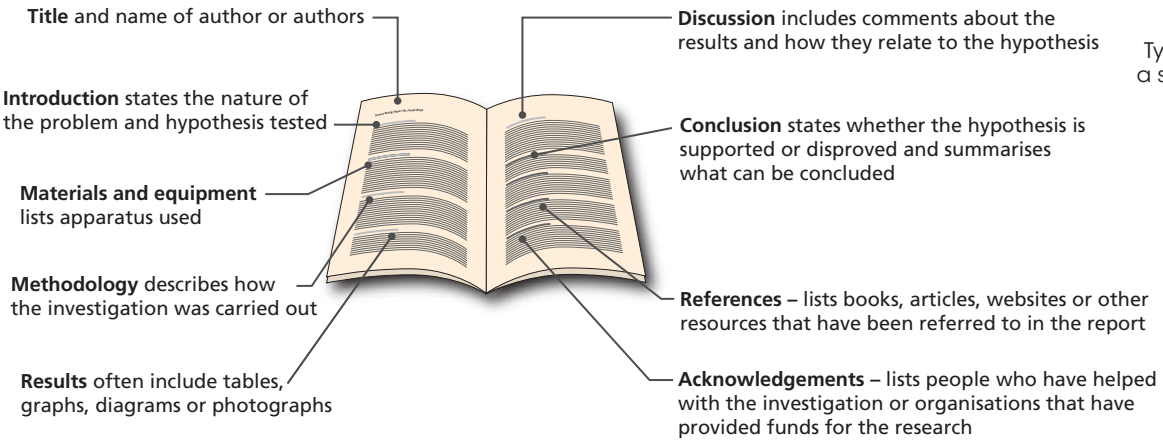
Go through your method, results and analysis. Check that your equipment was correctly calibrated, and that you were using it correctly. Check that data are recorded in the correct units, and that units are correctly carried through all calculations during analysis. Check your analysis carefully. If you are working in a group, get another person to repeat the calculations.

RECALL

- It is never good enough to conclude simply that the experiment 'didn't work'. Either a mistake was made or the model used was not appropriate for the situation. It is your job to work out which.

Communicating your results

If research is not reported on, then no one else can learn from it. An investigation is not complete until the results have been communicated. A report is usually written and the results may also be presented in an oral format or a poster. If presenting your results in a visual format such as a slide show, follow the tips below, but break the sections up on different slides and remember that less is usually more on slides – reduce the text that you have on each slide, and use the images and text on the slides to complement the words you will say with each slide, in a way that doesn't distract your audience. If you are presenting your results as a report, you can include more text and more detail, but most of the tips below, on presenting them as a poster, are also relevant for writing scientific reports. A concise, objective writing style using scientific terminology is important for conveying your key findings without losing the attention of the reader.



◀ **Figure 12.16** Typical format of a scientific report

Presenting your work as a scientific poster

Poster sessions are common at scientific conferences and provide an important networking opportunity for researchers. Sharing your work and receiving feedback is a central part of being a scientist, and having the chance to see what other people are studying may help to guide your own research. At your poster session, you will usually stand by your poster and be ready to give an overview of your work to others who are interested. When creating a poster, it is essential to consider your audience. Sometimes these might be judges for a poster prize, or eminent scientists in the field, and it is important to learn what makes a good poster early in your scientific career.

Table 12.3 Features of an effective scientific poster

An effective poster is ...	An effective poster will ...
Focused on a clear and concise message	Help to communicate your main points clearly
Graphic, with figures telling most of the story and text used sparingly	Engage readers and advertise your results
Ordered so that readers are easily oriented and can follow the 'story' of the poster	Encourage readers to discuss the study with you

Components of a scientific poster

Scientific articles and posters have common components: a title, a list of contributing authors, an introduction, hypothesis and aims, methodology used in the study, a results section with figures and legends, and a discussion and/or conclusions section. However, posters have much less text than an article or report, and the main points must be made clearly and concisely. It is important to keep these sections in this order because it orientates the reader and makes it easier for them to follow the 'story' of the poster.

Title

The title of your investigation is the first thing that will attract the reader's attention, and is a way of immediately conveying the key question and findings of your study. It should be informative, concise and clear and, for a poster, in large font at the top of the poster. Immediately below the title and in smaller font, list any contributing authors (in this sense, meaning people who contributed to the study) in the order of their contribution from most to least, and underline the name of the presenting author (this is probably you). It is conventional to have the senior author, the person who oversees, advises upon and provides the equipment or infrastructure for the study, listed at the end. If you are preparing a report, the title may be on the first page together with the list of contributing authors, or at the top of the report.

Introduction

The introduction outlines the existing knowledge surrounding the research topic, in essence summarising the **state of the field** and providing any background information

needed to understand the rest of the report. This is the place to summarise any existing theories, models, concepts and similar studies, all of which should be correctly referenced, as described in the section on referencing below. On a poster, this section is not usually more than 200 words, depending on the length of the abstract and the space available.

The introduction is important for conveying the reason for your study and for justifying your hypothesis. The best introductions progress so that by the end, the reader has a clear understanding of what the most important 'burning question' is (your research question, of course!), and what to expect from the rest of the poster. To make this even clearer for the reader, the introduction usually contains a stated **hypothesis** followed by the **aims** of the study. On a poster, and sometimes in a report, the aim or aims of your study are sometimes written as a single point or numbered points immediately below your hypothesis. The aims state clearly what you set out to test and will usually have already been concisely written when you were designing the study.

Methodology

The main methodology used in your study should be briefly but clearly described. It is not a recipe for someone else to follow. Write your methodology using sentences, not dot points. Remember that these need to be written in past tense. You are not commanding anyone to do anything. You are telling people what you did. For example, you would write 'root length was measured' not 'measure the root length'. Your methodology needs to be able to be substantiated from your logbook entries.

Sometimes it is helpful to include diagrams, flow charts or photographs that illustrate your methodology, particularly when it is complicated, although this depends on the space you have available on your poster. Don't waste precious space on figures in this section if they do not provide helpful information. The diagrams in your logbook will usually be rough sketches. The diagrams in your report should be very neat and carefully labelled. Flow charts can be useful to describe any procedures in which a series of steps was followed.

If your study contains potential safety issues or ethical considerations, these should be identified in this section, and the ways in which these issues were handled should be described.

Results

The results section is a *summary* of your results. Do not interpret your results in this section, unless it is a combined results and discussion section.

Avoid including tables of raw data in your report unless they compare the results of a few different experiments. Wherever possible use a graph instead of a table.

If a table has more than a few rows of data, it is better to represent that data in some other way. Usually this will be a graph.

Think about what sort of graph is appropriate. The type of graph you use should be the one that most clearly shows any trends or patterns, and the range of your axes is particularly important for this. If you want to show a relationship between two variables, use a scatter plot. Display your data as points with error bars and clearly label any lines you have fitted to the data. Always make sure you label your axes, including units. Choose an appropriate scale so that the data take up most of the plot area.

See Chapter 11 for more on the use of scatter plots to help display correlations.

Scatter plots, column graphs and bar charts are useful for comparing two data sets, such as average root length with different types of fertiliser. Do not use a column or bar chart to try to show a mathematical relationship between variables. Figure 12.17 gives examples of two types of graphs.

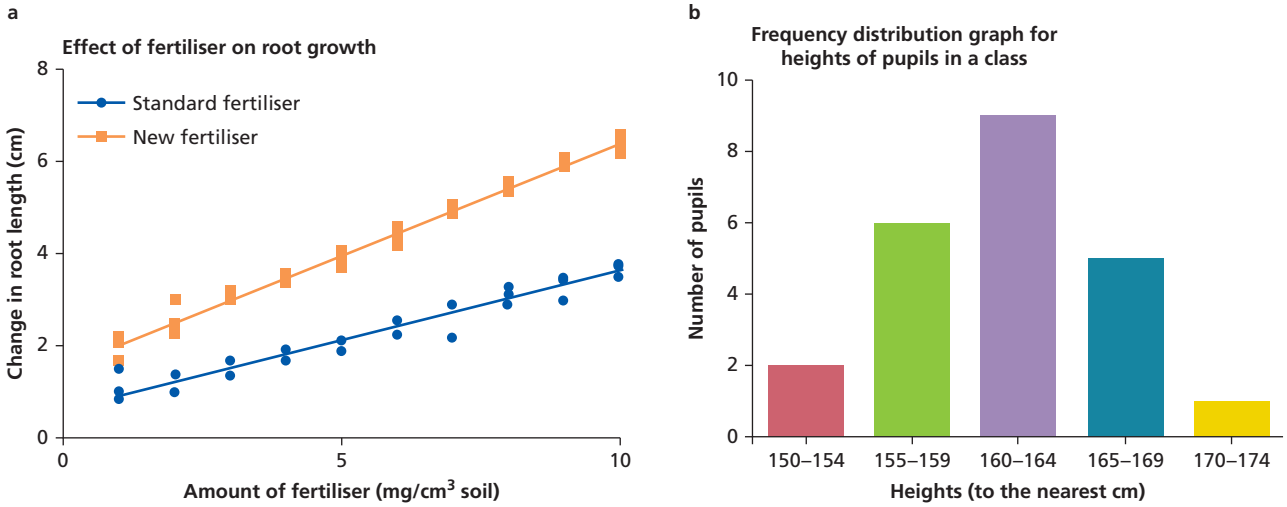


Figure 12.17 ▲
(**a**) A scatter plot with linear regression demonstrating a mathematical relationship; (**b**) A column graph comparing numbers between different groups

Any data and derived results should be given in appropriate units with standard errors of the mean or standard deviation, as appropriate. If you performed calculations or statistical analyses of the data, show the equations or describe the statistics you used. You might want to show one example calculation.

You may find it beneficial to have several results subsections, each one with a heading, a figure and some brief text clearly stating the result that addresses one of your aims. Most readers will focus mainly on the subsection headings and the figures under each of those headings.

When stating a finding of your study in the main text of the results section, refer immediately afterwards to the figure in which the finding is shown. For example:

> The vertical growth of *Arabidopsis* seedlings was significantly greater following two weeks of treatment with new fertiliser than with standard fertiliser or water alone (Figure 1).

Figures

There are several types of figures that may be included in a scientific poster. The most informative figures are quantitative, such as graphs or tables, although it is often useful to include qualitative data such as cross-sections or photographs. Regardless of the type of figure used, it should be chosen for its ability to best communicate the findings of your study. Sometimes a figure will have multiple panels (labelled A, B etc.) – for example, a graph and a photograph showing the same pattern could be presented in two panels of the same figure.

Each diagram should have a figure number and you should refer to it in the text of your report. Position the diagram close to where it is referred to in the text. You should take the time to learn how to position figures neatly using your chosen software. When including images taken on a microscope, a scale bar and the magnification must always be noted.

Figure captions, usually referred to by scientists as figure legends, are essential. These are usually below the figure, and begin with a number followed by a title, then if required, a brief description of the methods used to obtain the results. The figure legend does not contain any interpretation of the data; this is reserved for the discussion section. Important statistical information can be included in the figure legend, including the sample size (*n*), any statistical results presented and the number of times the experiment was repeated (Figure 12.18).

The figure legend uses up space and including such information in it makes it longer to read, and so you may be able to present the information more effectively by annotating the figure rather than putting the information in the figure legend (Figure 12.19).

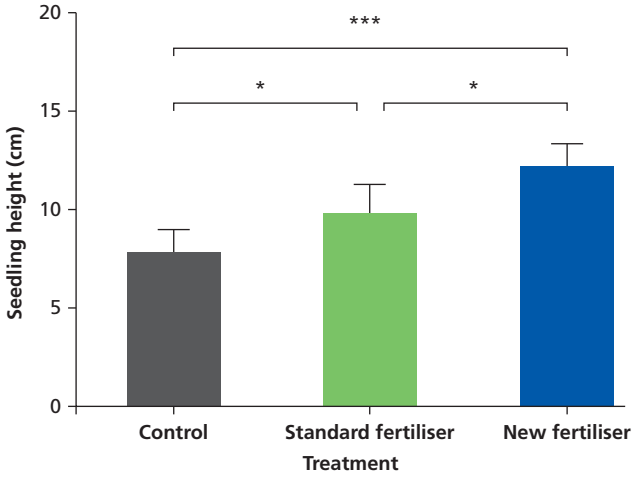


Figure 12.18 ▲
Effect of new fertiliser on seedling height. Seedlings were grown in standard conditions to a height of 2 cm, then separated and treated daily for two weeks with 50 mL 2% new fertiliser or 2% standard fertiliser in tap water. The control group was given water alone. Bars show mean ± standard deviation; $n = 6$ per group. $^{*}P < 0.05$, $^{***}P < 0.0001$. Results are representative of three independent experiments.

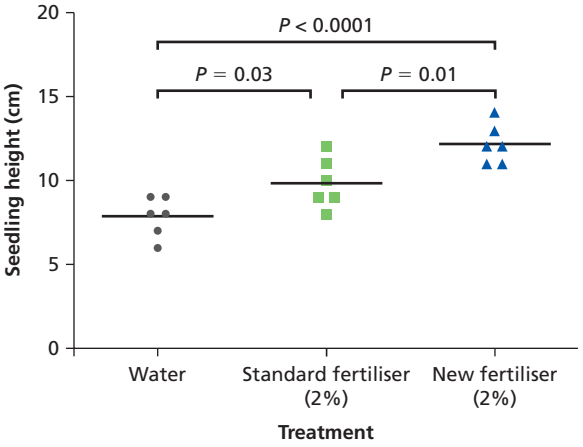


Figure 12.19 ▲
Effect of daily treatment with new fertiliser on *Arabidopsis* seedlings over two weeks

P is a representation of statistical significance related to margin of error (see page 351) and is derived from a statistical test such as a *t*-test (see page 398). It describes the probability of the difference between two means arising by chance alone. It is essentially a measure of the rate at which an observed difference may be considered a false alarm. For a *P* value of 0.01, the probability that the populations are the same is only 1%, which is very low. They are therefore considered statistically significantly different. A *P* value of 0.05 or less is considered significant.

Discussion

The discussion section is the place for analysis and evaluation of your observations. The discussion should explain *what your results mean*. Here, you can interpret your data and discuss its novelty (what is new about it) and significance. Identify the key findings of your investigation and outline how they fit with existing biological concepts. If you began with a research question, give the answer to the question here. If you began with a hypothesis, state whether or not your results support your hypothesis. If not, explain why. (You might only be able to say that the model was not suitable for the situation being investigated.)

This section also gives you the opportunity to *discuss and connect ideas* you have formed from your own study and the background research you conducted as part of the study. If there are any implications of your work, such as implications for better agricultural processes or the design of better medicines, put them here.

The discussion is also the place to briefly describe any difficulties that you had and to make suggestions for improving the process. Remember that you should never say 'the experiment didn't work' if you didn't get the results you expected. You might choose to make some comments on possible further work that could be done.

Some questions you should consider when writing your discussion section are:

- Did your results support or refute your own hypothesis?
- Did you have any outliers in your data and if so, how did you treat them?
- What were the limitations of your study, and how could you address these in (hypothetical or real) future studies?
- What do your results add to the current scientific knowledge of biological concepts?
- Do your results agree with or contradict other published findings?
- How might your findings affect the scientific community, industry, medical practice or the community at large?

It will be difficult to address all these questions in the limited space you have available. Start by writing down all the key points, then read through several times, cutting out unnecessary words each time. Don't remove your own connections and ideas – this type of critical thinking is often a significant part of what is assessed in scientific writing. Remember that concise, coherent writing is an important scientific skill to practise.

Conclusions

This short section allows you to draw conclusions based on the evidence you have gathered during your study. It is a *very* brief summary of the results and their implications. It should provide a response to your research question and directly address the hypothesis you proposed in your introduction. Say what you found out and what it means. A conclusion should only be a few sentences long.

If you are making a poster, in a busy poster session some readers may only look at the hypothesis and conclusion, and so these should make sense together and provide the key information about the study. Sometimes you may have enough space to be able to include a schematic (cartoon) diagram that summarises your results and how they fit into the current state of scientific knowledge.

Acknowledgements

You should thank anyone who helped you in your investigation. This includes people who supplied equipment or funding, as well as people who gave you good ideas or helped with the analysis. In science, as in other aspects of life, it is polite to say thank you.

References

See Chapter 11 for more on referencing.

A reference list details all sources of information that were actually used to write the text and figures for the poster. Wherever a piece of information or quotation is used in your poster, it must be referenced *at that point*. This is typically done by placing either a number in brackets at the point (2), or the author and year of publication in brackets (Smith, 2014). The reference list is then provided in a single, complete list at the bottom of the poster. Referencing must be done in a consistent style. Check with your teacher about which style is preferred. There are several good online guides to referencing.

A reference list is *not* the same as a bibliography. A bibliography is a list of sources that are useful to understanding the research. They may or may not have actually been used by the report authors. You should have a bibliography in your logbook from the planning stage of your investigation. The references will be a subset of these sources.

Formatting a poster

Formatting a poster requires careful thought, with readability and accessibility in mind. Your poster should have colour and font themes – that is, a restricted number of complementary colours and fonts used for background, section boxes (if using), section headings and so on.

All text, including figure labels (titles, legends, axes and other labels) should be large enough to be read easily from at least a metre away. Avoid large blocks of text. Be consistent with font sizes in the body text and section titles, and always left-align the text. The font size for body text may need to be at least 20 points to be clearly readable, with section headings larger and highlighted (e.g. using a different, easily readable colour). Too many colours or fonts may distract the reader and reduce the effectiveness of the poster in clearly conveying the scientific information it has been designed to present.

Keep sections in the order presented in this book, and think of a poster as having two or three columns: readers' eyes will move down the columns from top to bottom, then from left to right.

You may find it difficult to fit everything you want to include on your poster, but it is much easier to begin with more text (that you later cut down) than to have too little information and forget to include the key points. However, text should be used sparingly in posters. As a guide, aim for no more than 1000 words in total on your poster. Let the figures tell the story – include enough text to help the reader understand the figures and the parts of the story that the figures can't tell.

Software used to create posters can vary. You can use any program that can create a document of the appropriate size and orientation (usually A0 in portrait orientation), which allows you to insert images and text boxes and move these around with fine enough accuracy. A good starting point is Microsoft PowerPoint, but Adobe Illustrator or InDesign will give you much more flexibility if you have access to these programs.

Scientific writing: choosing your words

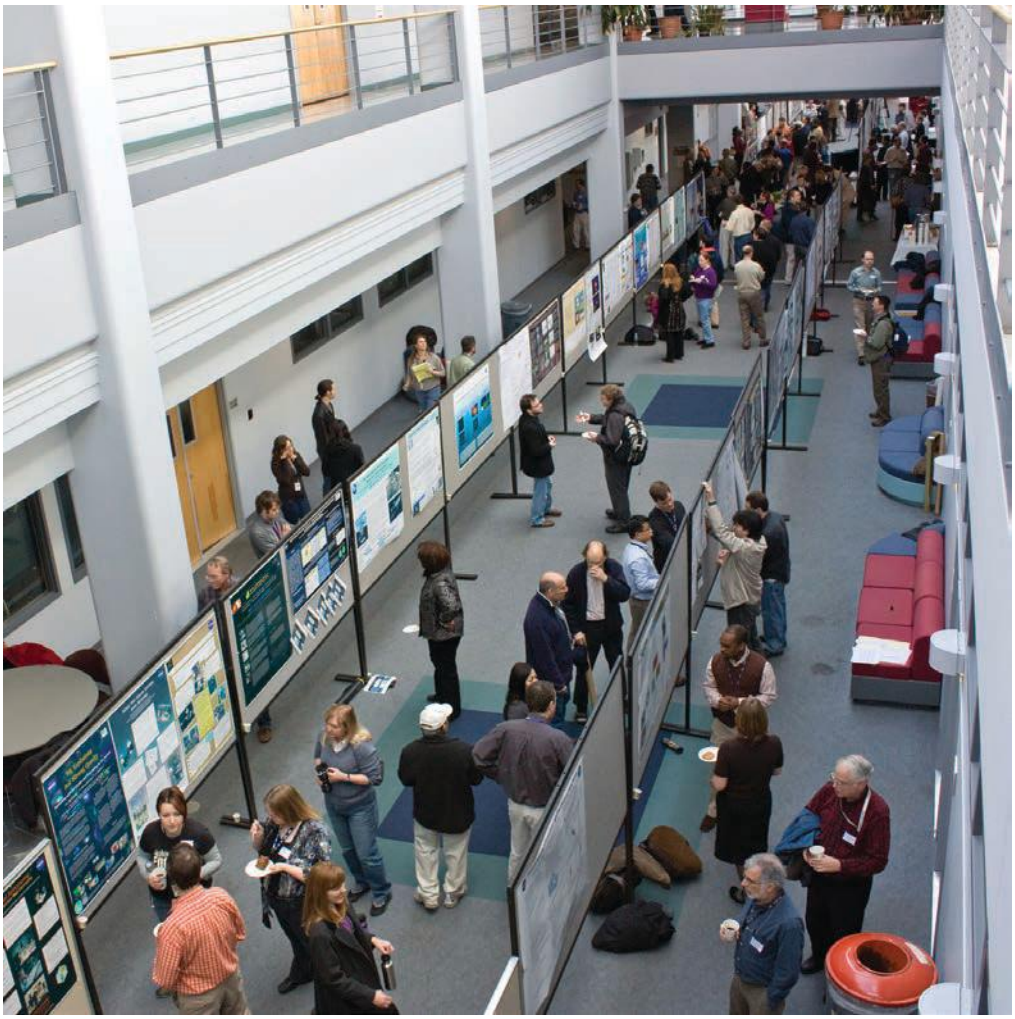
However you communicate your work, make sure the aim of your writing is clear and the content and language are appropriate to the audience.

Language used in posters and in scientific articles is clear, accurate, technical and not colloquial, or conversation-style. Be careful to use correct units and symbols where appropriate and to use the correct scientific terminology for your topic. You should get ideas for this from your background reading. Past tense is used to describe your own findings and the findings of others, unless those findings have been repeated enough times to make the phenomenon a scientific consensus, in which case the observation is stated in present tense. When stating the findings of others, or a theory or hypothesis already proposed by another person or group, it is always necessary to reference the peer-reviewed report or article in which that finding or hypothesis was published. It is normal to have a short reference section at the bottom of the poster. This can be in a smaller type size – if the reader is interested in the detail, they can come close for this one!

Poster sessions

Having completed your poster, you will want it to be seen! Poster sessions are included as part of most conferences and can be large affairs (Figure 12.20) or smaller, more intimate sessions, depending on the setting (Figure 12.21). It is customary to stand by your poster and be ready to answer questions about your work, to explain and discuss

Figure 12.20 ▶
A poster session at a large international conference



Alamy/NG Images

Figure 12.21 ▶
A poster session is a common way to present scientific findings at a conference.



Reproduced with permission of Helen Kiriazis (photographer)

the findings presented in your poster, or often to quickly talk through the poster from start to finish (3–5 minutes), pointing to sections or figures as you go. Make sure you use engaging conversation and don't overwhelm your audience with details.

If you practise this with your friends or colleagues, you will quickly realise whether you have included relevant figures that are easily interpreted by the reader and which you can refer to as you discuss your study. In fact, you may wish to ask your classmates to read your poster, provide feedback and summarise the main points of the poster. This could tell you whether you have included enough information, whether the poster is focused and clear, and whether your figures and text convey all the information you are trying to present. If your reader can't remember the main points of your study after reading it, it's time to go back and look at how you can improve the poster. If they can summarise the aims, findings and relevance of your study, and even ask you questions about your study, then your poster has done its job.

A new fertiliser stimulates seedling growth of the newly discovered and rare *Eucalyptus pyrenea*

Arthur B. Ruse, Jacqueline Hammond, Rufus C. Smith, Karen Trace and Leigh B. Waters,
Pyreness State High School, Warrenmang, Victoria, Australia

Introduction

The recent identification of a new rare Eucalyptus species in the Pyrenees region of north west Victoria, *Eucalyptus pyrenea* (Figure 1), has prompted efforts to try to cultivate the species (1). This would allow for regeneration of local areas with the native tree, promoting conservation of this species and enriching the natural biodiversity of the area.

Growing *E. pyrenea* seedlings has proven difficult without the addition of a fertiliser, although the standard low-phosphorus fertiliser used for Eucalyptus species, Super Ready, has not stimulated the same enhanced growth that is usual in other species (2).

A new fertiliser, ExtraGro, has recently become available for native Australian plants. It contains identical levels of phosphorus, potassium and trace elements to those in Super Ready but has double the amount of nitrogen, which promotes foliage growth (3). The aim of this study was to determine whether ExtraGro, containing greater nitrogen, enhanced *E. pyrenea* growth above that stimulated by Super Ready.

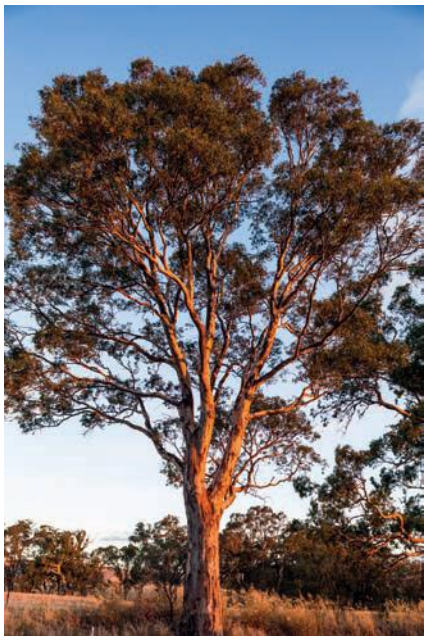


FIGURE 1 *Eucalyptus pyrenea*

Methodology

Seedlings were obtained from a nursery at a length of 10cm±2cm and grown in 300g of standard Australian native plant potting mixture (Figure 2). Plants were exposed to full sunlight and were watered every second day with 25mL tap water.

Fertiliser (2mg per seedling) was applied to the soil immediately prior to each watering.

After two weeks, seedlings were analysed for total length, shoot length, root length, total dry weight, shoot dry weight and root dry weight.

Six replicate seedlings were tested per condition.



FIGURE 2 Seedlings in their growing containers. Left pot, seedling treated with standard fertiliser and right pot, Super Ready.

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Results: ExtraGro stimulates enhanced root growth

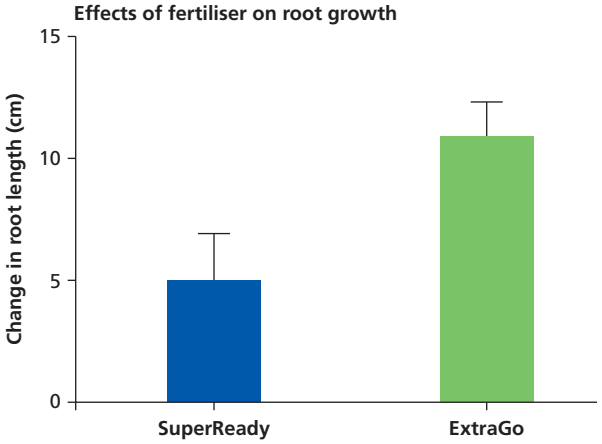


FIGURE 5 Change in root length of seedlings after two weeks of treatment, normalised to untreated seedlings (difference in treated seedling length divided by difference in untreated seedling length).

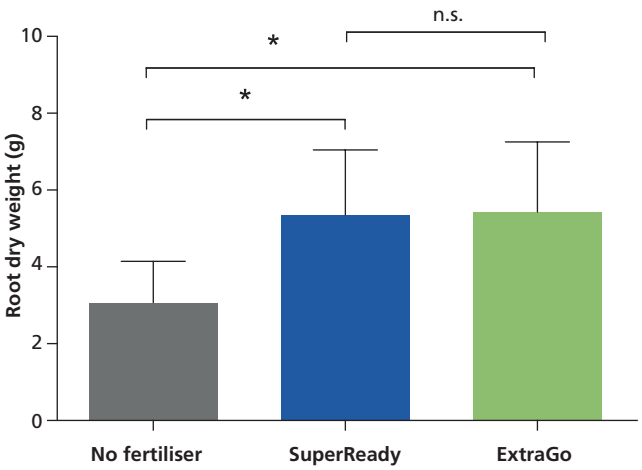


FIGURE 6 Root dry weight after two weeks of treatment. *P<0.05, n.s. = not significant. Bars show mean ± standard deviation, n = 6.

Results: ExtraGro promotes greater shoot growth



FIGURE 3 Representative seedlings after two weeks of treatment. Left, untreated seedlings. Centre, seedlings treated with SuperReady and right, seedlings treated with ExtraGro.

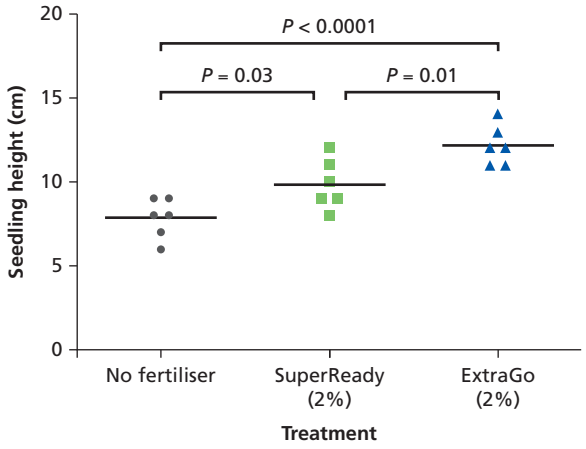


FIGURE 4 Effects of fertilisers on seedling height after two weeks of treatment

Treatment of *E. pyrenea* seedlings with the standard Australia native plant fertiliser, Super Ready, increased seedling height over a growing period of two weeks above the height reached by treatment with water alone. However, ExtraGro caused superior seedling shoot growth in terms of biomass (e.g. Figure 3) and height (Figure 4).

In addition to stimulating shoot elongation and biomass accumulation, we found ExtraGro to have superior root-enhancing properties over Super Ready. Root length increased significantly more over two weeks following treatment with ExtraGro than with Super Ready (Figure 5). However, root biomass was not increased by ExtraGro (Figure 6), suggesting that the increased nitrogen in this fertiliser stimulated the growth of longer but thinner roots.

Conclusions

We tested whether the ExtraGro fertiliser, containing twice as much nitrogen, stimulated enhanced *E. pyrenea* seedling growth over that stimulated by the standard Australian native plant fertiliser Super Ready.

ExtraGro promoted greater shoot elongation and biomass accumulation. In addition, it stimulated increased root elongation, although it did not alter root biomass gain over a two-week period.

Therefore, we have found that *E. pyrenea* seedlings respond better to a high-nitrogen fertiliser than standard fertiliser. This significant finding may inform future efforts to cultivate this species.

References

1. Perugia E., et al. 'A new Eucalypt native to the Victorian Pyrenees State Park'. *Australian Journal of Native Flora*, Vol 3, pp.206–8, 2011.

Acknowledgements

We thank the Pyrenees Nursery for kind provision of the *E. pyrenea* seedlings. We also thank P. Whitely for contributions to plant maintenance, and we thank our teacher Ms. M Marshall for valuable contributions to our study design and poster preparation.

GLOSSARY

aseptic technique the technique of working under sterile conditions to prevent contamination of samples

assay an experimental technique or procedure used to test a specific biological process or effect; for example, an enzyme kinetic assay

autoclave a device used to sterilise equipment, reagents or contaminated waste; autoclaves work by subjecting contents to pressurised steam at 121°C for a set time

capture–mark–recapture an ecological surveying technique used to measure animal populations, in which individual animals are captured, marked and released; after a time, the population is re-sampled and the number of marked animals caught gives an indication of population size

continuous variable a variable that is able to take any value within a range; examples are length, time and temperature

controlled variable the variable that is controlled by the experimenter, so its values are chosen; also called the independent variable

dependent variable the variable that changes as a result of changes to the independent or controlled variable

direct observation a method used to measure abundance; for example, recording sightings at particular intervals; can be time-consuming and dangerous

discrete variable a variable that may take only certain values; examples are number of individuals or number of legs on an animal

error bars drawn above and below and/or to left and right of a data point on a graph to indicate the size of the uncertainty in that point

extrapolation extension beyond the measured range of data to read or construct new data that has not been measured

falsifiable able to be disproved

hypothesis a tentative prediction, usually based on an existing model or theory; also a tentative explanation of an observation based on an existing model or theory

independent variable a variable upon which another variable depends; usually the controlled variable

International System of Units (Système International d'Unités, SI) a modern form of the metric system; a standardised worldwide system of measurements used in science and commerce

interpolation to read or construct a new data point that has not been measured but is within the range of measured data

linear regression a statistical tool used to model the dependence of one variable on another

line of best fit the line that most accurately fits the data, usually calculated using linear regression

logbook the record of an experiment or investigation kept by the scientist performing the experiment; it is a legal record of the experiments and their results

model a representation of a system or phenomenon that explains the system or phenomenon; it may be mathematical equations, a computer simulation, a physical object, words or in some other form

negative control a condition in which no substantial change is expected, providing a baseline to increase confidence that no unidentified independent variables are acting in the experiment

outlier a data point that does not fit the pattern shown by other measured data points

plagiarism presenting someone else's work, including their words or ideas, as your own

positive control a condition in which an effect is expected, giving confidence that the experimental set-up can yield the expected results

primary data data that you have measured or collected yourself

quadrat a method used in population sampling where a square is placed on the ground to count each individual of a species and determine their density; useful for stationary organisms

qualitative measurement measurement with descriptive or non-numerical results

quantitative measurement measurement with numerical values

reference the source of a specific piece of information or quotation

reliable highly likely to be true; a trustworthy source of information or reproducible data

repeatable giving the same result, within uncertainty limits, when repeated measurements are made by the original investigator

replicate one of several experimental samples subjected to all the treatment combinations to be compared in an experiment; for example, duplicate refers to two repetitions of the conditions, triplicate to three repetitions

reproducible giving the same result, within uncertainty limits, when repeated measurements are made by other researchers

research question the specific question that a particular experiment or investigation is attempting to answer

sample a small group of organisms selected from the total population; is representative of the whole population

scatter graph a graph or plot showing data points, without a line joining the points, and used to demonstrate or determine a mathematical relationship between variables; the axes are defined by the variables

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secondary data data or information that has been collected by someone else

sensitivity limit the lowest level of a substance that can be detected by a test

significant difference a difference between data values that is statistically significant; the probability (p) of the difference being due to chance is so small (usually less than 5%) that the result is considered true

standard abbreviations abbreviations that are conventionally used in scientific communication

standard deviation a measure of the dispersion of a set of data from its mean; expresses the variability of a population or set of data

***t*-test** a statistical test commonly used to analyse differences between two sets of data

theory a collection of models and concepts that explain specific systems or phenomena; scientific theories allow predictions to be made and hence are falsifiable

transect a method used in population sampling whereby a line is drawn through a community and information is gathered along it and used to determine the distribution of species; can be used in conjunction with quadrats and is useful for stationary organisms

valid results results that are affected by only a single independent variable and hence are reproducible

variable something that can change or be changed, as distinct from a constant, which does not change

GLOSSARY

abiotic factor a physical or chemical environmental factor

abiotic the non-living components of an ecosystem

absorption the main role of digestive system; the taking up of digested molecules

abundance how many; the number of a species in a population

active transport the process whereby cells actively transport substances across a membrane from a low concentration to higher concentration of the substance; characterised by the fact that the process consumes energy

adenosine diphosphate (ADP) a low-energy compound composed of adenine and ribose and two phosphate groups attached; it is converted to ATP for energy storage when it gains a phosphate group

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

adhesion protein a membrane protein that helps link cells together

adhesion the strong forces that exist between water molecules and other substances, due to the polar nature of the water molecules

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

aerobe an organism that requires oxygen

aerobic cellular respiration mitochondrial pathway of cellular respiration that occurs in the presence of oxygen and generates about 36 ATP

albumin a protein abundant in blood plasma

alcohol fermentation a form of anaerobic respiration (no oxygen present); glucose is converted to ethanol, a type of alcohol

allele one of different versions of the same gene (at the same locus) determined by small differences in the DNA sequence of the gene

alveoli (alveolus) tiny air sacs located on the end of the bronchioles

amensalism a symbiotic relationship whereby one species is inhibited or destroyed while the other remains unaffected.

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

ammonia a toxic form of nitrogenous waste produced as a by-product of protein digestion

amylase a substance present in saliva and secreted from salivary glands near the base of the tongue

anticoagulant a substance in the blood that inhibits normal blood clotting

amyloplast a type of leucoplast that often stores starch

anaerobe an organism that can live without oxygen and regulates movement of substances into and out of the cell

aneuploidy describes a genome that varies from the conventional by the loss or addition of one or just a few chromosomes

annotated diagram a descriptive diagram with labelling to show specific parts, highlight sections or describe functions

anomaly something that deviates from what is standard, normal or expected

antidiuretic hormone hormone that affects how much water is reabsorbed into the collecting tubules in the kidneys

anus the exit point of waste products and the end point of the gastrointestinal tract

aorta the largest artery; takes blood to all parts of the body (i.e. the systemic circulation)

apoptosis a programmed series of events that lead to cell death

arrector pili muscle small muscle attached to hair follicles

arrhythmia an alteration in rhythm of the heartbeat

arteriole a small artery

artery a blood vessel that takes blood away from the heart

artificial selection *see* selective breeding

aseptic technique the technique of working under sterile conditions to prevent contamination of samples

asexual reproduction a form of reproduction in which offspring are produced from a single parent

assay an experimental technique or procedure used to test a specific biological process or effect; for example, an enzyme kinetic assay

atria two thin-walled chambers of the heart

authority an accepted source of information or advice, or an expert in a subject; quotations from such a source give credibility to ideas or an argument

autoclave a device used to sterilise equipment, reagents or contaminated waste; autoclaves work by subjecting contents to pressurised steam at 121°C for a set time

autosome a chromosome that is the same in both males and females of a species; autosomes do not include sex chromosomes

autotroph an organism capable of making its own food from inorganic substances using light (through photosynthesis) or chemical energy (through chemosynthesis); includes green plants, algae and certain bacteria

bar graph a chart that uses bars to show comparisons between categories of data

basal metabolic rate the rate at which the body uses energy while at rest to maintain vital functions

beneficence an action done for the benefit of others; can be done by helping prevent or remove harm or by improving the situation of others

bias a preference for a particular outcome that interferes with ability to be impartial, unprejudiced or objective; as part of the scientific method, scientists try to remove all factors that could introduce bias

bilayer a double layer

bile a substance produced by the liver and transported into the duodenum; it is not an enzyme and is involved in mechanical digestion of fats due to its detergent-like action

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

binomial system a system of naming organisms using two parts: a generic name and a specific name

biodiversity the full range of different living things in a particular area or region; it can be described at various levels, including the range of different species, genetic diversity, or the diversity of ecosystems present in a larger area

bioethics the application of ethics to the science and practice of biology

bioinformatics the science of managing and analysing biological data using advanced computing techniques; it is especially important in genomics research because of the large amount of complex data this research generates

biological cloning producing a copy of an entire organism

biomimicry the design and production of materials, structures and systems that are modelled on biological entities and processes

biotic factor a factor related to the effect a living organism has on another living organism

biotic the living components of an ecosystem

bivalents visible bodies in a cell during prophase I of meiosis, made up of two homologous chromosomes joined together

blastocyst a hollow ball of cells formed during early embryonic development

bleb a balloon-like outgrowth of the plasma membrane

blind study an experiment where information about the test that could lead to bias in results is concealed from participants; if it is also concealed from those taking measurements, it is a double-blind study

Bowman's capsule the structure in which the glomerulus is found, at the beginning of the nephron

bronchi (bronchus) two branches of the trachea that lead to the lungs

bronchiole the smaller tube of the bronchus

brown fat a type of fat involved in the rapid production of heat

budding the development of a new organism from an outgrowth of the parent organism

capillary a small blood vessel that links arteries and veins

capture–mark–recapture an ecological surveying technique used to measure animal populations, in which individual animals are captured, marked and released; after a time, the population is re-sampled and the number of marked animals caught gives an indication of population size

carbohydrate an organic compound that serves as a structural component and a major energy source in the diet of animals; includes glucose, starches and cellulose

carbonic acid most of the carbon dioxide produced in respiration is converted into carbonic acid in the plasma

carcinogen a cancer-causing agent

cardiac relating to the heart

cardiovascular system the heart, blood and blood vessels

carnivore an organism that feeds on other animals

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

carrier usually used in reference to disease; a healthy, heterozygous organism carrying an allele for a recessive phenotype; the organism may transmit the recessive allele and resulting phenotype to its offspring or to others

carrying capacity the maximum population size of a species that can be supported in a given environment

case study an in-depth investigation of a person, group, event or community where data are gathered from a number of sources including interviews and observations

catalysed when the rate of a chemical reaction is increased by a chemical (catalyst) that is unchanged chemically at the end of the reaction

causation using controlled experiments to determine the cause of an effect or the reason for a phenomenon

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

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

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

cell the basic structural unit of all life forms on Earth

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

cellulose a complex carbohydrate molecule found in cell walls

centriole a minute rod-shaped body present in many resting cells just outside the nuclear membrane; it doubles before mitosis, moving apart to form the poles of the spindle; usually absent in plants; produces and organises microtubules

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

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

character matrix a table that lists the characteristics of organisms and is used to construct cladograms

characteristic a feature or quality of an organism that can be used to classify and identify it

chemical digestion a process whereby complex substances are broken down into their simplest forms via enzyme action

chemoreceptor a sensory cell or organ that detects chemical stimuli

chemosynthesis the synthesis of organic substances using energy from chemical reactions

chiasmata the point of contact between homologous chromosomes during prophase I of meiosis

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

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

chloroplast DNA (cpDNA) DNA contained in a chloroplast

cholesterol a type of steroid associated with heart disease

chromatid daughter strands of a duplicated chromosome

chromatids daughter strands of a duplicated chromosome that are joined by a centromere

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

chromoplasts a type of plastid containing coloured pigments other than green

chromosome a structure composed of DNA and protein that contains along its length linear arrays of genes carrying genetic information; prokaryotes have one circular chromosome while eukaryotes have a number of linear chromosomes

chyme 'soupy' contents of the stomach (partially digested food)

circulatory system the body's main internal transport system

clade a taxonomic group that contains all of the descendants of a common ancestor

cladistics a method of classifying organisms based on the characteristics they share

cladogram a diagram constructed using cladistics that shows the evolutionary relationship between organisms

classification key a tool used to identify organisms based on their characteristics

cleavage division of the cytoplasm in an animal cell

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

clone an organism genetically identical to its parent

closed circulatory system a type of circulatory system in which blood is confined to a set of vessels

clumped (grouped) distribution a pattern of distribution in which individuals in a population are grouped together where biotic and/or abiotic factors are favourable

coding DNA a sequence of DNA that codes for a protein

co-dominant a state in which both alleles of a heterozygous individual are fully expressed in the phenotype

coevolve the evolution of adaptive features in two different species that have placed selective pressures on each other

coexistence different species living together peacefully

cognitive bias thinking errors that can prevent us from understanding reality even when confronted with the evidence to form an accurate view; the scientific method helps to eliminate cognitive bias

coherence the quality of forming a logically consistent argument, theory or policy

cohesion the strong forces that exist between water molecules

cohort studies studies that observe what happens to a cohort (a group of people who are linked in some way) that are all experiencing a particular variable compared to a group that has not had the experience

colon the first section of the large intestine, where water, minerals and vitamins are absorbed into the body

commensalism a symbiotic relationship whereby one species benefits and the other is unaffected

common ancestor a species from which two different species both evolved

community the sum of the different species inhabiting a particular habitat at one time

competition the struggle between two or more species for resources to fulfil their need for survival

complementary bases the nucleotide bases that pair on the opposite strands of DNA; A pairs with T and C pairs with G

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

conciseness giving a lot of information clearly and in few words; from the Latin 'to cut down'

conduction the transfer of heat energy from a relatively hot object to a relatively cool object by direct contact

confirmation bias the tendency to search for and interpret evidence that confirms your existing beliefs or theories; can interfere with objectivity

consumer any organism that cannot manufacture its own food, but depends on others for its food

continuous variable a variable that is able to take any value within a range; examples are length, time and temperature

continuous variation variation in a characteristic that shows a smooth gradation of different phenotypes

contractile vacuole the vacuole found in some freshwater unicellular organisms that maintains osmotic balance by collecting water and emptying it from the cell

controlled variable the variable that is controlled by the experimenter, so its values are chosen; also called the independent variable

convection the transfer of heat by means of rising currents of warm air or liquid

coronary angioplasty a procedure to open narrowed or blocked blood vessels that supply blood to the heart

coronary arteries arteries supplying blood to the heart

coronary heart disease disease of the heart and heart blood vessels

correlation a statistical measure of the relationship or connection observed between two factors

crenation the crinkling of red blood cells when they lose water

cristae the folding of the inner membrane into the matrix of the mitochondria, thus increasing the total surface area of the inner membrane

critical thinking the objective analysis and evaluation of an issue in order to form a judgement

crossing over the process of chromatids breaking and re-joining during prophase I of meiosis

cross-sectional survey a descriptive study of a situation at one particular time that is used to provide information; does not attempt to explain why, as variables are not manipulated by researchers

cyclin a type of molecule that regulates the cell cycle

cytokinesis division of the cytoplasm

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

cytoplasmic streaming the mixing and movement of the cytoplasm

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

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

daughter cell one of the cells resulting from the division of a cell

deamination a process that separates the nitrogen-containing amine group from the rest of the amino acid

defibrillator an apparatus used to attempt to restore the heart to a normal effective rhythm by application of an electric current to the chest wall or directly to the heart

demographic the statistical data of a population relating to factors such as age, sex, socioeconomic status, etc

density-dependent factor a factor that affects a population more as the population increases, e.g. disease-causing organisms or parasites; the greater the density of a population, the more individuals die or fail to reproduce

density-independent factor a factor that affects all individuals and usually leads to a drastic decline in population due to death or emigration; e.g. severe weather conditions, volcanic activity and habitat destruction by clearing or fire

dependent variable the variable being tested in a scientific experiment; measured in response to the researcher changing the independent variable; generally is recorded on the *y* axis of a graph

detritus organic wastes, including faeces and dead tissues

diaphragm a sheet of muscle that, along with the ribs, moves air into and out of the lungs

dichotomous describes a classification system where each branch has two options

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

diffusion the movement of a dissolved substance from an area of high concentration to an area of low concentration; the process does not require an input of energy

digestion the main role of the digestive system; the breaking down of complex organic molecules mechanically and chemically

digestive system where digestion takes place, also known as the gastrointestinal tract

dihybrid cross a cross between two organisms that are heterozygous at two gene loci

dihybrid inheritance inheritance of two pairs of contrasting characteristics

diploid (2*n*) describes a cell or organism that has a genome comprising two copies of each chromosome; the number of chromosomes in a diploid cell is represented by 2*n*

direct observation a method used to measure abundance; for example, recording sightings at particular intervals; can be time-consuming and dangerous

discontinuous variation a variation in a characteristic that shows two or just a few clearly distinct phenotypes

discrete variable a variable that may take only certain values; examples are number of individuals or number of legs on an animal

disjunction the moving apart of homologous chromosomes during anaphase of meiosis

distal tubule the portion of the nephron between the loop of Henle and the collecting duct

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

DNA methylation the attachment of a methyl group to nucleotides or histone proteins

DNA sequence the order of nucleotide bases within a DNA molecule

dogmatism the tendency to state principles as undeniably true without considering the evidence or opinions of others

dominant a phenotype that requires only one copy of its allele in an individual to be expressed

double helix the spiral shape of a DNA molecule

double-blind study *see* blind study

ecosystem a self-sustaining unit consisting of the interactions between the community and the environment

ectoderm the outer tissue layer of the embryo; it gives rise to the outer covering of the body

effector an organ, cell or protein that acts in response to a stimulus

egestion the removal of wastes from the digestive system

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

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

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

endoderm the inner tissue layer of the embryo

endoplasmic reticulum (ER) an organelle in eukaryotic cells consisting of an interconnecting system of thin membrane sheets dividing the cytoplasm into compartments and channels; lipid synthesis occurs here

endothermic describes animals that are able to generate their body heat through biochemical processes within their bodies

environment abiotic and biotic factors of an area

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

epidermis the surface layer of plant or animal cells, generally responsible for separating and protecting the organism from its environment

epigenetics the study of chemical modifications to gene function that are not due to DNA sequence changes; DNA methylation is an example

epigenome chemical compounds that modify the genome

epiphyte a type of climbing plant, such as lianas, which uses trees as support as they reach for light

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

equity the quality of being just and fair

error bars drawn above and below and/or to left and right of a data point on a graph to indicate the size of the uncertainty in that point

erythrocyte a red blood cell that is non-nucleated when mature; contains haemoglobin pigment that transports oxygen from the lungs to the tissues

ethical principles universal standards of right and wrong that guide decision making and actions; include the goals of equity, beneficence, least harm, respect for autonomy and justice

eukaryote a complex type of cell with a nucleus and membrane-bound organelles; a member of Domain Eukarya

evaluate assess the significance, worth or quality of a thing.

evaporation the process in which liquid water changes to water vapour through heating

evidence the available body of facts and information that is helpful in forming a conclusion or judgement as to whether a belief or idea is true or valid

excretion removal of wastes from the body

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

exponential occurring at an increasingly rapid rate

external environment the environment surrounding a cell outside the plasma membrane

exteroceptor a receptor that receives signals from the external environment

extracellular fluid the fluid that bathes the outside of cells in multicellular organisms

extrapolation extension beyond the measured range of data to read or construct new data that has not been measured

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

faeces the waste material eliminated from the body through the anus

falsifiable able to be disproved

feedback mechanism a mechanism in which the output or response affects the input or stimulus

fertilisation the fusion of gametes to produce a zygote

field guide a book used to identify organisms using photos and descriptions

filtrate the fluid remaining after filtration takes place

first filial generation (F_1) the first generation of offspring produced from a cross between two purebreeding parents (P)

first-order consumer a consumer that feeds directly on producers; also known as a herbivore

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

foetus the developing individual after the second month of pregnancy

food chain one organism occupying a trophic level is consumed by an organism in a higher trophic level, creating a chain whereby energy and matter are passed to progressively higher levels

frugivore a fruit-eating animal

gall bladder the organ that stores bile if there is no food to digest in the small intestine

gamete a cell produced for sexual reproduction; combines with another gamete at fertilisation; in humans, the gametes are ova and sperm cells; in flowering plants, pollen grains contain male gametes and ova contain female gametes

gastric juice substances produced due to the presence of food in the stomach; gastric juice contains mucus, water, hydrochloric acid, and pepsin and protease enzymes

gastrointestinal tract see *digestive system*

gene a unit of heredity that transmits information from one generation to the next; a segment of DNA that codes for a polypeptide

genetic cloning the process of making numerous identical copies of a gene

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

genetics the study of the mechanism and patterns of inheritance through the transmission of coded chemical instructions from one generation to the next

genome all the genetic material contained in an organism or a cell; includes the chromosomes within the nucleus and the DNA in mitochondria and chloroplasts

genomics the study of the genome – how genes interact with each other and the environment, and the resultant proteins produced; it requires a knowledge of an organism's entire DNA sequence, so studies rely on powerful technologies and bioinformatics

genotype a specific combination of alleles for a particular gene locus belonging to an individual or cell

glomerulus a network of capillaries that are located in the Bowman's capsule and are the first step in filtering the blood through the nephron

glucagon a hormone formed in the pancreas that promotes the breakdown of glycogen to glucose in the liver

glycogen an important energy-storing polysaccharide

glycolysis an energy-yielding process occurring in the cell cytosol in which glucose is partially broken down to pyruvate in enzyme reactions that do not require oxygen; this first stage of cellular respiration produces two ATP molecules

goitre a swelling in the neck caused by an enlarged thyroid gland

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

grafting when part of one plant is artificially attached to another

grana the stack of thylakoid membranes in a chloroplast that contain chlorophyll

habitat an area or environment where an individual or species lives within an ecosystem

haemodialysis the process of dialysis whereby blood is passed through an artificial kidney or dialysis machine

haemoglobin the respiratory pigment of most vertebrates and some invertebrates; contains iron; blood appears red when oxygenated

haemolysis the bursting of red blood cells

haploid (*n*) describes a cell or organism that has a genome that contains one copy of each chromosome; the number of chromosomes in a haploid cell is represented by *n*

heat balance when there is a balance between heat gain and heat loss

hemizygous describes a gene that occurs only as a single copy in a diploid organism or cell

herbivore a first-order consumer that feeds on plants

heredity the study of inheritance; the genetic transmission of characteristics from one generation to another

heterosomes non-identical chromosomes that pair up at meiosis (e.g. the X and Y chromosomes in human males)

heterotroph an organism that cannot synthesise its own organic compounds from simple inorganic material; it depends on other organisms for nutrients and energy requirements

heterozygous a genotype with two different alleles for a single gene locus

histone a protein around which DNA winds in eukaryotic cells

homeostasis the maintenance of a relatively constant internal environment within small tolerance limits, despite changes in the external environment

homologous chromosomes a pair of chromosomes that have the same size, shape and genes at the same locations

homozygous a genotype with two identical alleles for a single gene locus

homozygous lethal phenotype a phenotype that arises from a homozygous recessive genotype, leading to the premature death of an organism

hormone a chemical messenger

host an organism that another organism lives on or in

hydrogen bond a weak molecular chemical bond

hydrophilic tending to interact with and dissolve in water

hydrophobic avoiding association with water

hyperglycaemia elevated blood sugar levels

hyperthermia a state in which the internal temperature rises above the set point

hyperthyroidism high levels of thyroxine

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

hypoglycaemia a state in which the blood glucose level drops below the set point

hypothalamus a region of the brain

hypothermia a state in which the internal temperature falls below the set point

hypothesis a tentative prediction, usually based on an existing model or theory; also a tentative explanation of an observation based on an existing model or theory

hypothyroidism low levels of thyroxine

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

importance a measure of the significance or value of an idea, study or authority; how influential the idea or study is

incomplete dominance the state in which a heterozygous individual has a phenotype that is intermediate between those of the corresponding homozygous individuals; also known as partial dominance

independent assortment when alleles of gene pairs redistribute independently into different combinations in gametes during meiosis **inheritance** the genetic acquisition of characteristics by offspring from their parents

independent variable the variable that is varied by the researcher during an experiment; usually found in the first column of a table and recorded on the *x* axis of graphs

ingestion the taking in of nutrients

inorganic a compound that is not organic; includes simpler carbon compounds such as carbon dioxide

insulin a hormone produced in the pancreas by the islets of Langerhans, which regulates the amount of glucose in the blood.

intercellular occurring between cells

internal environment all material contained within the plasma membrane

International System of Units (Systeme International d'Unites, SI) a modern form of the metric system; a standardised worldwide system of measurements used in science and commerce

interoceptor a receptor that receives signals from the internal environment

interphase the stage between nuclear divisions

interpolation to read or construct a new data point that has not been measured but is within the range of measured data

interspecific interactions or relationships between members of different species

interstitial fluid fluid that lies in the spaces between cells; also known as extracellular fluid

intracellular occurring within a cell

intraspecific interactions or relationships between members of the same species

isotonic describes fluid with an equal solute concentration to another fluid

issues points or matters of discussion, debate or dispute; personal or social problems or difficulties that require resolution

justice the quality of being fair and reasonable using the principles of moral rightness and decency

karyotype a display of the number and appearance of the chromosomes of an organism or cell observed at metaphase

keystone species a species of relatively low abundance that has a large influence over lower trophic levels by allowing the coexistence of these species in a particular area

kidney an organ that removes wastes and controls the body's fluid balance

lacteal a vessel that transports materials to and from the villi of the small intestine

lactic acid fermentation a form of anaerobic respiration (no oxygen present) that occurs in animal cells and some anaerobic bacteria; glucose is converted to lactic acid

large intestine the final length of the gut; consists of the colon and the rectum; functions to compact undigested food material, and absorb water and some salts back into the body

larynx the voice box

leucoplast a colourless plastid not containing pigments

leukocyte a type of white blood cell that defends the human body against infectious diseases and foreign particles; the number circulating increases when injury or infection occurs

light-dependent stage the first stage of photosynthesis; it requires light energy that is absorbed by chlorophyll; water molecules split to produce oxygen and hydrogen ions and ATP

light-independent stage the second stage of photosynthesis; through a series of reactions carbon dioxide, hydrogen ions and ATP produce carbohydrate

lignin found in xylem cells; provides strength and structure to the cell wall and plant

line graph a graph where the relationship between two variables is represented by a line; used for continuous data to reveal how a factor changes over time or over space

line of best fit the line that most accurately fits the data, usually calculated using linear regression

linear regression a statistical tool used to model the dependence of one variable on another

linkage group genes that are inherited together; all the genes of a given chromosome are linked

linked genes genes on the same chromosome

linked refers to genes (or their alleles) that are inherited together more frequently because they are located on the same chromosome

lipoprotein a biochemical structure that contains both lipids and proteins

locus the position a gene occupies in a chromosome

logbook the record of an experiment or investigation kept by the scientist performing the experiment; it is a legal record of the experiments and their results

loop of Henle the portion of a nephron that connects the proximal convoluted tubule to the distal convoluted tubule

lumen the narrow central cavity of blood vessels

lymph colourless fluid that circulates through the lymphatic vessels to be returned to the blood

lymph vessel a thin-walled tube with valves that carries lymph around the body

lymphatic system a system of vessels that drains excess fluid from the tissues

lysosome an organelle within the cytoplasm containing digestive enzymes

margin of error the maximum difference expected between a true population parameter and the sample estimate for that parameter

marginal niche a set of environmental conditions in which an organism can survive but not thrive

marker a DNA sequence with a known physical location on a chromosome that is located close to the gene of interest

mean a measure of central tendency; the sum of all values divided by the number of values

mechanical digestion the process whereby large pieces of food are broken down through chewing or muscular movement in the stomach

mechanoreceptor a sensory cell or organ that detects mechanical stimuli such as touch, pressure, vibration or tension

median a measure of central tendency revealing the middle value in a range of values; determined by arranging values in numerical order and choosing the central value

meiosis a two-phase type of cellular division in which the chromosome number of a cell is halved to the haploid number; meiosis is the basis of gamete formation

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

Mendelian genetics explanation of patterns of inheritance based on the discoveries of Gregor Mendel and his statistical analysis and breeding experiments on pea plants

mesoderm the middle tissue layer of an embryo

metabolism the sum of all chemical reactions occurring within an organism to maintain life

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

micro-propagation a tissue culture technique for plant propagation, in which tissue is taken from a plant and grown in a laboratory to produce plantlets that are genetically identical to the parent

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

microtubules fine tubes that help to maintain the shape of the cell and separate chromosomes during mitosis

microvilli tiny projections on the surface of villi that increase the surface area of the gut

misconception a view or opinion that is incorrect because of faulty thinking or understanding

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

mitochondrial DNA (mtDNA) DNA contained in mitochondria

mitochondrial matrix a gel-like material occupying the space enclosed by the inner membrane of a mitochondrion

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

mode the most frequent response or value in a data set

model a representation of a system or phenomenon that explains the system or phenomenon; it may be mathematical equations, a computer simulation, a physical object, words or in some other form; a systematic description of an object or phenomenon that shares important characteristics with the object or phenomenon; used in learning, in the formation of scientific theories, for making predictions and for forecasting

monoculture the agricultural practice of growing a single crop or plant species over a wide area for a large number of consecutive years

monohybrid cross a cross between two organisms that are heterozygous at one gene locus

monophyletic describes organisms that are grouped together as a clade

monoploid describes a cell or organism that has a functional genome consisting of one copy of each chromosome, represented by 1*n*

monosomy the condition in which somatic cells contain one copy of a particular chromosome

morals the judgement of the rightness or wrongness of human actions and character

multiallellic when three or more alleles of a gene exist among members of a population

multicellular describes an organism consisting of more than one cell

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

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

mutualism a symbiotic relationship whereby both species in the relationship benefit from each other

myocardial infarction a heart attack

myocyte cell a type of muscle cell

negative control a control group in an experiment in which no response is expected; the opposite of a positive control, in which a known response is expected

negative feedback a response to a stimulus that counteracts the stimulus and reverses the direction of the change

nephron the structure of the kidney where filtration of the blood occurs

neurotransmitter chemical that transmits or carries a nerve impulse to another nerve

niche the set of environmental conditions an organism lives in

nitrogenous base a structural component of nucloetides, DNA has adenine (A), cytosine (C), guanine (G) and thymine (T); in RNA thymine is replaced with uracil (U)

nociceptor pain receptor

non-disjunction the failure of sister chromatids in mitosis or homologues in meiosis to separate and go to opposite poles

non-maleficence the principle that we should act in ways that do not cause harm or inflict suffering upon others

nuclear membrane the membrane surrounding the nucleus

nucleoid the region within a prokaryotic cell that contains the genetic material

nucleolus a structure found within the nucleus of a non-dividing cell; a site in which the protein and RNA subunits of ribosomes are assembled

nucleotide base pair two complementary nucleotide bases that are joined together by hydrogen bonding in a DNA double strand

nucleotide the basic building block of nucleic acids (DNA and RNA), which are linked together by phosphodiester bonds; each nucleotide is made up of a five-carbon sugar, a phosphate group and a nitrogenous base

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

objective impartial; not influenced by personal feelings or opinions when considering and representing facts to make judgements or arguments

oedema an excessive build-up of fluid in the body's tissues

oesophagus the muscular tube that transports food from mouth to stomach

omnivore an organism that feeds on a range of foods, including plant and animal matter

oncogenes genes that can promote cancer

optimum range the narrow range within the tolerance range an organism has for a particular factor, at which the organism functions best

organ a structure made up of different types of tissue working together

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

organic describes complex, carbon-containing compounds

osmoreceptor a receptor that responds to changes in the osmotic pressure of the blood

osmoregulation processes by which internal water and solute concentrations are maintained despite fluctuations in the external environment

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

outlier a data point that does not fit the pattern shown by other measured data points; something that lies outside the main body or group; in statistics, a value that is much bigger or much smaller than most values in a set of data

oxyhaemoglobin the combination of oxygen and haemoglobin that is carried around the body in red blood cells

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

pain receptor a sensory cell or organ that detects pain signals

pancreatic juice the secretions by the pancreas into the small intestine via the duodenum; contains amylase, trypsin, lipase and bicarbonate

paraphrasing using your own words to express someone else's ideas or results; the idea is clearly someone else's but the writing is your own; a citation is required

paraphyletic describes a group that does not contain all of the organisms descended from the most recent common ancestor

parasite an organism, such as a bacterium, virus, fungi, worm or arthropod, that lives on or in another organism

parasitism a symbiotic relationship whereby one species benefits to the detriment of the other

parenchyma large, thin-walled cells that make up the cortex of the plant

parental generation (P) two individual organisms that represent the start of a breeding experiment; their offspring are the F_1 generation

partial dominance *see* incomplete dominance

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

patent the exclusive right granted by a government to an inventor to manufacture, use or sell an invention for a certain number of years

pedigree analysis a way of finding out the type of inheritance of a characteristic by following the inheritance pattern over two or more generations

peristalsis waves of muscular contractions that push food down the oesophagus

peritoneal dialysis dialysis occurring inside the body using the peritoneum as the membrane across which wastes can be removed

permeable able to pass through

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

phenotype the actual form of a specific feature in a particular individual based on their genotype; can be used in reference to particular traits or characteristics or to the overall form of an individual

phloem a vascular tissue in plants, mainly responsible for the transport of sugars from leaves to the rest of the plant; it is composed of living cells

photoreceptor a sensory cell or organ that detects light signals

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

phylogenetic tree a system of classification based on common ancestry, often determined through genetic analysis; a diagram that shows the evolutionary relationship between organisms

physiological stress stress caused when an organism experiences conditions outside its tolerance range

phytoplankton the collective term for the tiny photosynthetic organisms present in bodies of water

pie chart a type of graph where a circle is divided into sectors that represent a proportion of the whole; each sector represents the relative size of each value

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

placebo a substance that has no therapeutic effect, used as a control in testing new drugs

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

plagiarism duplicating the work of another person without referencing them, thus claiming their work or ideas as your own

plaque a semi-hardened accumulation of substances

plasma membrane the insoluble boundary of all living cells that maintains the contents of the cell

plasma the pale yellow liquid component of the blood that holds blood cells, proteins and nutrients in suspension

plasmid a small circular piece of DNA, found in bacteria, which is able to replicate independently of the cell's chromosomes

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

plastid an organelle in a plant cell containing coloured pigments

platelet a small cell fragment involved in the clotting property of the blood

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

pollinator an organism that is able to transfer pollen from one flower to another

polygene a gene for which the alleles have an additive effect on a phenotype; many polygenes together contribute to continuous variation in a phenotype

polygenic inheritance transmission between generations of characteristics that are controlled by more than one gene

polymer a large molecule built up from linking smaller molecules together

polypeptide many amino acids linked together forming a protein or part of a protein

polyploidy when a cell or organism has a genome comprising three or more copies of each chromosome, represented by 3*n*, 4*n*, 5*n*, 6*n* etc.

population a group of individuals belonging to the same species living in a particular area at the same time; a set of individuals, objects or data from which a statistical sample can be drawn

population pyramid a graphical illustration that shows the distribution of various age groups in a population

positive control a condition in which an effect is expected, giving confidence that the experimental set-up can yield the expected results; *see* negative control

positive feedback when a change of variable (stimulus) occurs, a response that changes the variable even more in the same direction

predator an organism that hunts another organism for its food

preferred niche a set of environmental conditions in which an organism can thrive

pressure group a group that tries to influence public policy in the interest of a particular cause

prey an organism that is hunted by another organism for food

primary data data that you have measured or collected yourself

primary germ layers the embryonic tissues from which all tissues and organs of the body will develop; the ectoderm, endoderm and mesoderm

producer an autotrophic organisms that can synthesise organic matter from inorganic matter, using the energy of the Sun (if it is photosynthetic) or that from chemical reactions (if it is chemosynthetic)

professional association a body of people engaged in the same profession that control entry to the profession, maintain standards and represent the profession in discussions with other bodies

prokaryote a simple type of cell that lacks a nucleus and membrane-bound organelles; a member of Domain Archaea or Bacteria

proteomics the study of the entire protein content expressed by a cell

proto-oncogene a gene that can promote cancer

proximal tubule the section of the tubule in the nephron that leads from the Bowman's capsule to the loop of Henle

pulmonary circulation the system of blood vessels that leads to and from the lungs

Punnett square a grid used to graphically predict the outcome of a cross or breeding experiment

purebreeding a line of organisms that always produce offspring with the same phenotype when crossed with each other

pyloric sphincter the small muscular opening that controls the amount of food that can leave the stomach and enter the small intestine

pyruvate the end product of glycolysis

quadrat a method used in population sampling where a square is placed on the ground to count each individual of a species and determine their density; useful for stationary organisms

qualitative measurement measurement with descriptive or non-numerical results

qualitative study exploratory research used to define a problem or develop an approach to a problem; used to gain an understanding of underlying reasons, opinions and motivations, and so focus groups, in-depth interviews and observation are often used to collect information

quantitative measurement measurement with numerical values

quantitative study research used to investigate a specific question using observable phenomena; tries to understand how prevalent a phenomenon is by sampling a large population or repeating experiments and analysing results using statistics to achieve an unbiased result that can be generalised to a larger population

quiescent inactive

quoting to copy text or speech word for word and acknowledge the source

radiation the transfer of heat from a hot object by infrared waves

random distribution a pattern of distribution in which organisms are spaced irregularly; the location of an organism does not affect the location of another

randomised controlled trial a quantitative study where selected participants are randomly allocated to be either in a treatment group or in a control group

range the difference between the highest and lowest value in a data set

receptor a structure that detects or receives a stimulus

receptor protein a protein that binds hormones and other signal molecules

recessive a phenotype that requires two copies of its allele in an individual to be expressed

recognition protein a protein that acts as a marker on membranes

recombinant offspring offspring with combinations of alleles that are not found in either parent

recombinants offspring with different combinations of DNA than their parents, due to mixing of genes

rectum the final section of the large intestine, where wastes may be stored prior to evacuation

reference the source of a specific piece of information or quotation

references list a list of the sources of information referred to in a report or presentation

reliable describes evidence gained from studies where the test was replicated a number of times, yielding consistent results, when an independent researcher can replicate the experiment and get similar results, and when the results are plausible, that is, they align with other evidence in the field

renal artery the branch of the aorta that brings blood (containing nitrogenous waste and water, blood proteins, red blood cells and minerals dissolved in the blood plasma) to the kidneys

renal pelvis the section of the kidney where urine is collected and directed to the ureter

repeatable giving the same result, within uncertainty limits, when repeated measurements are made by the original investigator

replicate one of several experimental samples subjected to all the treatment combinations to be compared in an experiment, for example, duplicate refers to two repetitions of the conditions, triplicate to three repetitions

reproducible giving the same result, within uncertainty limits, when repeated measurements are made by other researchers

reproduction the creation of a new generation of single cells, single-celled organisms or multicellular organisms

research question the specific question that a particular experiment or investigation is attempting to answer

retinoblastoma a cancer of the retina in the eye

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

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

root pressure the force that pushes water up the stem from the roots

rough endoplasmic reticulum endoplasmic reticulum with ribosomes attached

sample in statistics, a group drawn from a larger group (the population) that is used to estimate the characteristics of the whole population

scatter graph a graph or plot showing data points, without a line joining the points, and used to demonstrate or determine a mathematical relationship between variables; the axes are defined by the variables

scatter plot a graph in which the values of two variables are plotted along two axes, the pattern of the resulting points revealing any correlation

scavenger a consumer that feeds on dead and decaying flesh or remains

scientific concept a scientific theory or law that is a well-substantiated explanation of some aspect of the natural world; often generated using the scientific method and repeatedly tested and supported through observation and experimentation

scientific report an account of an investigation of a scientific phenomenon or issue designed to convey information to a particular audience

scientific table a method of arranging data for interpretation by an audience; the data are often statistically analysed

scion the piece of the plant that is artificially attached to the base of another (stock) in grafting

second filial generation (F_2) offspring of the F_1 generation; the second generation produced from a cross between two homozygous parents (P)

secondary data data or information that has been collected by someone else

seed disperser an organism that feeds on fruits and seeds for nutrition; when the animal defecates, it deposits the seeds in a new location where they can germinate and grow

seed predator an organism that feeds on seeds and generally acts as a seed disperser

selective breeding a process by which humans domesticate animals or plants by purposely choosing individuals with the most desirable characteristics as parents for each successive generation of breeding

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

sensitivity limit the lowest level of a substance that can be detected by a test

septum the dividing wall that keeps the deoxygenated blood on the right side of the heart from mixing with the oxygenated blood on the left side

set point optimal level

sex chromosomes the pair of chromosomes that determines the sex of an individual

sex-linked genes genes found on the sex chromosomes

sex-linked refers to the inheritance pattern shown by a gene located on a sex chromosome

significant difference a difference between data values that is statistically significant; the probability (p) of the difference being due to chance is so small (usually less than 5%) that the result is considered true

small intestine the longest part of the gastrointestinal tract; receives material from the stomach

smooth endoplasmic reticulum endoplasmic reticulum with no ribosomes attached

sodium–potassium pump a membrane protein that uses energy to transport sodium ions out of, and potassium ions into, cells against their concentration gradients

solute a substance that can be dissolved in another substance

solution a mixture of solute and solvent

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

somatic cell a normal body cell, as compared with a germ-line cell from which a gamete (i.e. sperm or ovum) is derived

source a person or report from which evidence and ideas originate

sphincter a circular muscle that when constricted closes a natural body passage and relaxes as required to allow flow of substances through the passage

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

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

spore a reproductive body able to withstand harsh environmental conditions

standard abbreviations abbreviations that are conventionally used in scientific communication

standard deviation a measure of the dispersion of a set of data from its mean; expresses the variability of a population or set of data

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

stent a small mesh tube that is used to treat narrow or weak arteries

stimulus (plural stimuli) a signal that causes a response

stock the base of a plant, to which part of another plant (scion) is attached in grafting

stomata the openings in leaves, and some stems, that control the movement of gases into and out of the plant; singular is stoma (or sometimes stomate)

stroma the jelly-like semifluid interior of a chloroplast

subspecies a subdivision of a species

summarising using your own words to shorten a report so that it only includes the essential information; should provide a clear indication of the main points made in the report

surface tension the force that creates the effect of a stretched membrane over liquid

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

surfactant the thin layer of fluid that covers the internal membrane of each alveolus

survey a series of questions designed to query participants in a study in order to collect data for analysis

symbiosis the relationship between individuals of two or more species that interact together whereby at least one organisms benefits from the relationship

synapsis the pairing of homologous chromosomes

systemic circulation the general body system of blood vessels

taxa/taxonomic level a group of organisms; the major taxa are known as Domains, Kingdoms, Phyla, Classes, Orders, Families, Genera and Species

taxonomist a scientist who studies organisms and places them into taxa

teratogen an agent that causes physical defects in a developing foetus

terminally differentiated cells cells that have lost their ability to replicate

terrestrial land dwelling

test cross a cross using an organism with a recessive phenotype to determine the genotype of an organism with a dominant phenotype

tetraploid having four haploid sets of chromosomes in each cell, represented by $4n$

theory a collection of models and concepts that explain specific systems or phenomena; scientific theories allow predictions to be made and hence are falsifiable

thermoreceptor a sensory cell or organ that detects changes in temperature

thermoregulation temperature regulation

thylakoid membrane the interconnected, folded membranes within chloroplasts

thyroid stimulating hormone (TSH) a hormone produced by the pituitary gland in response to signals from the hypothalamus

thyroxine a hormone produced by the thyroid gland

tissue a group of specialised cells working together to perform a specific function

tolerance range the range within which an organism can function and reproduce

tonoplast the membrane surrounding the vacuole

top consumer the last link in the food chain

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

trachea an organ that carries gases to the lungs via the bronchi and bronchioles; it is strengthened with rings of cartilage to stop it collapsing

tracheid an elongated cell in the xylem of plants; mature tracheids are dead cells

trait a heritable characteristic; phenotype

transect a method used in population sampling whereby a line is drawn through a community to determine the distribution of species; can be used in conjunction with quadrats and is useful for stationary organisms

transpiration stream a continuous column of water that runs the length of the stem of a plant

transpiration the loss of water from plants through evaporation

transpirational pull the force arising from the evaporation of water from leaves and transmitted down the xylem

transport protein a protein that carries molecules across membranes

triploid having three haploid sets of chromosomes in each cell, represented by 3*n*

trisomy the condition in which somatic cells contain three copies of a particular chromosome

trophic efficiency relates to the percentage of energy at one trophic level that ends up in the next trophic level

trophic level a feeding level in the food chain of an ecosystem

***t*-test** a statistical test commonly used to analyse differences between two sets of data

tumour suppressor gene a gene that inhibits cell division

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

umbilical cord the cord that attaches the foetus to the placenta

unavailable niche environmental conditions that are outside the tolerance range of an organism

unicellular an organism made up of a single cell

uniform (continuous) distribution a pattern of distribution in which organisms are evenly spaced; the presence of one organism determines how close or distant another will be

urea the compound to which most nitrogenous wastes (produced from the oxidation of amino acids) are converted; it is excreted in urine

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

valid describes evidence gained from studies using suitable and accurate techniques and equipment, with appropriate control of variables and randomisation; measured by evaluating the design of a study used to determine cause and effect; controlled laboratory experiments have high validity; studies in difficult to control environments are less valid; randomisation increases validity

valid results results that are affected by only a single independent variable and hence are reproducible

values important and lasting beliefs or ideals shared by the members of a culture about what is good or bad and desirable or undesirable

variable something that can change or be changed, as distinct from a constant, which does not change

vascular bundle a combined bundle of xylem and phloem tissues in plants

vascular tissue (in plants) the plant tissue devoted to the bulk transport of water, nutrients, sugars and other substances; comprising the xylem and phloem

vasoconstriction decrease in the diameter (narrowing) of blood vessels, particularly arterioles

vasodilation dilation (widening) of blood vessels, particularly arterioles

vasopressin an antidiuretic hormone responsible for increased permeability of the distal tubules of the kidney, increasing water reabsorption and reducing urine volume

vegetative propagation the cloning of plants

vein a blood vessel that carries blood to the heart

vena cava the vein that delivers deoxygenated blood from the general body system to the right atrium

ventricle one of the two muscular chambers of the heart

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

vessel element one type of cell comprising xylem tissue of flowering plants; they have perforations at each end of the usually dead cells to allow the free flow of water

villi the projections from the surface of the small intestine that increases its surface area and thus increases absorption

water potential the capacity of water to do work based on the kinetic energy of its individual molecules; the work is done as water moves across selectively permeable membranes due to osmosis

wildlife corridor a narrow area of wildlife habitat that provides a link between areas of similar wildlife habitat

wilt to become limp and floppy

X-linked related to a gene located on the X chromosome

xylem a vascular tissue in plants, mainly composed of dead cells, responsible for the bulk transport of water and nutrients from the roots to the rest of the plant

Y-linked related to a gene located on the Y chromosome

zooplankton a collective term for the tiny heterotrophic organisms present in bodies of water

zygote the first cell of a new individual, formed by fusion of a sperm and an ovum at fertilisation

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