

NELSON QSCIENCE

BIOLOGY

UNITS

1

2

Pam Borger
Kelli Grant
Louise Munro
Jane Wright





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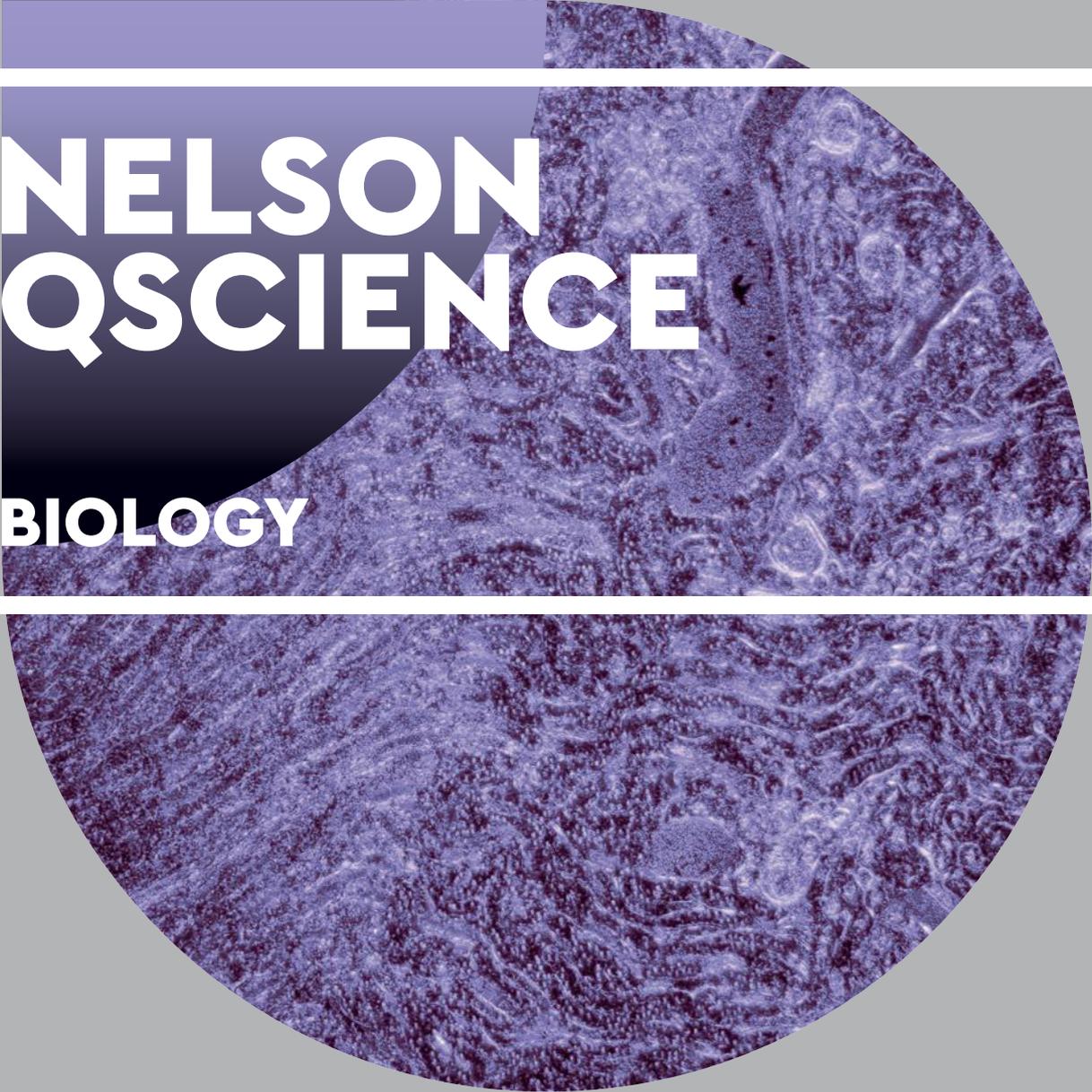
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Nelson QScience Biology Units 1 & 2

1st Edition

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Cover design: Chris Starr (MakeWork)

Cover image: iStock.com/defun

Production controller: Erin Dowling

Typeset by: MPS Limited

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Acknowledgements

Contributing authors: Stephen Bird, Tony Chiovitti, Jacinta Duncan, Merrin Evergreen, Wayne Gerdtz, Patrick-Jean Guay, Genevieve Martin, Xenia Pappas, Katrina Walker and Jim Woolnough, with Sarah Jones.

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This syllabus forms part of a new senior assessment and tertiary entrance system in Queensland. Along with other senior syllabuses, it is still being refined in preparation for implementation in schools from 2019.

For the most current syllabus versions and curriculum information please refer to the QCAA website <https://www.qcaa.qld.edu.au/>

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National Library of Australia Cataloguing-in-Publication Data

A catalogue record for this book is available from the National Library of Australia.

Cengage Learning Australia

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South Melbourne, Victoria Australia 3205

Cengage Learning New Zealand

Unit 4B Rosedale Office Park
331 Rosedale Road, Albany, North Shore 0632, NZ

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Printed in Hong Kong by China Translation & Printing Services.

1 2 3 4 5 6 7 22 21 20 19 18



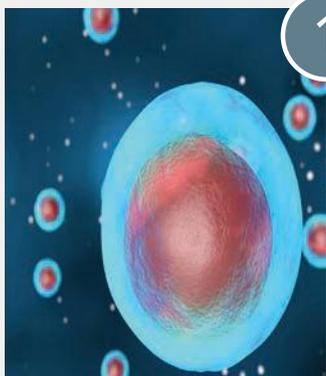
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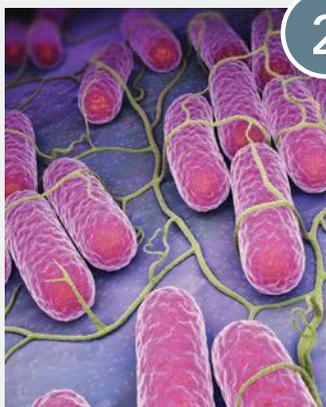


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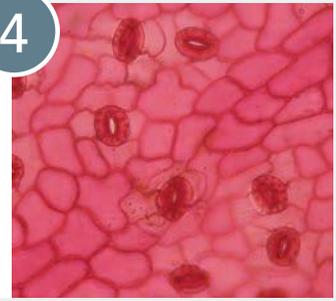
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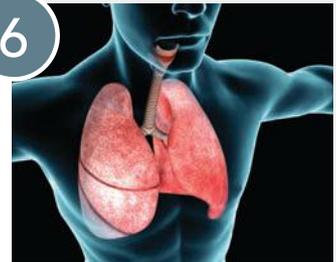


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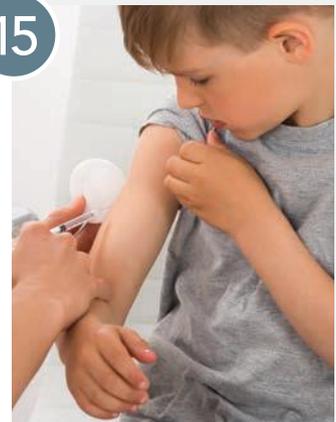


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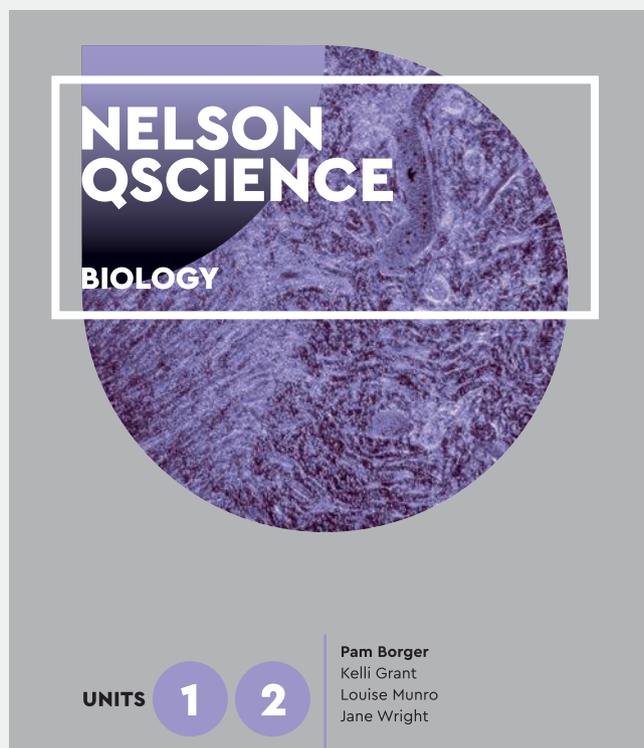
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PREFACE

Nelson QScience Biology Units 1 & 2 has been written to meet the requirements of the QCAA Senior Secondary Science Syllabus – Biology. Each page has been carefully considered to provide students with all of the information they need to meet the content and skills requirements of the new syllabus.

With the introduction of the QCE external examination, *Nelson QScience Biology* includes features such as practice exams at the end of each section, a Unit 1 & 2 practice examination, chapter quizzes (available on *NelsonNet*) and *ExamView* (available on *NelsonNet*).



AUTHORS AND REVIEWER TEAM

Nelson QScience Biology Units 1 & 2 has been adapted from the following titles: *Nelson Biology Units 1 & 2 for the Australian Curriculum* by Stephen Bird, Pam Borger, Merrin Evergreen, Genevieve Martin, Xenia Pappas, Katrina Walker, Jim Woolnough and Jane Wright; and *Nelson Biology Units 3 & 4 for the Australian Curriculum* by Pam Borger, Tony Chiovitti, Jacinta Duncan, Wayne Gerdtz, Patrick-Jean Guay, Genevieve Martin, Katrina Walker, Jim Woolnough and Jane Wright, with Sarah Jones.

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SYLLABUS REFERENCE GRID

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UNIT ONE » CELLS AND MULTICELLULAR ORGANISMS	
TOPIC 1: CELLS AS THE BASIS OF LIFE	
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Infectious disease	Chapter 14
Immune response and defence against disease	Chapter 15
Transmission and spread of disease (epidemiology)	Chapter 16

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ABOUT THIS BOOK

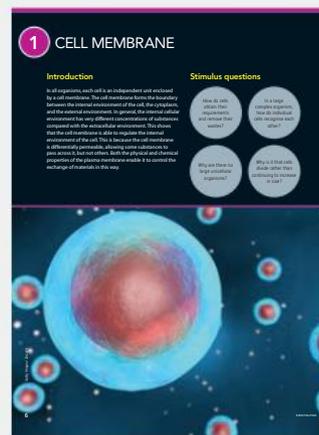
At the beginning of unit and topic

- Unit introductions are an overview of the key content in the unit.
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At the beginning of each chapter

- A short chapter summary introduces students to the key content and skills covered.
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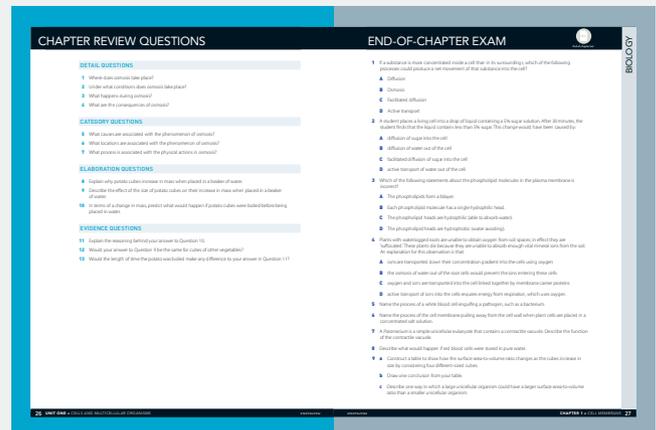


In each chapter

- Key formulas** are highlighted in the margin.
- Key glossary terms** are highlighted in the margin.
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- Inquiring Further** provides opportunities for students to further investigate scientific concepts and develop scientific research skills.
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- **Chapter review questions** are written in the style of Marzano and Simms (2014) questioning sequences.
- **End-of-chapter examinations** occur at the end of each chapter to help students develop skills in decoding and answering exam-style questions.



At the end of the book

- **Practice exam** questions provide an extended practice of the content and skills learnt across the text.
- **Glossary** provides explanations of all of the new terms introduced in the text.
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» UNIT ONE

CELLS AND MULTICELLULAR ORGANISMS

- Topic 1: Cells as the basis of life
- Topic 2: Multicellular organisms

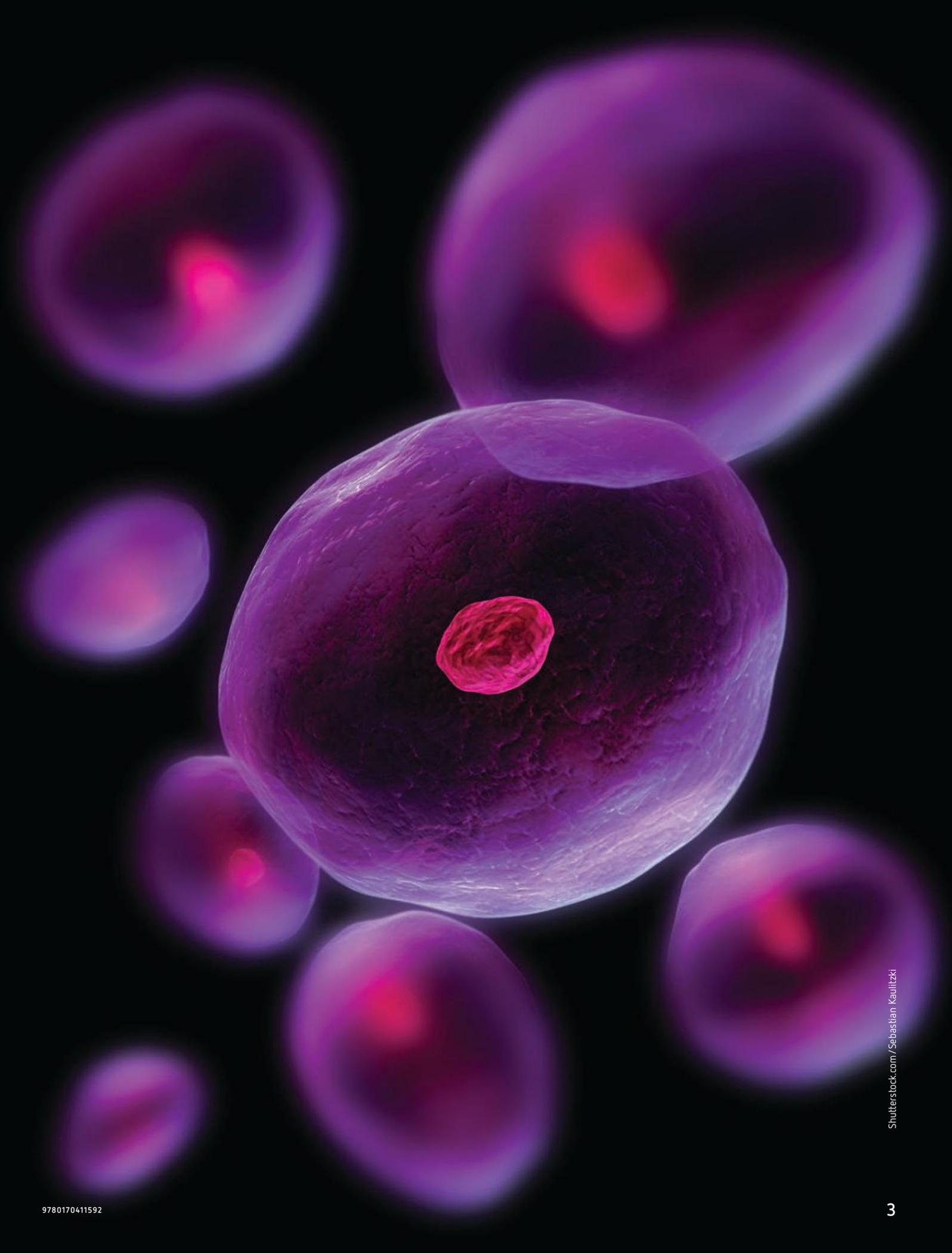
All organisms, no matter how simple in arrangement, are made up of structurally similar units, called cells. All cells have many similar features. Reasons for differences in some features are so that organisms can function more effectively. Single-celled organisms carry out all of the functions related to the need to exchange matter and energy with their immediate environment. Multicellular organisms are composed of more than one cell and are more structurally complex. These organisms are made up of specialised cells, which are organised to carry out specific functions vital for survival.

UNIT OBJECTIVES

By the end of this unit, students should be able to:

- 1 describe and explain cells as the basis of life, and multicellular organisms
- 2 apply understanding of cells as the basis of life, and multicellular organisms
- 3 analyse evidence about cells as the basis of life, and multicellular organisms
- 4 interpret evidence about cells as the basis of life, and multicellular organisms
- 5 investigate phenomena associated with cells as the basis of life, and multicellular organisms
- 6 evaluate processes, claims and conclusions about cells as the basis of life, and multicellular organisms
- 7 communicate understandings, findings, arguments and conclusions about cells as the basis of life, and multicellular organisms

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» UNIT ONE

CELLS AND MULTICELLULAR ORGANISMS



Topic 1: Cells as the basis of life

All cells have common requirements. They need a source of energy and matter and they need to remove wastes. All cells have a membrane that allows some substances to move into the cell and other substances to leave. The semipermeable nature of the cell membrane determines which substances are exchanged with the surrounding environment. Numerous life-sustaining chemical reactions occur in cells, many of which are controlled by enzymes. A large number of reactions occur simultaneously in eukaryotic cells due to the presence of membrane-bound organelles. Green plants are able to transform light energy to chemical energy through the process of photosynthesis. Cellular respiration releases the chemical energy for use in other cellular reactions.

SCIENCE AS A HUMAN ENDEAVOUR

Students should investigate the ways stem cells can be used to repair and replace organs, the use of photosynthesis in food or fuel production and the continued research into the fluid mosaic model.

1 CELL MEMBRANE

Introduction

In all organisms, each cell is an independent unit enclosed by a cell membrane. The cell membrane forms the boundary between the internal environment of the cell, the cytoplasm, and the external environment. In general, the internal cellular environment has very different concentrations of substances compared with the extracellular environment. This shows that the cell membrane is able to regulate the internal environment of the cell. This is because the cell membrane is differentially permeable, allowing some substances to pass across it, but not others. Both the physical and chemical properties of the plasma membrane enable it to control the exchange of materials in this way.

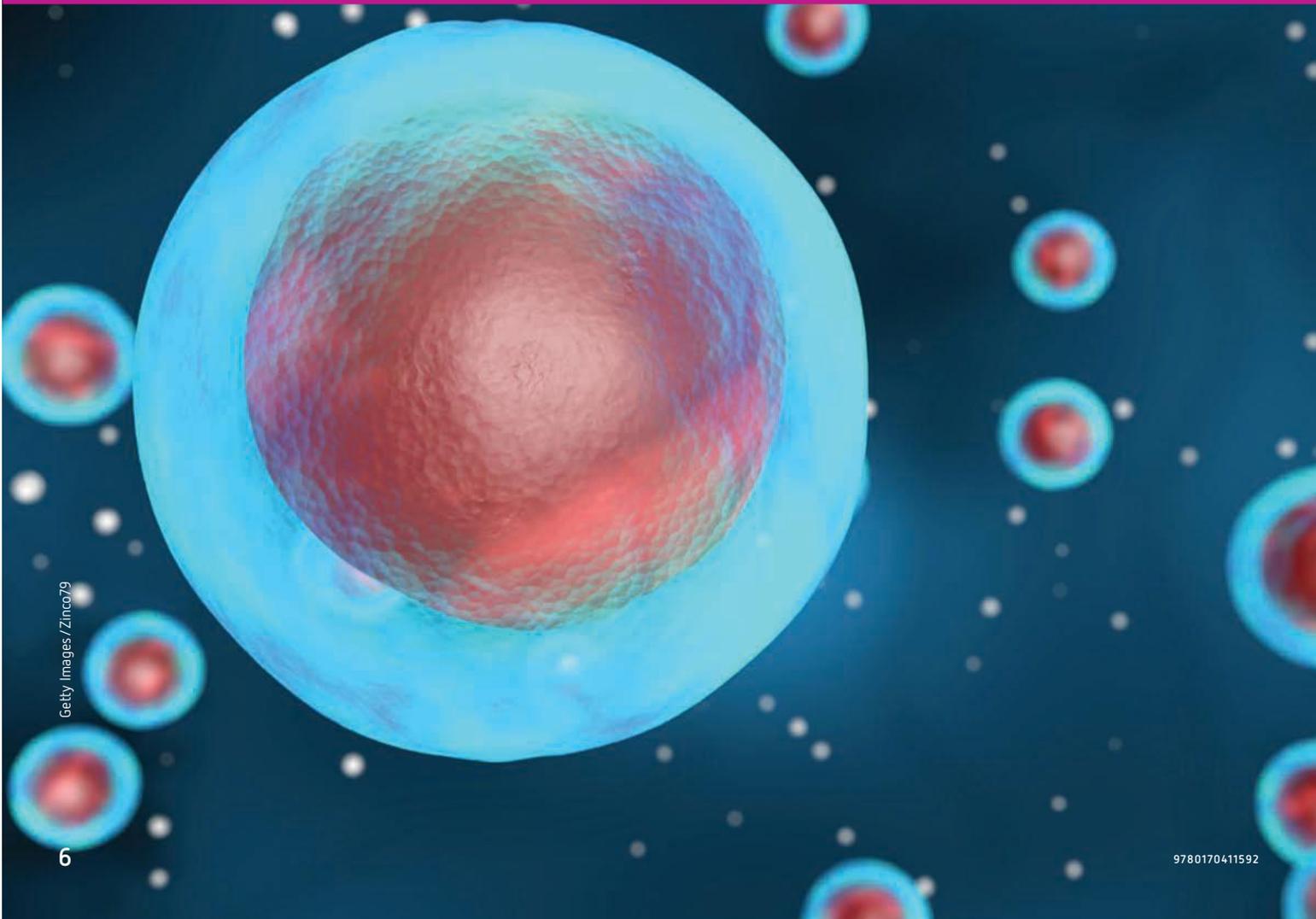
Stimulus questions

How do cells obtain their requirements and remove their wastes?

In a large complex organism, how do individual cells recognise each other?

Why are there no large unicellular organisms?

Why is it that cells divide rather than continuing to increase in size?



1.1

Structure of the cell membrane

The **cell membrane** (also called a plasma membrane) is **differentially permeable**. Its ability to keep the concentration of substances inside the cell fairly constant and very different from the **external environment** depends on its structure.

The current concept of membrane structure is called the **fluid mosaic phospholipid bilayer model**. This model, originally simply called the fluid mosaic model, was proposed in 1972 by Singer and Nicolson. It 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 membrane proteins can move laterally, and others are fixed in position (Figure 1.1.1). Both proteins and the lipid bilayer help to control the exchange of materials between the external and **internal environments**.

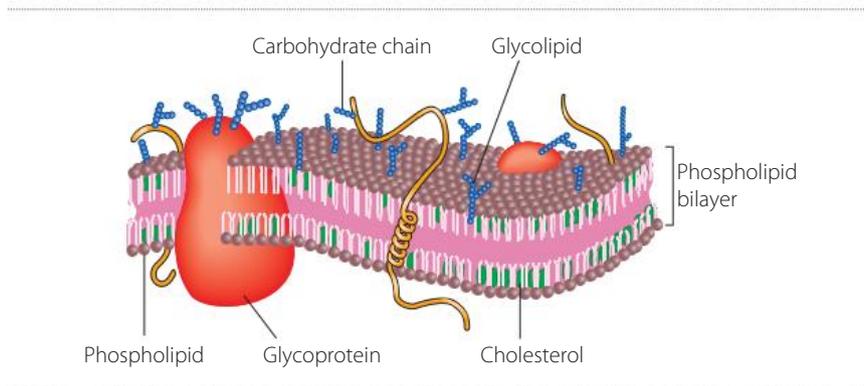


FIGURE 1.1.1
A three-dimensional view of a plasma membrane based on the fluid mosaic model

Phospholipids

Phospholipids are a type of lipid that are a major component of cell membranes. Each phospholipid can be represented by a head and two tails (Figure 1.1.2). A phosphate group on the head makes this end **hydrophilic** (able to absorb water or dissolve in water) and the two fatty acid tails are **hydrophobic** (water

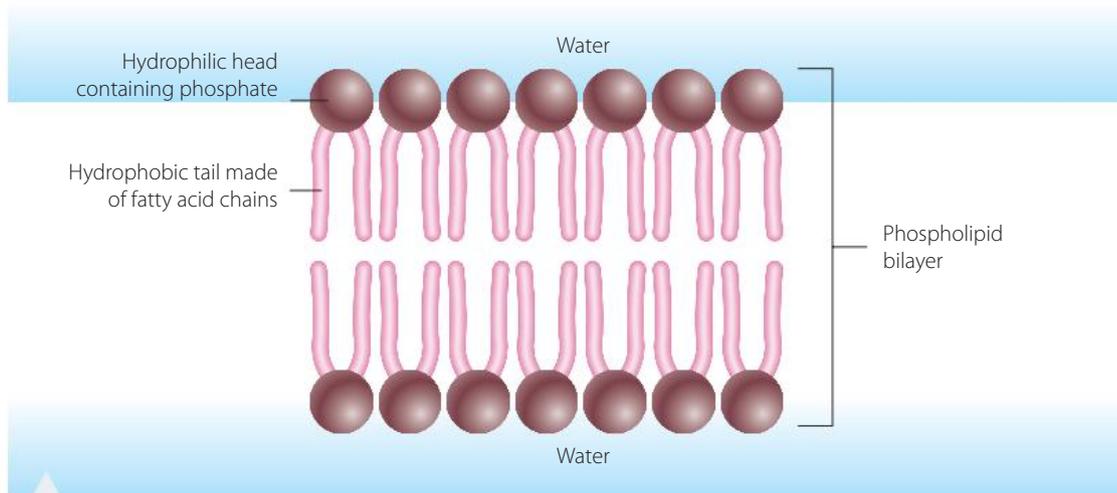


FIGURE 1.1.2 Phospholipid molecules. The hydrophilic head is attracted to water whereas the hydrophobic tails repel water. Phospholipids form a bilayer in membranes.

cell 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

differentially permeable
a quality of a membrane that means only certain kinds of molecules can pass through it

external environment
the environment surrounding a cell outside the cell membrane

fluid mosaic phospholipid bilayer model
the generally accepted model of membranes in which proteins are embedded in a phospholipid bilayer

bilayer
a double layer

internal environment
all material contained within the cell membrane

phospholipid
a type of lipid in which the head end is hydrophilic and the tail end is hydrophobic

hydrophilic
tending to interact with and dissolve in water

hydrophobic
avoiding association with water

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

cholesterol
a type of lipid found in cell membranes that maintains membrane fluidity

phytosterol
a type of plant-derived lipid compound that is similar to cholesterol in structure and function

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

- 1.1.1 Cell structure: cell membrane
- 1.1.2 Insights into the cell membrane
- 1.1.3 Active plasma membranes
- 1.1.4 Visualising the plasma membrane

avoiding or unable to dissolve in water). This means that while the heads are attracted to water, the tails are repelled. When phospholipids spontaneously form a bilayer, their fatty acid tails turn inwards, away from the watery environment and **cytoplasm**, and towards each other, rather like salad oil forming a film on the surface of water.

Cholesterol

In animal cell membranes, another type of lipid called **cholesterol** is interspersed among the phospholipid molecules. Cholesterol is an essential structural component of membranes. It stabilises and strengthens the membrane and maintains it at a suitable fluidity. In plants, **phytosterol**, instead of cholesterol, regulates membrane fluidity.

Membranes are fluid

The lipid components of all membranes provide membranes with the unique properties of being flexible and fluid. This allows cells to change shape and grow. During cell division and **vesicle** formation, membranes can break and reassemble themselves. The fluid nature of membranes also enables them to repair themselves. If the plasma membrane is punctured, some of the cytoplasm will leak out, but the phospholipids will move sideways and quickly seal the hole.

Membrane proteins

A range of different proteins are embedded in the phospholipid bilayer, with many penetrating from one side of the membrane to the other (Figure 1.1.3). For example, adhesion proteins link cells together, receptor proteins bind hormones and other substances that cause changes to the cell's activities and recognition proteins act as markers, allowing the immune system to distinguish between 'self' and 'non-self' cells.

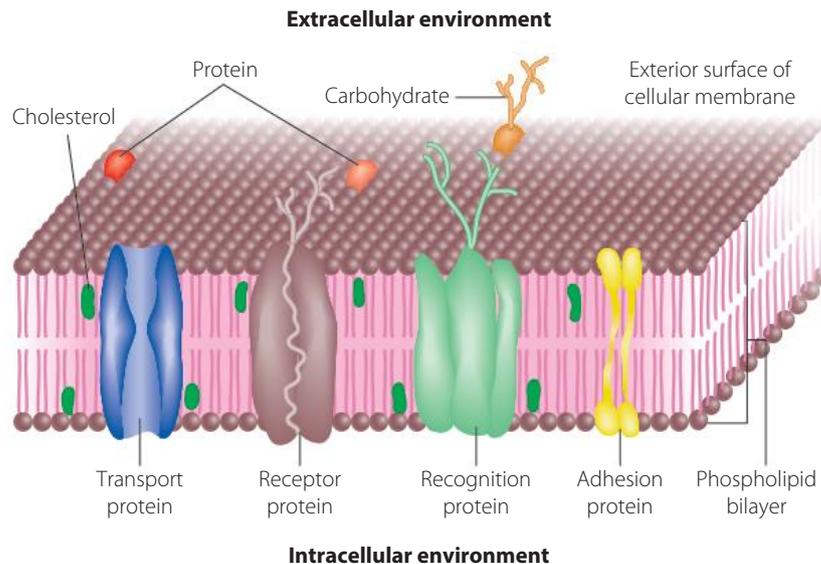


FIGURE 1.1.3 A view of part of the cell membrane showing embedded proteins: transport protein, receptor protein, recognition protein and adhesion protein

Protein channels

Transport proteins assist certain substances to cross the membrane. **Channel proteins** are a type of transport protein. They form a **protein channel** that acts as a passageway that allows specific substances to move across the membrane. These channels are found in the cell membranes of nearly all cells. An example is the rapid movement of charged particles across the membrane when a nerve is stimulated. This causes a dramatic change in the electric potential difference (the difference in positive and negative charges) across the membrane and explains how the electrical charge of a nerve impulse is transmitted along nerve cells. The rate of transport through channels is very high, often in the order of 10^6 particles per second.

INQUIRING FURTHER

The venoms produced by some organisms, for example spiders, scorpions and snakes, contain toxins capable of shutting down the nervous systems of predators and prey. Identify one venom or organism of interest and conduct research to identify and explain how it disrupts the normal functioning of a specific protein channel.

INQUIRING FURTHER

Ongoing studies continue to refine the work of Singer and Nicolson's fluid mosaic model. Conduct research to identify the latest lines of scientific inquiry in regards to the structure and type of protein channels in the membrane.

SECTION REVIEW

1.1

REMEMBERING

- 1 Describe the characteristics of a differentially permeable membrane.
- 2 Name the structures or substances responsible for each of the following features of the cell membrane.
 - a Has the ability to bind hormones
 - b Regulates membrane fluidity
 - c Allows movement of specific charged particles into or out of cells
- 3 Describe the role of channel proteins in cell membranes.

UNDERSTANDING

- 4
 - a Identify which part of the cell membrane is described as fluid and which part is described as mosaic.
 - b Explain why each of these terms is used.

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

protein channel
a passageway formed across the membrane for the movement of specific substances

1.2 Passive movement

To maintain relatively stable internal conditions, the cell membrane must control the movement of materials into and out of the cell. This exchange of materials across the membrane occurs both with and without the expenditure of energy.

Movement that does not require energy is called **passive transport**. A simple analogy is riding a bicycle – if you are sitting at the top of a hill, you can roll passively down the hill, without using any energy to move the pedals. Many molecules move across the cell membrane passively, without using energy. This type of movement relies on a process called **diffusion**. Diffusion occurs in liquids and gases (fluids) because the particles in these substances are constantly moving.

Diffusion

If you drop a crystal of potassium permanganate (KMnO_4) into a beaker of water, and do not stir the beaker, the purple colour of the permanganate spreads through the water until it is evenly distributed. As the crystal dissolves, the potassium and the permanganate particles diffuse through the water (Figure 1.2.1, page 10).

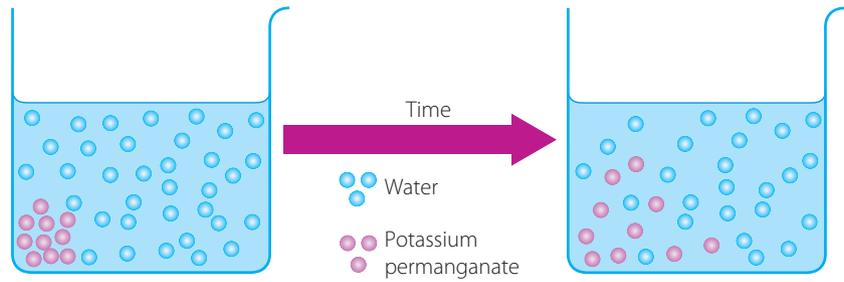
passive transport
the movement of molecules that does not require input of energy

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

1.1.5 Diffusion

1.1.6 Facilitated diffusion

FIGURE 1.2.1
Diffusion of potassium permanganate in water over a period of time



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 many more of them near the crystal, increasing the probability that they will move away from the crystal. This causes a net (overall) movement of potassium permanganate particles away from the crystal. This is the process of diffusion.

Diffusion is the net movement of particles from a region of high particle concentration 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 results in particles becoming distributed evenly throughout the system. At this point, **equilibrium** is said to have been reached. Particles will continue to move randomly, but at equilibrium they move at equal rates in all directions.

Diffusion takes place in gases and liquids, in both living and non-living systems. For example, scent diffuses into the room from an open perfume bottle and oxygen diffuses from your lungs into your blood. The particles in liquids and gases move about in constant, random motion, and over time, they spread out and become evenly distributed without the input of energy. The higher the temperature, the faster the speed of the particles. This means that increasing the temperature of a substance will increase the rate of diffusion.

Increasing the concentration gradient by increasing the difference in particle concentration between two regions will also increase the rate of diffusion.

Diffusion across membranes

Substances such as oxygen, water, carbon dioxide and other small, uncharged particles move easily through the cell membrane of a cell by simple diffusion. Figure 1.2.2a shows these particles passing between the phospholipid molecules from a high to a low concentration.

Facilitated diffusion

Charged particles (such as sodium and potassium ions) and relatively large molecules (such as glucose and amino acids) do not readily pass through the differentially permeable phospholipid bilayer. They must be helped into or out of the cell. Membrane transport proteins assist such particles to diffuse across the plasma membrane. This process is called **facilitated diffusion**.

Two types of transport proteins 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 1.2.2b). 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.

concentration gradient

the difference in concentration of a substance between two different regions

equilibrium

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

facilitated diffusion

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

carrier protein

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

Channel proteins form narrow passageways through which small ions can diffuse rapidly from a high ion concentration to a lower ion concentration (Figure 1.2.2c). Only ions of a specific size and shape can pass through a particular channel protein.

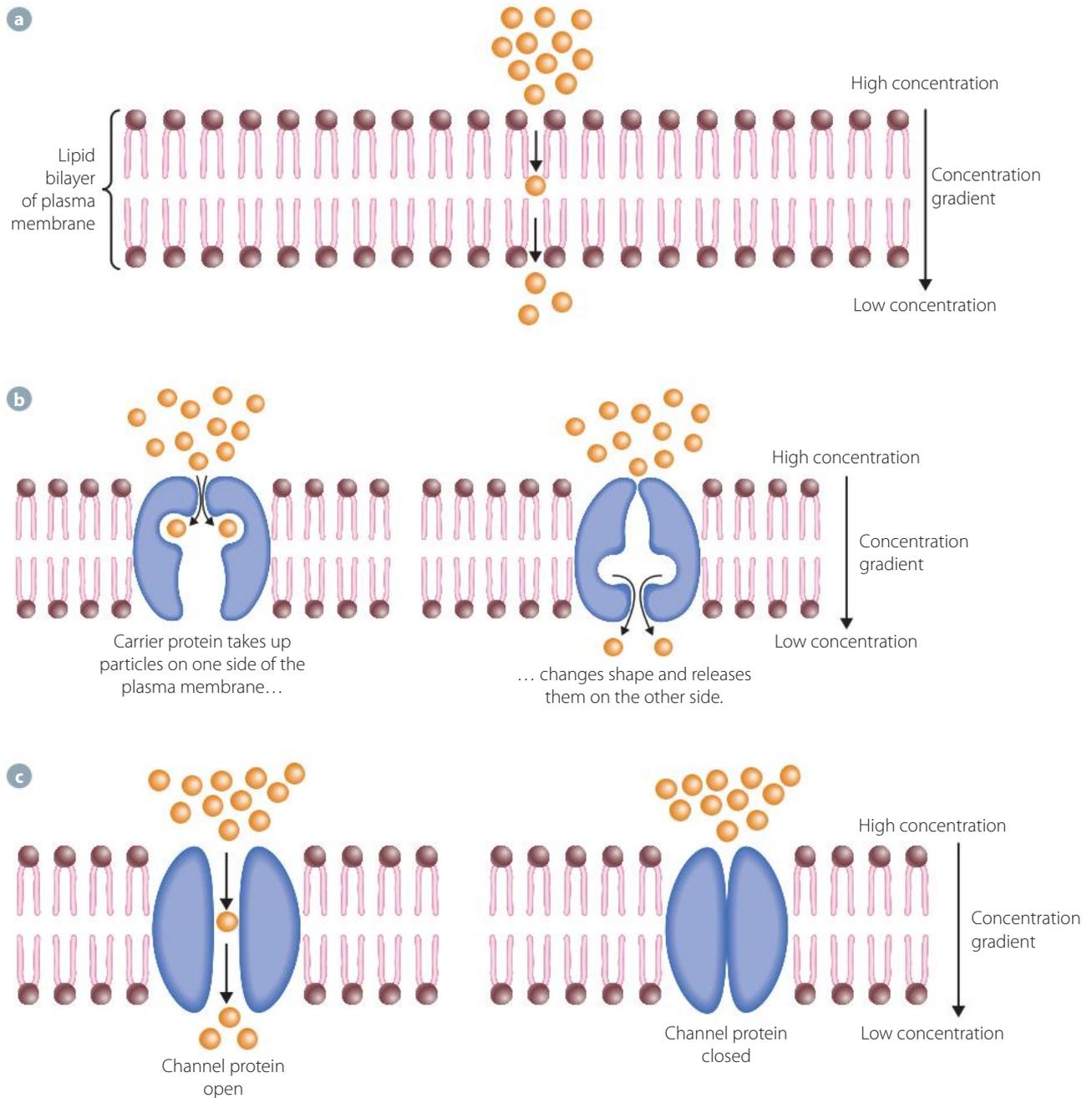


FIGURE 1.2.2 (a) Simple diffusion of small molecules through the cell membrane is dependent on the concentration gradient. (b) Facilitated diffusion using a carrier protein in the cell membrane moves particles such as glucose down their concentration gradient. (c) Facilitated diffusion of ions through a channel protein in the cell membrane. Movement is down the concentration gradient.

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

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

solute
a substance that can be dissolved in another substance

solution
a mixture of solute and solvent

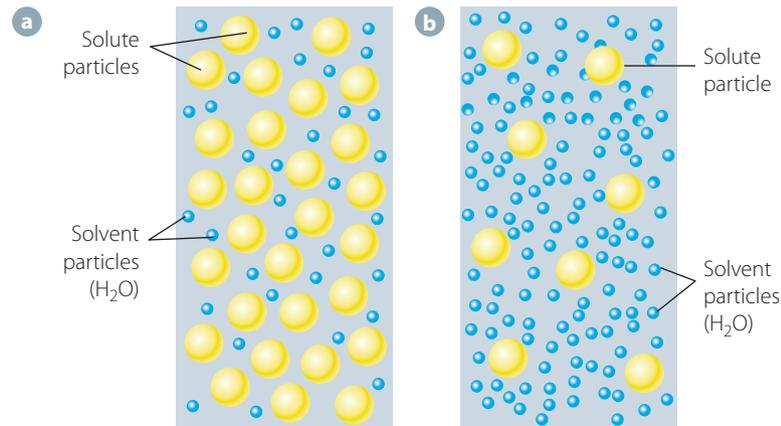
Osmosis: a special type of diffusion

Without water, no life can survive. Water is the medium in which biochemical processes take place. Water is so important to living cells that the diffusion of water across a membrane has been given a special name – **osmosis**.

Water is 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 compared to solute particles dissolved in it, whereas a concentrated solution has a low concentration of solvent molecules and a high concentration of solute particles (Figure 1.2.3).

FIGURE 1.2.3

Making solutions: (a) a concentrated solution and (b) a dilute solution



1.1.7 Osmosis

1.1.8 How osmosis works

1.1.9 Osmosis in red blood cells

isotonic
fluid with an equal solute concentration to another fluid

hypotonic
solution with a lower solute concentration than another solution

hypertonic
solution with a higher solute concentration than another solution

permeable
able to be passed through

Water molecules diffuse rapidly through the differentially permeable cell membrane, but solutes do not. If the concentration of water molecules inside a cell is lower than the concentration outside, water will diffuse into the cell until a balance or equilibrium is reached. This process of osmosis is defined as the diffusion of water across a differentially permeable membrane from an area of high water concentration (low solute) to an area of low water concentration (high solute). As osmosis is a special type of diffusion in which water moves down its concentration gradient (Figure 1.2.4), osmosis requires no input of energy.

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 plants

The effect of osmosis on plant cells can be understood if their structure is examined. Plants have firm but **permeable** cell walls surrounding their cell membranes. Inside almost all plant cells is a vacuole containing cell sap with high concentration of solutes, surrounded by a differentially permeable

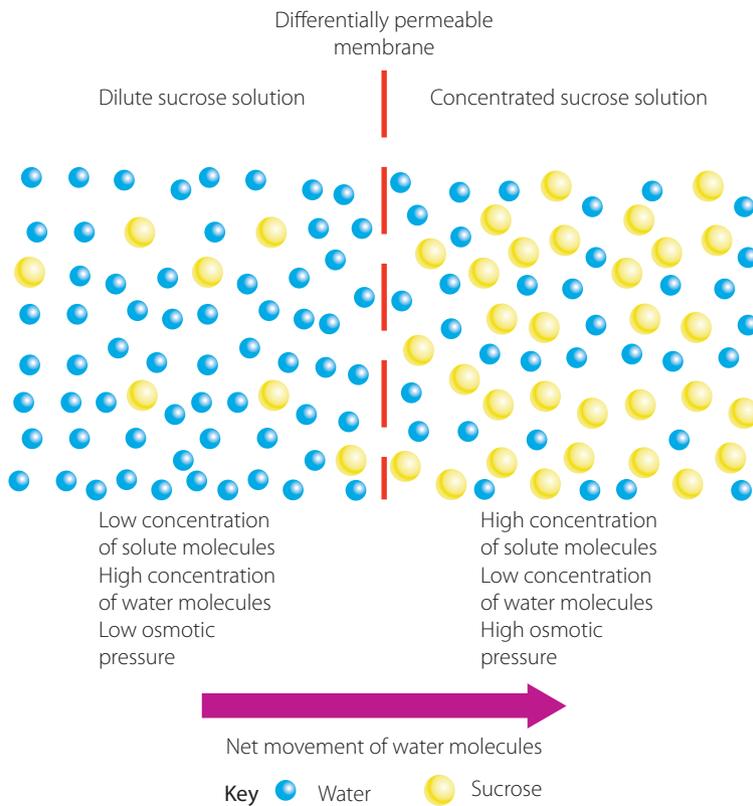


FIGURE 1.2.4

A summary of the conditions on the two sides of a differentially permeable membrane

membrane. When a hypotonic solution surrounds a plant cell, water molecules diffuse by osmosis, first into the cytoplasm and then into the vacuole. The vacuole swells, pushing the cytoplasm and cell 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 1.2.5).

Turgor is very important for plants. It maintains their shape and form and helps to keep them rigid. The stems of non-woody plants are kept erect by the turgid, tightly packed cells that fill them. Turgor is also responsible for holding leaves in a flat, opened-out position.

Certain plant cells are able to undergo quite rapid changes in their solute concentration with consequent changes in turgor. This allows such cells to change their shape. Stomatal guard cells behave this way, as do cells responsible for the leaf movements of insectivorous plants like the Venus flytrap (*Dionaea muscipula*).

On a hot, dry day, you may see some plants **wilting**. When significant quantities of water evaporate from the plant, the concentration of water molecules outside the cells 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 cell membrane pulls away from the cell wall in a process called **plasmolysis**.

INQUIRING FURTHER

Formulate an inquiry question based on the claims you see in relation to isotonic drinks. For example, do isotonic drinks claim to have solute concentrations equal to our blood? Do isotonic drinks increase the performance of athletes? Research the question, identifying the scientific evidence to support the claim.

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

wilting
becoming limp and floppy

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

plasmolysis
the point at which the cell membrane pulls away from the cell wall because of water loss

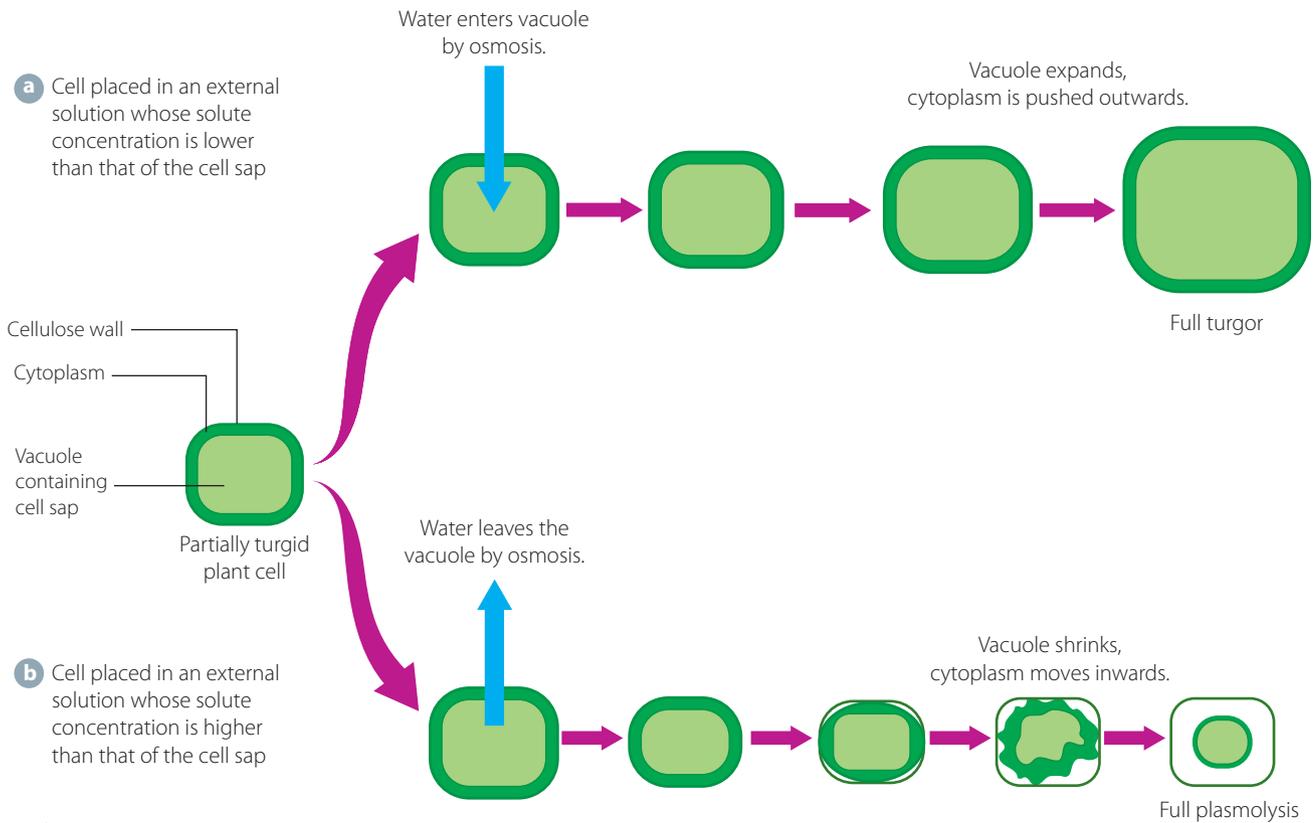


FIGURE 1.2.5 The effect of immersing a partially turgid plant cell in (a) pure water and (b) a high solute concentration

Osmosis in animals

The cells of unicellular eukaryotes and multicellular organisms, such as animals, are surrounded only by a cell membrane. This is unlike the cells of plants, fungi and bacteria, which have a rigid cell wall surrounding the cell membrane. Hypotonic solutions, such as fresh water, pose a special problem for these organisms. Water moving into their cells by osmosis can cause the cell 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 little pools of water in cytoplasmic organelles called **contractile vacuoles** (Figure 1.2.6). When these vacuoles stretch to a certain point, they contract and expel the water.

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 the 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.

contractile vacuole

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

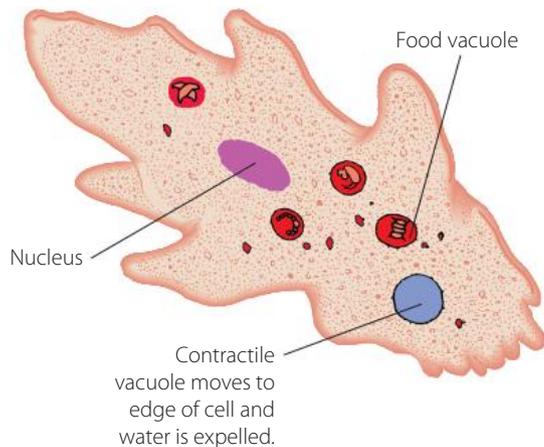


FIGURE 1.2.6

Amoebas are able to remove water from their cytoplasm using contractile vacuoles.



Chapter 7 explains how the kidneys function to maintain isotonic balance.

INQUIRING FURTHER

A number of unicellular organisms use contractile vacuoles to remove water. Conduct research into this topic to answer your own inquiry question or one of the following:

- Do contractile vacuoles remove wastes as well as water?
- Are contractile vacuoles found only in freshwater organisms?

SECTION REVIEW

1.2

REMEMBERING

- 1 A salt solution is a mixture of salt and water. Name which of these is the solvent and which is the solute.
- 2 List two factors that increase the rate of diffusion.
- 3 Describe facilitated diffusion. Name four substances that enter the cell by this process.
- 4 Identify one reason why plant cells do not burst when placed in a hypotonic solution.

UNDERSTANDING

- 5 Describe the pathway a water molecule would follow as it moved from the external environment into an *Amoeba* and back to the external environment via the contractile vacuole. Predict whether the contents of the contractile vacuole would be isotonic, hypertonic or hypotonic with the cytoplasm when it is filling up.
- 6 Describe why a person walking past a kitchen can smell food cooking.
- 7 Explain why red blood cells for blood transfusions are stored in saline (salt) solution rather than pure water.
- 8 If salad greens such as lettuce are left uncovered for a period of time, they become limp. Describe how you could restore their crispness and justify your answer by explaining your reasoning.
- 9 Explain what advertisers mean when they claim their sports drinks are isotonic.

APPLYING

- 10 Animal cells are placed in three different solutions. After a period of time, cells in solution X burst. Cells in solution Y remained the same and cells in solution Z became shrivelled.
 - a Which solution was hypertonic compared with the animal cell?
 - b Which cell was isotonic compared with its surroundings?
 - c Describe how plant cells would look in each of these solutions.

1.3 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 was responsible, once the concentration 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 are able to actively pump glucose in through their plasma membranes.

active transport
the process of using energy to move a substance across a membrane from a region of low concentration to a region of higher concentration



Chapter 2 explains the role of mitochondria in cellular activity. Chapter 4 explains the role of ATP as an energy carrier.

Active transport of specific substances

When energy is needed to move a substance across the cell membrane, the process is called **active transport**. One example of active transport is when specific substances move through the membrane against a concentration gradient, from a region of low concentration to a region of higher concentration. One advantage of this process is that it enables cells to absorb dissolved substances from very dilute solutions.

Active transport is carried out by membrane carrier proteins, similar to those responsible for facilitated diffusion. In this case, the carrier protein is coupled to a source of energy. The carrier has binding sites that allow a specific dissolved substance to bind to the side of the membrane where it is at a lower concentration. They function in one direction only, like valves, and require energy to change shape and move the solute particle across the membrane (Figure 1.3.1).

Energy for active transport

The energy demands of active transport 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 this process have huge numbers of mitochondria whose function is to make energy available to the cell. These organelles build up **adenosine triphosphate (ATP)**, which is the energy source for the active transport of most substances.

adenosine triphosphate (ATP)
the short-term energy storage molecule of cells

- 1 When energy is provided, carrier proteins take up particles on one side of the plasma membrane ...

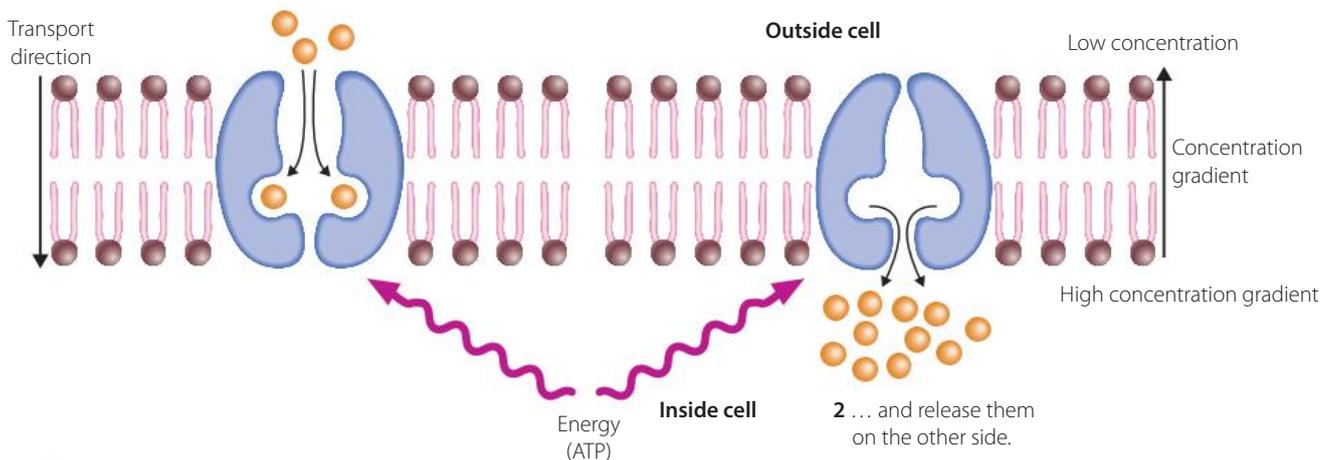


FIGURE 1.3.1 Active transport via a carrier protein in the cell membrane of a cell. Energy is transferred to the carrier protein, enabling it to move the substance against its concentration gradient.

Examples of active transport

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 cell membrane. For every two potassium ions pumped in, three sodium ions are pumped out. This pump has a particular significance for nerve cells, because the rapid movement of ions across the membranes of nerve cells enables the transmission of nerve impulses.

A spectacular example of active transport in plants is provided by certain seaweeds. They take up iodide ions so vigorously that this ion is more than a million times more concentrated inside the cells than in the surrounding sea water. Similarly, land plants need to absorb various mineral salts from the soil where the salts exist in very dilute concentrations. Root cells can do this because their membranes contain many types of carrier proteins, each capable of actively transporting a different mineral ion from the soil. Active transport enables these cells to take up salts from a dilute solution, against their concentration gradient.

sodium-potassium pump

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

SECTION REVIEW

1.3

REMEMBERING

- 1 Name the structures responsible for active transport of molecules and ions across membranes.
- 2 Name the typical source of energy for active transport.

UNDERSTANDING

- 3 State two differences between active transport and simple diffusion.
- 4 Identify two types of cells in which a great deal of active transport occurs and explain why this form of transport is necessary in these cells.
- 5 Compare and contrast the passive and active cellular uptake of glucose molecules.

1.4 Movement of large molecules

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

Endocytosis

Because of their size and charge, large **polar** molecules cannot pass through the hydrophobic cell membrane or via membrane transport proteins. Instead, they are transported into the cell by a process called **endocytosis**.

When a cell takes up a substance by endocytosis, it changes shape by sending out projections that surround the material. When the cell

polar

a molecule with an uneven distribution of charge, giving it distinct charged ends

endocytosis

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

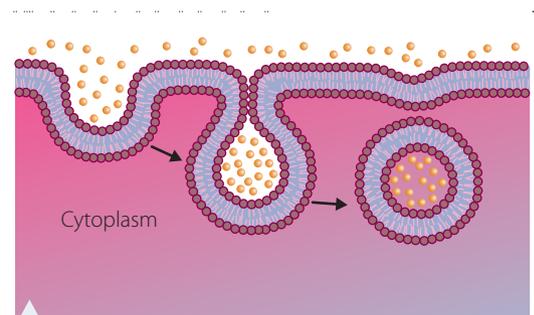


FIGURE 1.4.1 The process of endocytosis

membrane of the projections meet, the membrane fuses and forms a vesicle, which then stores or transports the substance within the cytoplasm (Figure 1.4.1, page 17).

Phagocytosis

phagocytosis
the bulk transport of solids into a cell inside a vesicle

Phagocytosis is the transport of solid particles into a cell inside a vesicle. It is a form of endocytosis. During phagocytosis, a cell sends out projections that surround the solid material and when the projections meet, the plasma membrane fuses. This results in the formation of a phagocytotic vesicle, which stores or transports the substance within the cytoplasm (Figure 1.4.2).

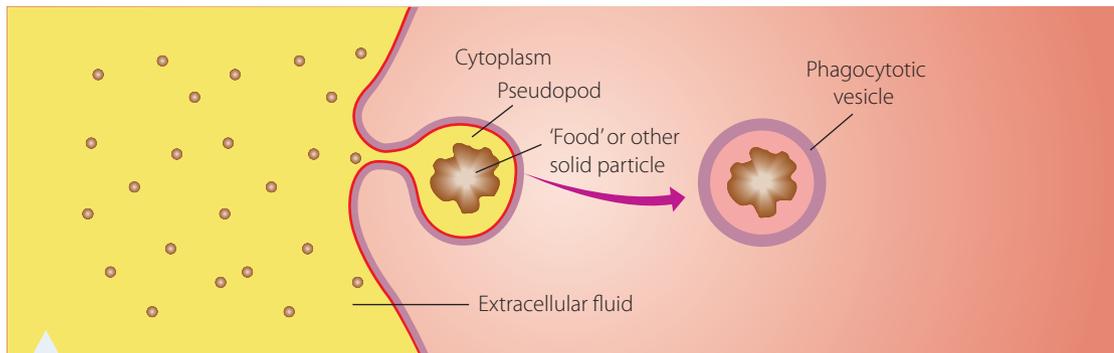


FIGURE 1.4.2 The process of phagocytosis

Phagocytosis can be observed in both unicellular organisms such as the *Amoeba* (Figure 1.4.3) and multicellular animals. Some white blood cells, called macrophages, are referred to as phagocytes because, in defending the body against disease, they engulf bacteria by phagocytosis (Figure 1.4.4). These macrophages use recognition proteins in the plasma membrane of the cells they encounter to discriminate between invading bacteria and body cells.

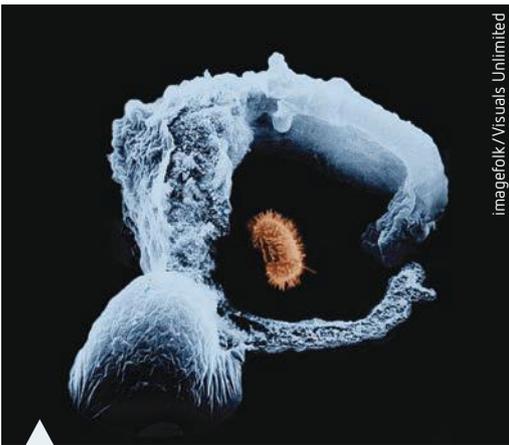


FIGURE 1.4.3 A scanning electron micrograph of an *Amoeba* surrounding its prey (*Tetrahymena*) for ingestion. Endocytosis is a selective process. For example, an *Amoeba* will ingest particles that have food value, but will rarely ingest particles that do not.

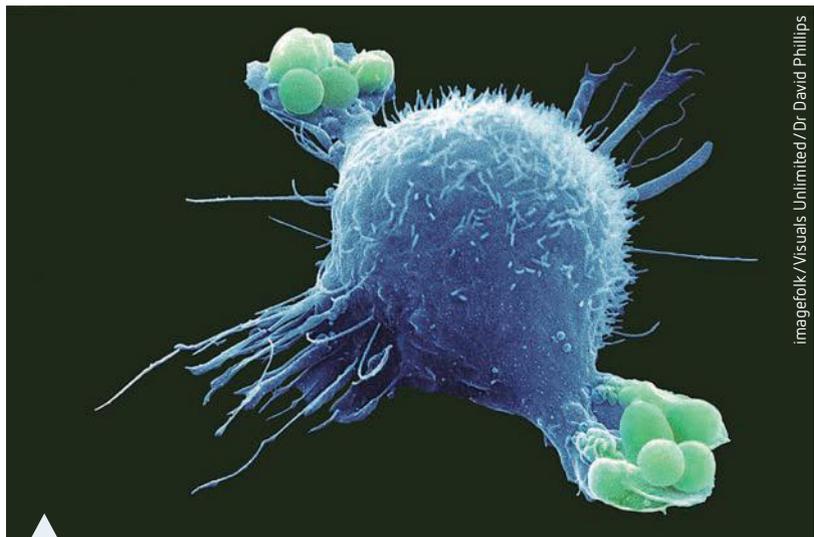


FIGURE 1.4.4 A macrophage engulfing cells by phagocytosis

Exocytosis

Specialised animal cells produce a variety of substances, such as hormones, mucus, milk proteins and digestive enzymes, that have important functions elsewhere in the organism. Similarly, specialised cells in plants produce growth regulators and toxins to ward off predators, which have to be relocated. **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 1.4.5).

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

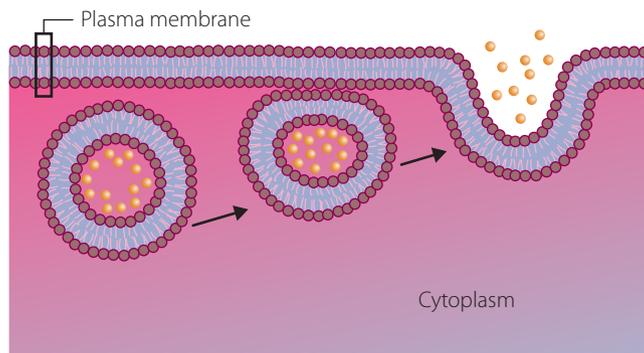


FIGURE 1.4.5
The process of exocytosis

SECTION REVIEW

1.4

REMEMBERING

- 1 State two characteristics of substances taken into cells by endocytosis.
- 2 Describe how the cell membrane is involved in the processes of endocytosis.
- 3 Explain why certain white blood cells are known as phagocytes.
- 4 Describe what it means to say that phagocytosis is a selective process.

UNDERSTANDING

- 5 You overhear a claim that endocytosis is the same as phagocytosis. Explain why this claim is not correct.

APPLYING

- 6 A student states that endocytosis should decrease the area of the cell membrane. Apply your knowledge of the process to critically examine this proposition.

1.5 Direction of movement

Whether or not a substance crosses a membrane, the direction it moves and the method it uses, is determined by characteristics of the differentially permeable membrane, the physical and chemical properties of the substance itself and the concentration gradient of the material being exchanged.

Chemical factors

The chemical properties of a substance indicate how it will behave in the extracellular environment and affect its transport across cell membranes. Ethanol and chloroform easily penetrate and cross membranes in either direction because they are uncharged molecules. This allows them to dissolve in the phospholipid bilayer. Charged ions such as sodium (Na^+), potassium (K^+) and calcium (Ca^{2+}), which

are hydrophilic, cannot cross the hydrophobic interior of the membrane (Figure 1.5.1). They move across membranes via membrane transport proteins – ion channels – which are specific for the substance they carry. The direction in which these substances move is determined by the concentration gradient of the material.

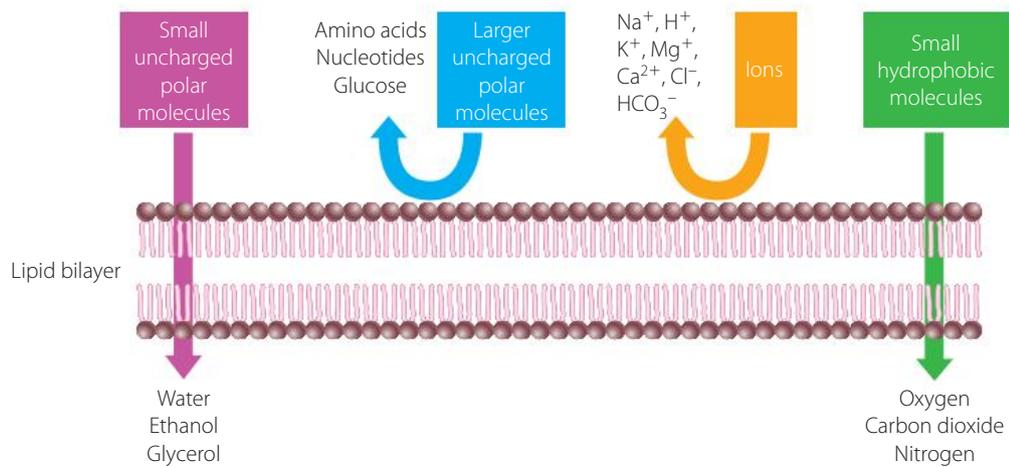


FIGURE 1.5.1 The relative permeability of a lipid bilayer to different classes of molecules

Physical factors

The physical properties of size and shape affect whether or not a substance moves across the plasma membrane and how it is transported. Small molecules such as water, oxygen and carbon dioxide can slip between the phospholipids. They cross the membrane easily and quickly, diffusing passively from a high concentration to a low concentration.

Large molecules such as glucose are physically too big to move in this way. They are transported by specific membrane carrier proteins that span the plasma membrane. The specificity of transport proteins depends on the physical shape of the molecule fitting into the carrier protein. In this process of facilitated diffusion, the direction of movement is determined by the concentration gradient of the substance, with the substance moving from a high concentration to a low concentration.

Concentration gradient

The direction of movement of a substance across cell membranes is generally determined by its relative concentration on either side of the membrane. The substance will move from where it is in a high concentration down its concentration gradient to where it is in a low concentration. The steeper the concentration gradient, the faster the substance diffuses. If the concentrations on either side of the membrane become more similar, the rate of diffusion will be slower.

An exception is when a substance is moved with the expenditure of energy, by active transport. In this case, the substance is moved against its concentration gradient, from a low to a high concentration. The substance may move either in vesicles, by endocytosis, or via a membrane transport protein pump using energy from ATP.

REMEMBERING

- 1 State two examples of physical factors that affect the movement of substances across cell membranes.

UNDERSTANDING

- 2 Explain why ions cannot cross membranes in the same way as ethanol.
- 3 Describe the effect of differing concentration gradients on the rate of diffusion of oxygen into a cell.

APPLYING

- 4 Predict, with reasons, the direction of movement of substances in the following examples, choosing from one of: into the cell, out of the cell or cannot cross.
 - a Water when an *Amoeba* is washed into the sea during a storm
 - b Carbon dioxide when muscle cells are working hard and respiring rapidly
 - c Chloroform breathed into the lungs during anaesthesia
 - d Sodium and chloride ions when salt is sprinkled on lettuce leaves
- 5 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 differentially 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.
Outline what must be done to the surrounding solution in order for the wastes to continue diffusing out of the dialysis tube and predict what would happen if this was not done.

1.6 Size of cells

Most cells are very small. The advantage for unicellular organisms to be microscopic and for multicellular organisms to consist of many small cells relates to the ability of a cell to obtain its nutrients and remove its waste products.

Surface-area-to-volume ratio

An important concept related to cell size is the **surface-area-to-volume ratio** (SA:V). This is expressed as a ratio (e.g. 3:1). It represents an important relationship between the surface 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 cell membrane. These materials are then used to fuel 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-to-volume ratio. That is, it needs a large surface area of membrane around the cell in relation to the volume of its 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 1.6.1 (page 22). 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 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.

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



1.10 Size of cells

TABLE 1.6.1 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
Surface-area-to-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. As a cell increases in size, it reaches a point where the inward movement of essential substances and the outward movement of wastes across the surface membrane by diffusion are not fast enough to service the increasing volume of the cell. For this reason, individual cells tend to be very small.

WORKED EXAMPLE 1.6.1

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

ANSWER

- 1 Calculate the surface area. Choose the correct formula.
Surface area of a cube is $6 \times$ area of one side.
- 2 Insert numbers into the formula. Calculate the answer.
Surface area = $6 \times 1 \times 1 = 6 \text{ cm}^2$
- 3 Calculate the volume. Choose the correct formula.
Volume of a cube = length \times width \times height
- 4 Insert numbers into the formula. Calculate the answer.
Volume = $1 \times 1 \times 1 = 1 \text{ cm}^3$
- 5 Calculate the SA:V ratio. Insert numbers into the formula and calculate the answer.
Surface area : volume = $6 \div 1$
= 6:1

Overcoming problems associated with surface-area-to-volume ratio

Because of the restrictions of the surface-area-to-volume ratio, most cells are too small to see without the aid of a microscope. For example, red blood cells are about eight-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 to the outside of the cell, just beneath the plasma membrane. This has two benefits: the distance materials need to diffuse when moving into or out of the cell is much less and the active volume of cytoplasm is less, thereby reducing the amount of exchange that must occur across the membrane.

In a multicellular organism, some cells need to be a certain size in order to perform their specific function. For example, nerve cells that connect the spinal cord to the toes are more than 1 m long. To explain how they overcome issues associated with increased size, it is important 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 smallest 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.

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 than spherical cells do. A good example is 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 1.6.1).



FIGURE 1.6.1 A scanning electron micrograph of root hairs in oregano, *Origanum vulgare*. Root hairs greatly increase the surface area for absorption of water.

Getty Images/Science Photo Library/Andrew Syred

Rate of diffusion and cell size

Cell size is also affected by the rate of diffusion of materials across the cell membrane. The greater the difference in concentration of a substance on either side of a membrane, the faster it diffuses. That is, the steeper its concentration gradient, the faster a substance will move across the cell membrane.

Increasing the rate of diffusion

There are various ways that cells can increase the concentration gradient across their membranes in order to maintain a rapid rate of diffusion. Plant cells often carry out **cytoplasmic streaming**, a process whereby the cytoplasm flows through the cell in a circular movement. The effect is to maintain a steeper concentration gradient. This is because the materials diffusing into the cell are rapidly removed, keeping them at a lower concentration than if the cytoplasm was stationary.

cytoplasmic streaming
the mixing and movement of the cytoplasm

In multicellular animals, the circulatory system helps to increase the rate of diffusion. Blood circulation through the lungs rapidly removes oxygen that has diffused into the body, maintaining a steep concentration gradient. Similarly, at the tissues, blood flow removing a waste, such as carbon dioxide, increases its rate of diffusion out of the body cells.

Inside a cell, the conversion of a diffused substance into another substance will lower its concentration, causing an increase in its rate of diffusion. For example, when glucose molecules diffuse into liver cells, some are used up and others are converted to glycogen. Both actions maintain a steep concentration gradient of glucose.

SECTION REVIEW

1.6

REMEMBERING

- 1 Calculate the surface-area-to-volume ratio of a cube $2\text{ cm} \times 2\text{ cm} \times 2\text{ cm}$.
- 2 Describe the change in surface-area-to-volume ratio as a small cell grows larger.
- 3 State two ways that cells can increase the rate of diffusion of substances across their cell membrane.

UNDERSTANDING

- 4 Explain how the shape of a cell affects its surface-area-to-volume ratio.
- 5 Explain how increasing the size of a cell affects the cell's ability to exchange substances by diffusion.

ANALYSING

- 6 Analyse the data in Table 1.6.1 and discuss whether or not there is a linear relationship between size and surface-area-to-volume ratio.

1.7

Mandatory practical

INVESTIGATING THE EFFECT OF SURFACE-AREA-TO-VOLUME RATIO ON CELL SIZE

Introduction

Cells must exchange materials with their external environment. To maintain normal cell functioning, this exchange must occur at an efficient rate. The size and shape of cells can affect their surface area-to-volume ratio.

In this practical, pink jelly cubes provide a simple model of a cell. The jelly was prepared using sodium hydroxide and phenolphthalein. Phenolphthalein is an indicator like litmus, changing colour depending on the acidity of its surroundings. The acid represents nutrients moving across the cell membrane into the cytoplasm. When the acid diffuses into this jelly, it neutralises the sodium hydroxide, causing the phenolphthalein to change from pink-purple to colourless.

Aim

To investigate how the surface-area-to-volume ratio of a model cell influences the movements of substances in and out of that cell and hence the size of the cell

Materials

Each group will require:

- 4 trays of agar/sodium hydroxide/phenolphthalein jelly (pink-purple coloured) that have been poured 10, 20, 30 and 40 mm thick
- 0.1 M sulfuric acid (150 mL per group)
- ruler
- razor blade
- 200–250 mL beaker
- clock or watch
- spoon or large spatulas to stir and remove the agar cubes in the acid
- paper towelling
- calculator

Procedure

- 1 If this has not already been done, your teacher should gently pry away the agar jelly from the tray sides and turn the trays upside down, revealing the four slabs of purple jelly, 10, 20, 30 and 40 mm thick.
- 2 Pour about 150 mL of the 0.1 M sulfuric acid into the 250 mL beaker.
- 3 Using the razor blade, cut out blocks of no less than 10, 20, 30 and 40 mm in size to take away to your area to trim more accurately. (Try not to destroy the remainder of the jelly so that others may also use it.)
- 4 Trim the blocks of jelly into 10, 20, 30 and 40 mm cubes. Do this as accurately as possible.
- 5 Gently add the cubes to the acid in the beaker without making splashes and gently stir every few minutes.
- 6 Note the time when the cubes were added and also the time when they should come out in 10 minutes.
- 7 Calculate the surface area, volume and SA:V for each of your cubes and complete Table 1.7.1.



- » 8 After 10 minutes, remove the cubes with a spoon and pat them dry on paper towelling.
- 9 Immediately cut each cube in half and measure the depth, to the nearest millimetre, of the clear parts. Decide on a typical measurement and record it in a table like the one below.
- 10 Follow your teacher's instructions when disposing of the materials.
- 11 Complete your table, ensuring you have put the correct units at the top of each column.

WHAT ARE THE RISKS IN DOING THIS EXPERIMENT?	HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?
The acid and indicator could irritate your skin.	Avoid getting chemicals into your eyes or cuts in your skin. Wash your hands after the investigation.
The razor blade is very sharp.	Take care when using the razor blade and do not walk around the room carrying it.



Observations and results

TABLE 1.7.1 Results table

	CUBE SIZE (mm)			
	10	20	30	40
SURFACE AREA				
VOLUME				
SURFACE-AREA-TO-VOLUME RATIO				
DIMENSIONS OF COLOURED CUBE				
VOLUME OF COLOURED CUBE (X)				
VOLUME OF WHOLE BLOCK (Y)				
VOLUME OF UNCOLOURED PORTION (Y – X)				
PERCENTAGE OF BLOCK UNCOLOURED				

Discussion

- 1 Explain why parts of the cube become clear in this activity.
- 2 Draw a graph, based on your results, showing the relationship between SA:V and the increase in size of the cubes. On the horizontal axis, label the size of the cubes you have tested. On the vertical axis, label the SA:V ratio.
- 3 From your graph, describe what happens to the SA:V as the cubes get bigger.
- 4 Draw a graph of your results. On the horizontal axis, label the size of the cubes you have tested. On the vertical axis, label the percentage of volume uncoloured.
- 5 From your graph, explain what happens to the diffusion of chemicals into the cubes as they increased in size.
- 6 Explain how your answers to questions 3 and 5 relate to nutrients diffusing into a cell through their surface.
- 7 Describe what you generally noticed about the depth of the clear part for all the cubes.
- 8 Could a cell grow into the size of a football? Explain your reasoning fully.

Conclusion

Refer to the aim of this activity. Have you achieved this aim? Write a conclusion based on what you have learnt by undertaking this activity.

CHAPTER REVIEW QUESTIONS

DETAIL QUESTIONS

- 1 Where does osmosis take place?
- 2 Under what conditions does osmosis take place?
- 3 What happens during osmosis?
- 4 What are the consequences of osmosis?

CATEGORY QUESTIONS

- 5 What causes are associated with the phenomenon of osmosis?
- 6 What locations are associated with the phenomenon of osmosis?
- 7 What process is associated with the physical actions in osmosis?

ELABORATION QUESTIONS

- 8 Explain why potato cubes increase in mass when placed in a beaker of water.
- 9 Describe the effect of the size of potato cubes on their increase in mass when placed in a beaker of water.
- 10 In terms of a change in mass, predict what would happen if potato cubes were boiled before being placed in water.

EVIDENCE QUESTIONS

- 11 Explain the reasoning behind your answer to Question 10.
- 12 Would your answer to Question 9 be the same for cubes of other vegetables?
- 13 Would the length of time the potato was boiled make any difference to your answer in Question 11?



- 1 If a substance is more concentrated inside a cell than in its surroundings, which of the following processes could produce a net movement of that substance into the cell?
 - A Diffusion
 - B Osmosis
 - C Facilitated diffusion
 - D Active transport

- 2 A student places a living cell into a drop of liquid containing a 5% sugar solution. After 30 minutes, the student finds that the liquid contains less than 5% sugar. This change would have been caused by:
 - A diffusion of sugar into the cell
 - B diffusion of water out of the cell
 - C facilitated diffusion of sugar into the cell
 - D active transport of water out of the cell.

- 3 Which of the following statements about the phospholipid molecules in the plasma membrane is *incorrect*?
 - A The phospholipids form a bilayer.
 - B Each phospholipid molecule has a single hydrophilic head.
 - C The phospholipid heads are hydrophilic (able to absorb water).
 - D The phospholipid heads are hydrophobic (water avoiding).

- 4 Plants with waterlogged roots are unable to obtain oxygen from soil spaces; in effect they are 'suffocated'. These plants die because they are unable to absorb enough vital mineral ions from the soil. An explanation for this observation is that:
 - A ions are transported down their concentration gradient into the cells using oxygen
 - B the osmosis of water out of the root cells would prevent the ions entering these cells
 - C oxygen and ions are transported into the cell linked together by membrane carrier proteins
 - D active transport of ions into the cells requires energy from respiration, which uses oxygen.

- 5 Name the process of a white blood cell engulfing a pathogen, such as a bacterium.

- 6 Name the process of the cell membrane pulling away from the cell wall when plant cells are placed in a concentrated salt solution.

- 7 A *Paramecium* is a simple unicellular eukaryote that contains a contractile vacuole. Describe the function of the contractile vacuole.

- 8 Describe what would happen if red blood cells were stored in pure water.

- 9
 - a Construct a table to show how the surface-area-to-volume ratio changes as the cubes increase in size by considering four different-sized cubes.
 - b Draw one conclusion from your table.
 - c Describe one way in which a large unicellular organism could have a larger surface-area-to-volume ratio than a smaller unicellular organism.

2

PROKARYOTIC AND EUKARYOTIC CELLS

Introduction

Living things, whether whales, fungi, snails, tomato plants or bacteria, have certain characteristics in common. This includes movement, growth and the ability to replicate or reproduce themselves. Living things 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.

As well as being made of cells, living things contain non-cellular products of their cells: the slime on the back of a frog, the exoskeletons of many insects, the bark of trees, the skin of grapes and your fingernails. Living things may also produce substances that help them live. For example, bees produce wax to form honeycombs, spiders produce the silk of their webs and many ocean molluscs secrete a shell to protect and support themselves.

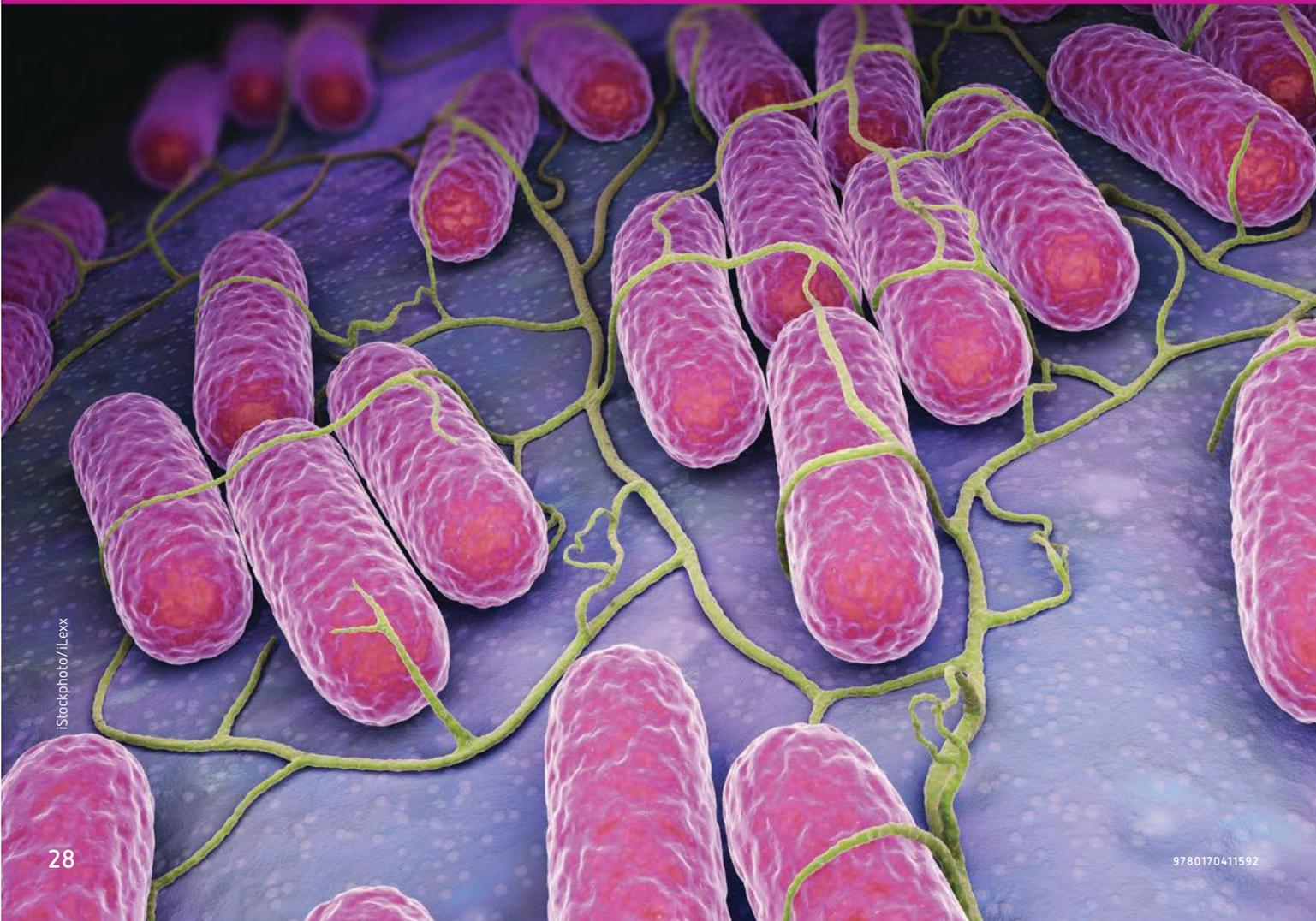
Stimulus questions

What do cells require for survival?

How do the basic structures of prokaryotes and eukaryotes differ?

How did eukaryotes evolve from prokaryotes?

What are the roles of specialised organelles in eukaryotes?



istockphoto/iLexx

2.1

Requirements for cell survival

Wherever living organisms exist, their cells depend on a source of energy, a supply of matter and the ability to remove wastes. Exactly how these three major needs are fulfilled depends on the environmental conditions in which the organisms live and characteristics of the organisms themselves.

Cells need energy

In all cells, energy is vital to power essential life processes. All organisms, with the exception of the kingdom Archaea, use glucose as the primary source of energy to drive the thousands of chemical reactions that are constantly occurring in each living cell. When chemical bonds in glucose are broken, energy is provided to the cell in a form it can readily use. This chemical process is known as **cellular respiration**.

Different organisms obtain this energy-containing glucose in different ways. Some organisms can directly harness light energy from the Sun to synthesise glucose. They use light energy to drive the chemical reactions involved in the process of **photosynthesis**. Organisms of this kind are called **autotrophs**, because they are capable of making their own food. Others rely on autotrophs to provide their energy for them, usually when consumed. These organisms are **heterotrophs**. Directly or indirectly, the Sun is the major source of energy for life.

Cells need matter

Every living cell is involved in synthesising large molecules that are needed to build cellular structures and to maintain the biochemical processes that keep them living: communication, transforming energy and relaying genetic information. These large molecules are called **macromolecules** and are grouped into four main classes on the basis of their chemical composition and structure. These four classes are carbohydrates, lipids, proteins and nucleic acids. Autotrophs are able to synthesise their own biological macromolecules from simple precursors.

By contrast, heterotrophs build macromolecules using complex compounds that they have ingested. They first break down their food into simpler substances in the process of digestion. These subunits are then built up into the various kinds of **organic compounds** that are required by the organism. Many important biological macromolecules are made in this way, when small subunits called **monomers** are linked together to form long chains called **polymers**.

Oxygen and carbon dioxide

Cellular respiration occurs continuously in cells to provide the energy needed for cellular reactions. Because oxygen is used in cellular respiration, oxygen levels inside cells are low. Hence, oxygen diffuses into the cell from a higher concentration outside to a lower concentration in the cytoplasm. Multicellular organisms usually have respiratory systems dedicated to providing oxygen to their cells; for example, gills in fish and lungs in birds, mammals and reptiles.

By contrast, during photosynthesis, autotrophs use carbon dioxide. They use the oxygen produced in photosynthesis to release the energy from glucose in the process of cellular respiration. When photosynthesis occurs at a greater rate than cellular respiration, excess oxygen is released into the atmosphere where it can be accessed by heterotrophs.

cellular respiration

a series of cellular biochemical reactions and processes using glucose and oxygen and producing carbon dioxide and water

photosynthesis

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

autotroph

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

heterotroph

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

macromolecule

a large molecule that has an important structural or functional role in cells

organic compound

a substance made up of molecules containing carbon (and also usually hydrogen and oxygen)

monomer

a small molecule that acts as a building block for macromolecules

polymer

a large molecule built up from linking smaller molecules together

Cells need simple nutrients

carbohydrate

a group of compounds containing carbon, hydrogen and oxygen, important as structural components and as energy sources

The most common compounds in living organisms are carbohydrates. Organisms use carbohydrates both as an energy source and as a starting point for the synthesis of important macromolecules. Each **carbohydrate** molecule consists of carbon, hydrogen and oxygen atoms in the ratio of 1:2:1, giving the general formula for carbohydrates as $n\text{CH}_2\text{O}$.

Monosaccharides

monosaccharide

a simple sugar, such as glucose, which cannot be broken down into smaller sugar molecules

The simple carbohydrate glucose is the most common single sugar molecule and is known as a **monosaccharide**, which means 'one sugar' (Figure 2.1.1). The most important role of glucose is to provide energy for virtually all cellular and physiological processes. Glucose is also an important building block needed to synthesise more complex carbohydrates, in both plants and animals.

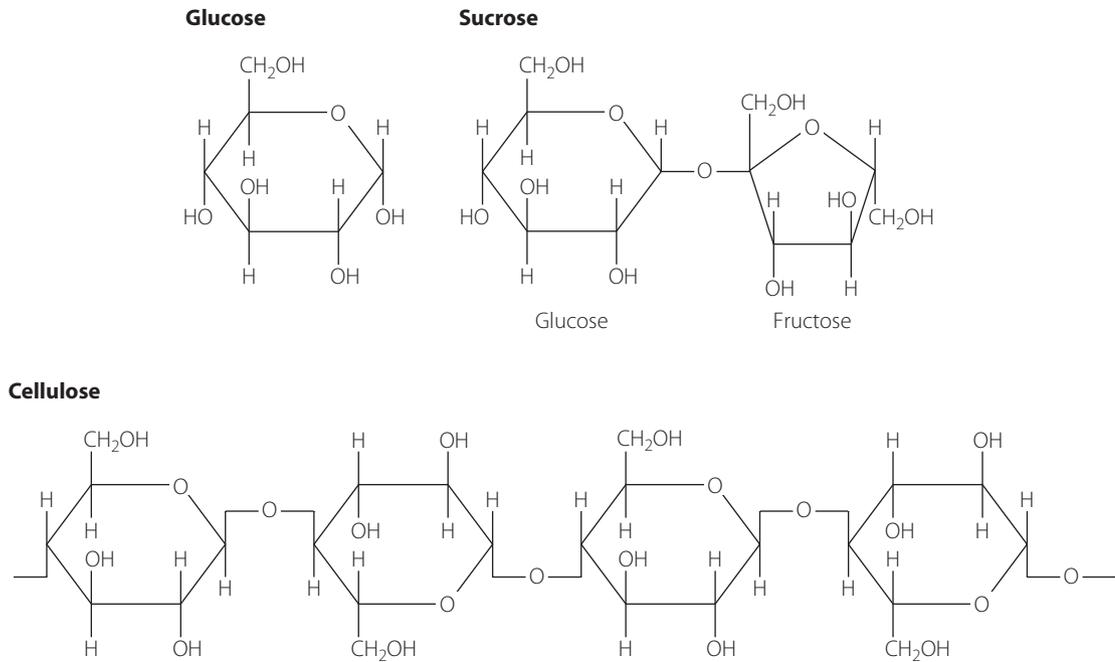


FIGURE 2.1.1 Glucose is a monosaccharide. Sucrose is a disaccharide formed by joining a glucose and fructose sugar. Cellulose is a polysaccharide formed by joining many glucose units.

Plants and some prokaryotes synthesise glucose molecules in photosynthesis. Heterotrophs obtain glucose by consuming and digesting food. Once absorbed, glucose circulates in the blood of animals as blood sugar, diffusing into cells as needed.

Disaccharides

disaccharide

two linked monosaccharide molecules

When two monosaccharide molecules join together, they form a **disaccharide** ('two sugars'). Sucrose or common table sugar is an example of a disaccharide (Figure 2.1.1). In animals, sucrose provides a quick source of energy. This is because it is split during digestion into glucose and fructose, causing a rapid rise in blood glucose. Sugars move around in the phloem of plants in the form of sucrose rather than glucose.

Polysaccharides

polysaccharide

a complex carbohydrate that is made by linking together simple sugars

If many monosaccharides join together, or two or more disaccharides join together, they form a **polysaccharide** ('many sugars'). Organisms use polysaccharides both as energy reserves and for structural components.

Starch is an important plant polysaccharide. Some starches contain over 6000 glucose molecules, which means they are useful glucose storage molecules. Most plants store excess starch in their roots and break it down into glucose when it is required for respiration. For example, potatoes are rich in starch.

Animals can store excess glucose in the form of another polysaccharide called **glycogen**, which is very similar to starch. Glycogen is stored in the liver and muscles and is converted back into glucose as the concentration of glucose in the blood begins to drop. This may happen during vigorous exercise or between meals.

Cellulose is another polysaccharide composed of many glucose molecules joined together. Cellulose is found in plant cell walls. The special linking patterns between the glucose molecules mean that cellulose fibres are tough, insoluble and resistant to being crushed and bent. This makes cellulose fibres ideal as the structural components of plant cell walls. The efficient functioning of plants depends on the properties of their tough cellulose cell walls.

starch
an important energy-storing polysaccharide in plants

glycogen
an important energy-storing polysaccharide in animals

cellulose
a polysaccharide made of glucose subunits that is the main component of plant cell walls

Cells need simple molecules and macromolecules

A variety of other substances are required for the proper functioning of cells. These include amino acids, fatty acids, glycerol, nucleic acids, ions and water.

Amino acids

Virtually everything a cell is, or does, depends on the proteins it contains. Proteins contribute to building many different structures and, as enzymes, control the thousands of chemical reactions that maintain life processes. All cells require **amino acids** because amino acids are the structural subunits required by a cell to build proteins.

Of the more than 100 different kinds of amino acids that exist, only 20 are used to form proteins in eukaryotes. It is the order and number of amino acids that make different types of protein. Like carbohydrates, amino acids are made up of the elements carbon, hydrogen and oxygen. However, they also contain nitrogen and sometimes sulfur and phosphorus (Figure 2.1.2).

Plants can synthesise their own amino acids, but animals need to obtain some of them from their diet. Once the digestive system has broken down proteins into their amino acid building blocks, the amino acids are absorbed and circulated in the blood. From there, they are taken up by cells when needed for protein synthesis.

Fatty acids and glycerol

Fatty acids and **glycerol** are the subunits that combine to produce two important groups of lipids – the **triglycerides** and the phospholipids. Plants can manufacture the variety of fatty acids they need, but animals must obtain some essential fatty acids from their diet. All fatty acids contain the elements carbon, hydrogen and oxygen, and are insoluble in water.

Triglyceride molecules typically form the fats of animals and the oils of plants. Fats are solid at room temperature and oils are liquid. Neither fats nor oils dissolve in water. The name ‘triglyceride’ gives a clue to their composition (‘tri’ = three), in terms of the number of fatty acid chains attached to a glycerol backbone (Figure 2.1.3). There are many different fatty acids that can be joined to a glycerol molecule and the three attached to the glycerol are usually different. Most natural lipids contain a complex mixture of individual triglycerides.

Phospholipids are a major structural component of cell membranes. They differ from triglycerides because one of the three fatty acids on the glycerol is replaced by a phosphate group. This causes one end of the phospholipid molecule to be hydrophilic and the other end to be hydrophobic.

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

fatty acid
a type of organic acid that combines with glycerol to form a fat molecule

glycerol
a molecule that combines with three fatty acids to form a fat molecule

triglyceride
a simple lipid formed by linking glycerol with three fatty acids

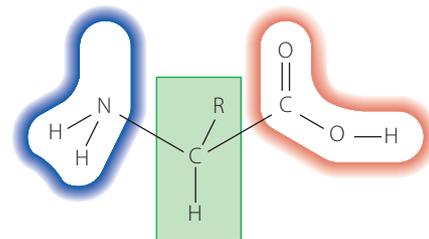


FIGURE 2.1.2 A chemical diagram of an amino acid where the R group can represent a number of different chemicals. Many amino acids join together to form a polypeptide.

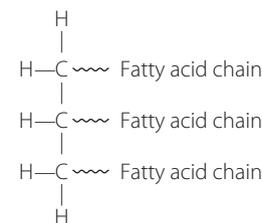


FIGURE 2.1.3 A triglyceride molecule contains a glycerol unit and three fatty acid chains.

Nucleic acids

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

RNA (ribonucleic acid)

the single-stranded nucleic acid involved in protein synthesis

nucleotide

an organic compound composed of a sugar, a phosphate group and a nitrogenous base

nucleus

the organelle in a eukaryotic cell containing most of the DNA; its function is to coordinate cell activities

ribosome

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

cytosol

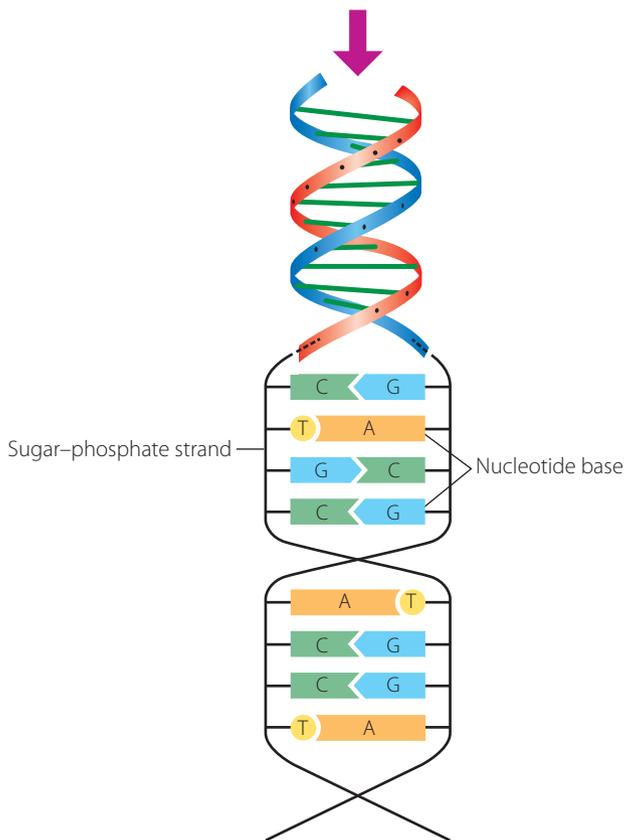
the part of the cytoplasm containing highly organised fluid material with dissolved substances; excluding the organelles

The two nucleic acids in cells are deoxyribonucleic acid (**DNA**) and ribonucleic acid (**RNA**). Both are composed of long strands of subunits called **nucleotides**. Each nucleotide is composed of a sugar, a phosphate group and a nitrogen-containing base. In DNA the sugar is deoxyribose and in RNA the sugar is ribose.

A molecule of DNA consists of two long strands of nucleotides wound around each other to form a double helix (Figure 2.1.4). Hydrogen bonding between the bases of the nucleotides joins the strands. In DNA, these bases are adenine, guanine, cytosine and thymine, with adenine bonding to thymine and guanine bonding to cytosine. By contrast, RNA is single-stranded and thymine is replaced by uracil.

FIGURE 2.1.4

DNA is a double-stranded nucleic acid made of four different kinds of nucleotides.



DNA is the genetic material of the cell. When a cell divides, the DNA is copied and passed on. DNA coordinates cell activities by coding for the production of proteins. These proteins catalyse and control the many chemical reactions occurring in the cytoplasm. As DNA is too big to leave the **nucleus**, RNA is used as a messenger to carry instructions for protein synthesis to the **ribosomes** in the cytoplasm.

Ions

Cells need specific amounts of ions in order to function effectively. This is demonstrated by the observation that the concentrations of ions such as sodium and potassium are very different in the **cytosol** compared with the external environment. These differences in ion levels are important in processes such as cell signalling and the contraction of muscle cells.

Organisms and the cells within them need some minerals in relatively large amounts. Calcium (Ca^{2+}), iron (Fe^{2+} or Fe^{3+}), magnesium (Mg^{2+}), potassium (K^+), sodium (Na^+), chloride (Cl^-), nitrate (NO_3^-), phosphate (H_2PO_4^-) and sulfate (SO_4^{2-}) are referred to as major mineral elements.



Chapter 4 investigates DNA structure and replication and the role of RNA in protein synthesis.

Some minerals are needed in smaller amounts and are called trace elements or micronutrients. Furthermore, some trace elements needed by animals are not required by plants, and vice versa. For instance, iodine (I^-) is an essential trace element for many animals, including humans, but does not seem to be required by plants.

Water

Water makes up about 70% of the total volume of a typical cell. It is vital for chemical activity in cells because all their chemical reactions take place in aqueous solution. This is possible because a wide range of substances dissolve in water, including sugars, amino acids, ions, small nucleic acids and proteins. Wastes produced in these reactions are transported away from cells dissolved in water. As well, many chemical reactions, including photosynthesis, require water as one of their reactants.

Cells need to remove wastes

Wastes are the unwanted and often toxic products of metabolism that must be removed from cells. They include carbon dioxide, oxygen, ammonia, urea, uric acid, water ions and heat.

The waste products of cellular respiration are carbon dioxide and water. These wastes diffuse out of the cell across the cell membrane. By contrast, during photosynthesis, autotrophs produce the waste products oxygen and water.

Nitrogenous wastes: ammonia, urea and uric acid

Most animals consume protein in their diet as a source of amino acids. Excess protein cannot be stored, so it is broken down in the process of **deamination** and used to provide energy. Protein contains nitrogen and the first product of deamination is **ammonia**, which is toxic to cells. Organisms must either excrete ammonia very quickly or convert it to less toxic substances such as **urea** and **uric acid** (Figure 2.1.5), which can be stored temporarily prior to elimination.

The form in which nitrogen is excreted from the body depends on the species and the amount of water available to it. Many aquatic vertebrates, which have a lot of water available (for example, most fish, larval amphibians such as the tadpole, some reptiles such as turtles and crocodiles), excrete nitrogen as ammonia, because it is very soluble in water.

In many organisms, such as humans, ammonia is converted to urea, which is less toxic and requires much less water to be excreted. Other vertebrates (for example, birds and some reptiles such as lizards and snakes) live in dry environments with very little water. In these animals, ammonia is converted to uric acid, which is much less toxic and insoluble in water.

Water

Water is a waste product formed during cellular respiration. It is also produced as a waste product in **condensation reactions** in which two molecules combine to form one larger molecule. For example, when two amino acids are joined during protein synthesis, a water molecule is produced. This water needs to be removed because it has osmotic effects on the cell.

Ions

Chemical reactions in cells may produce ions as waste products. Cells need specific amounts of ions in order to function effectively because they may exert an osmotic effect. Excess ions are removed from cells either by diffusion or by active transport.

Sea birds and marine reptiles have glands that secrete a concentrated sodium chloride solution. In birds, the glands open into their nostrils where the salty solution drips or is sneezed out. In turtles, the glands are located behind the eyes and the salty fluid appears as if the animal is shedding tears. This adaptation ensures a waste product is removed with little loss of water, which is vital where there is little, if any, fresh water available.

deamination

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

ammonia

a product of amino acid breakdown that is extremely toxic in humans (NH_3)

urea

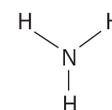
a nitrogenous waste produced when amino acids are broken down in mammals; it is excreted in urine

uric acid

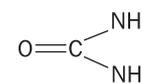
a nitrogenous waste product produced by desert animals, birds, reptiles and insects

condensation reaction

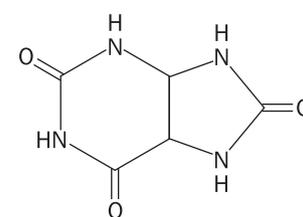
a reaction in which a molecule of water is eliminated when two monomers are bonded together



Ammonia



Urea



Uric acid

FIGURE 2.1.5 Molecules of the main nitrogenous wastes, ammonia, urea and uric acid



Chapter 13 identifies and explains the adaptations of animals that balance removal of waste nitrogenous products and water availability.



Chapter 12 identifies and explains the adaptations of animals that control heat exchange and metabolic activity.

Metabolic heat

Metabolism is the sum of chemical reactions that maintain life within an organism. All chemical reactions generate heat as a by-product and this is referred to as **metabolic heat**. Cellular respiration generates a significant amount of metabolic heat. Most of a cell's chemical reactions require the help of enzymes, which often have specific temperature requirements. Therefore, it is important that cells and organisms remove excess metabolic heat.

Single cells and small organisms readily lose heat to the environment, but larger organisms such as birds and mammals that maintain a constant internal temperature often have complex systems dedicated to temperature regulation.

SECTION REVIEW

2.1

REMEMBERING

- 1 Name the four main types of macromolecules found in all organisms.
- 2 Name four macromolecules that are polymers.
- 3 Describe the chemical composition of a carbohydrate.

UNDERSTANDING

- 4 Distinguish between the energy sources used by autotrophs and heterotrophs.
- 5 Explain why lipids are also called triglycerides.
- 6 Distinguish between:
 - a heterotrophic and autotrophic
 - b cellular respiration and photosynthesis
 - c DNA and RNA
 - d monomer and polymer.

2.2 Prokaryotic cells

metabolism

the sum of chemical reactions that maintain life within an organism

metabolic heat

the heat generated by chemical reactions of metabolism

prokaryotic cell

a simple type of cell that lacks a nucleus and membrane-bound organelles; a member of domains Archaea or Bacteria

plasmid

a small ring of DNA that is not a chromosome, most often found in prokaryotes

organelle

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

Prokaryotic cells exist as single cells and are grouped within two major classification domains: Bacteria and Archaea. They are very small, typically 1–10 μm in length and 0.2–2.0 μm in diameter. This is significantly smaller than eukaryotes, which range in size from 10 to 100 μm . Prokaryotic cells are the simplest type of cell (Figure 2.2.1, page 35). They contain a granular cytoplasm where the chemical reactions of life are carried out.

The genetic material in prokaryotes is contained in a single, circular chromosome of DNA. It lies in direct contact with the cytoplasm, not inside a nucleus. Numerous small rings of DNA, called **plasmids**, may also be present in the cytoplasm. These can reproduce independently of the main chromosome.

Although prokaryotic cells have structures, no structure is bounded by a membrane. Ribosomes are clearly distinguishable structures in prokaryotic cells. Although ribosomes are too small to be seen with a light microscope, under an electron microscope they are clearly visible, scattered throughout the cytoplasm. Both prokaryotic and eukaryotic cells contain ribosomes, which synthesise proteins using instructions from DNA. A lack of membrane-bound **organelles** limits the versatility of prokaryotes. Unlike more complex eukaryotes, prokaryotic cells cannot perform several different functions at the same time.

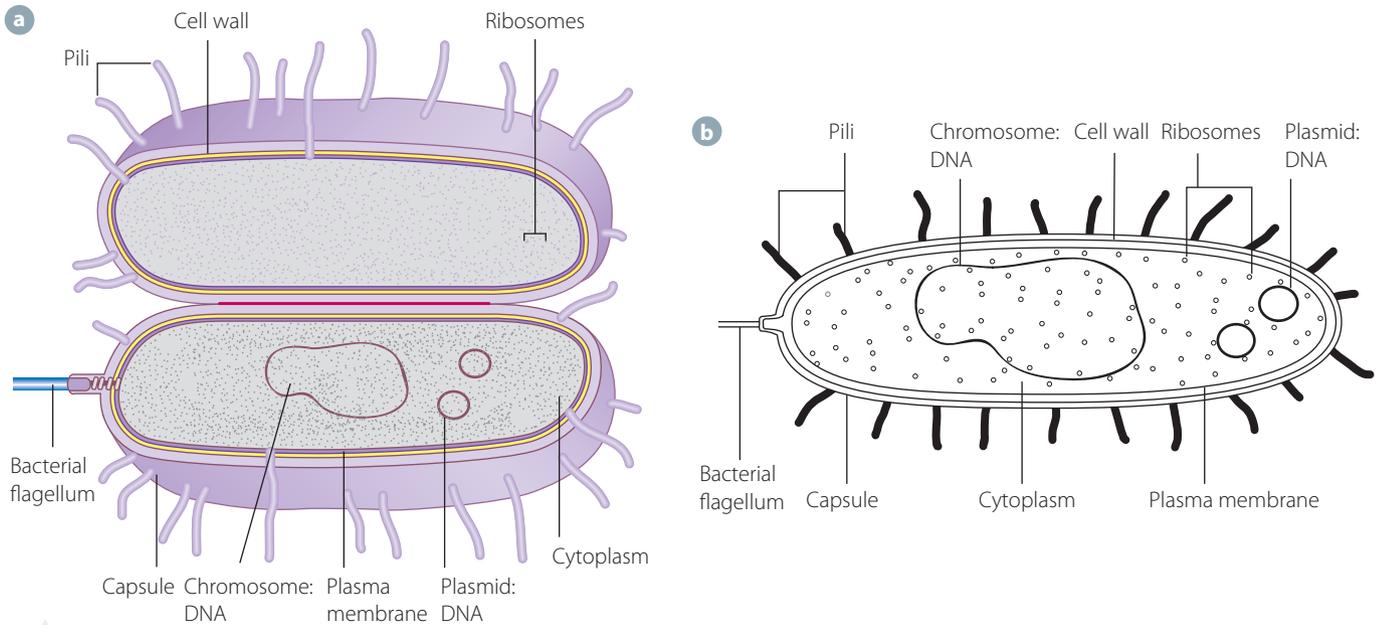


FIGURE 2.2.1 (a) A generalised diagram of a prokaryotic cell; (b) a line drawing of the cell

SECTION REVIEW

2.2

REMEMBERING

- 1 Describe the nature and location of genetic material in prokaryotic cells.
- 2 Name one structure in a prokaryotic cell.
- 3 Describe what plasmids are.

UNDERSTANDING

- 4 Explain the limitation of not having membrane-bound organelles.

2.3 Eukaryotic cells

Eukaryotic cells have specialised organelles

Unlike prokaryotes, **eukaryotic cells** have a number of membrane-bound organelles. This provides distinct compartments that can separate different reactants and provide special conditions, enabling many different reactions to occur simultaneously in the cell (Figure 2.3.1 and Figure 2.3.2, pages 36–7).

Photosynthesis occurs in chloroplasts

Chloroplasts are oval-shaped organelles, visible under the light microscope. Photosynthesis occurs in chloroplasts, in a series of chemical reactions, powered by light energy that combines carbon dioxide and water to produce glucose, oxygen and water. This conversion of solar energy into chemical energy is made possible by chlorophyll – a green pigment contained in chloroplasts – and a number of enzymes. Enzymes occur on the thylakoid membrane system and in the liquid part (stroma) of chloroplasts (Figure 2.3.3, page 38).

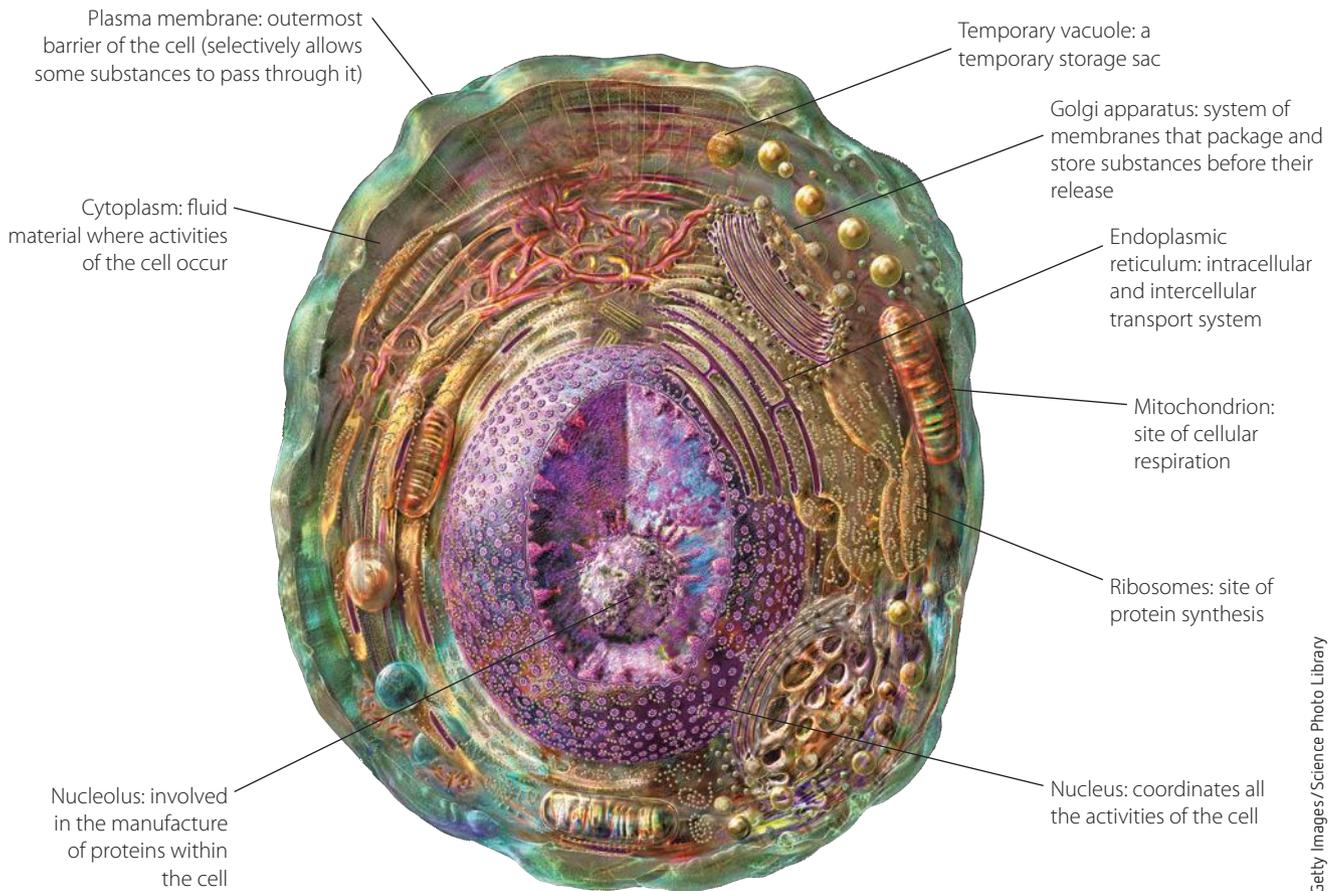
eukaryotic cell
a complex type of cell with a nucleus and membrane-bound organelles; a member of domain Eukarya



Chapter 3 investigates how the arrangement of internal membranes can control biochemical processes.

a

Eukaryotic animal cell



Getty Images/Science Photo Library

b

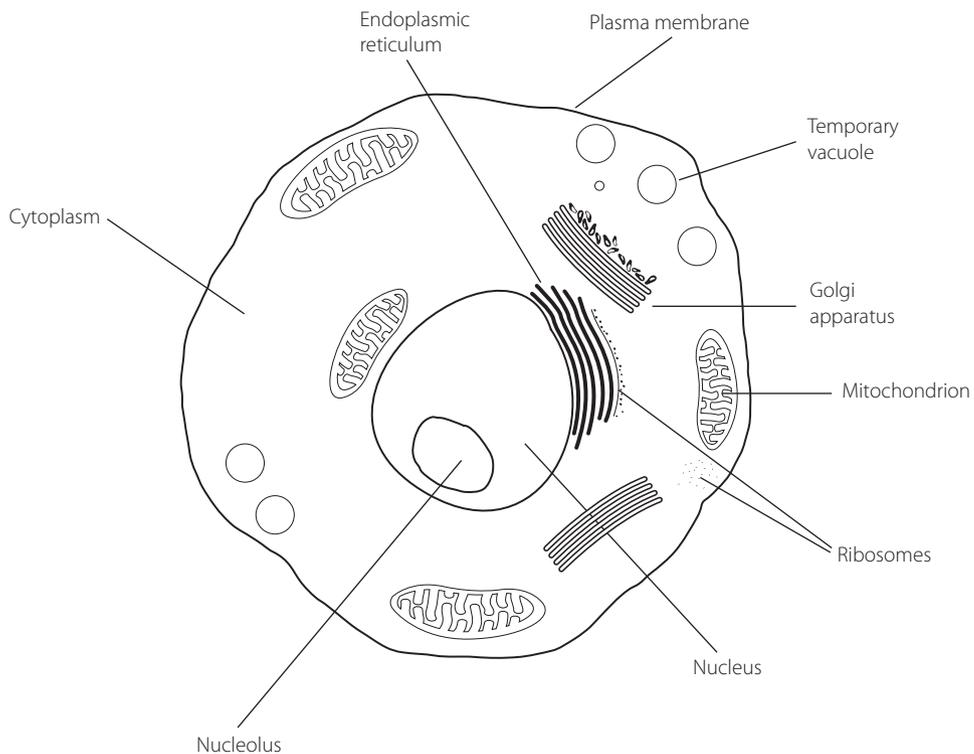
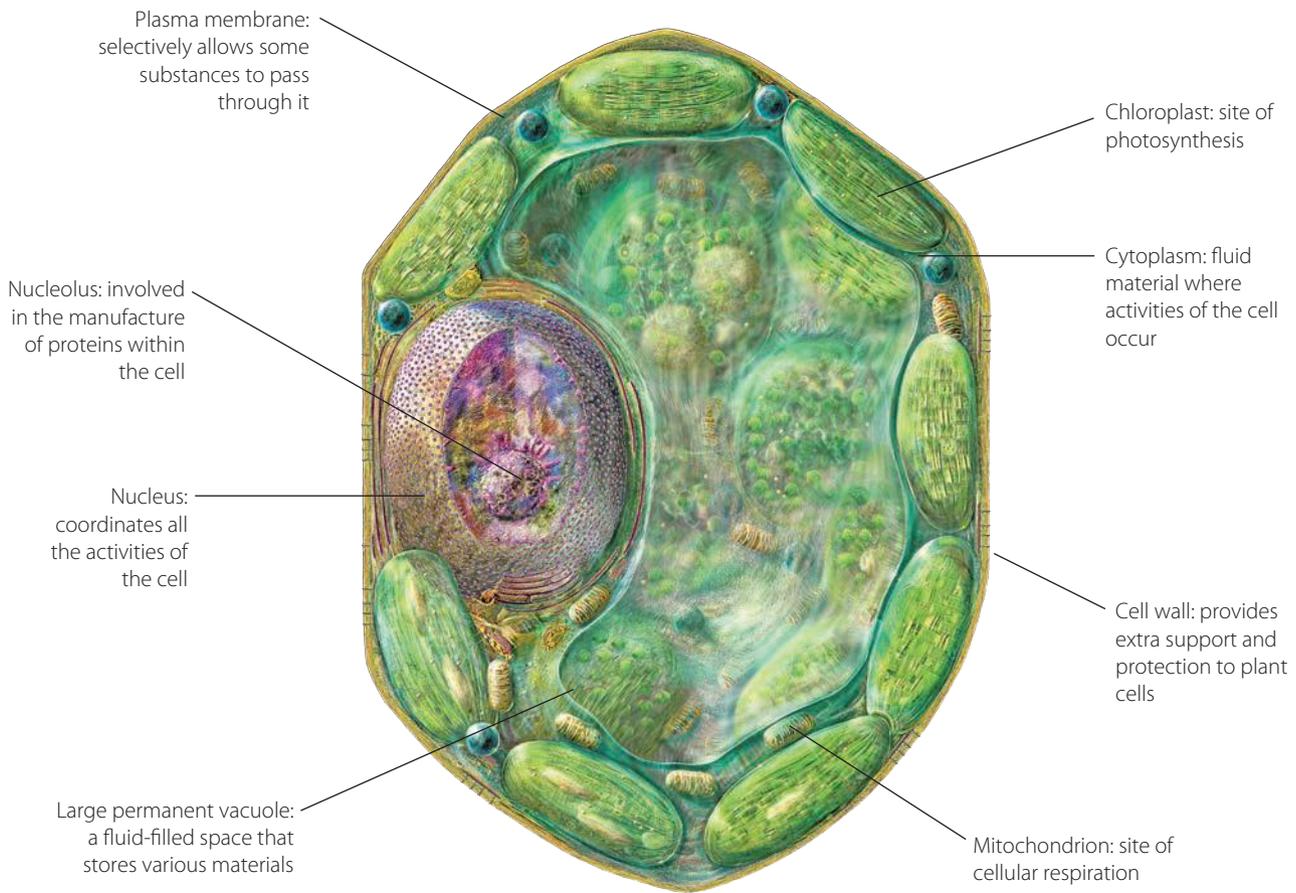


FIGURE 2.3.1 (a) A eukaryotic animal cell showing its plasma membrane and other organelles; (b) a line drawing of the cell

a

Eukaryotic plant cell



Getty Images/Science Photo Library

b

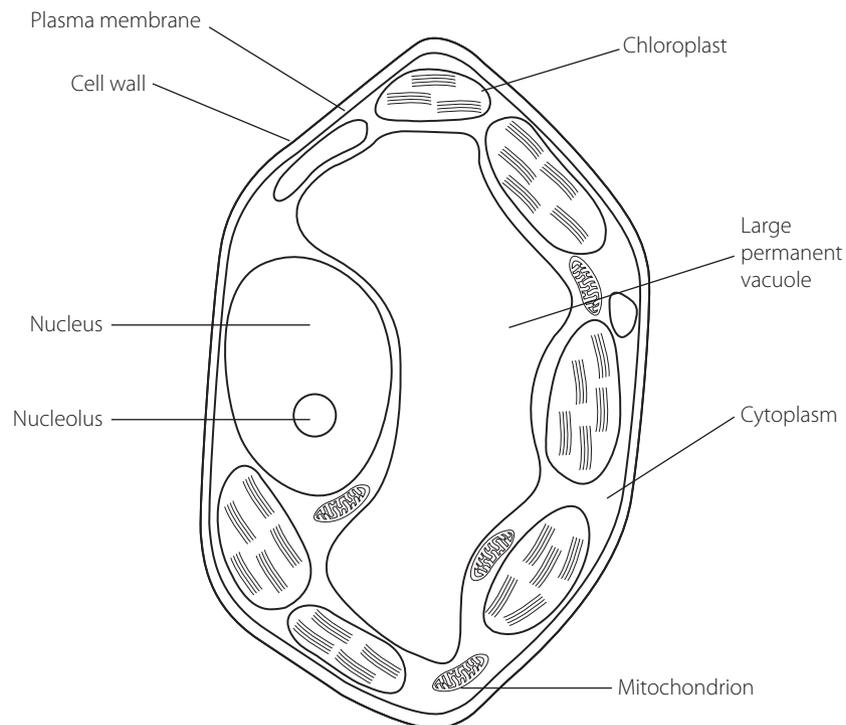
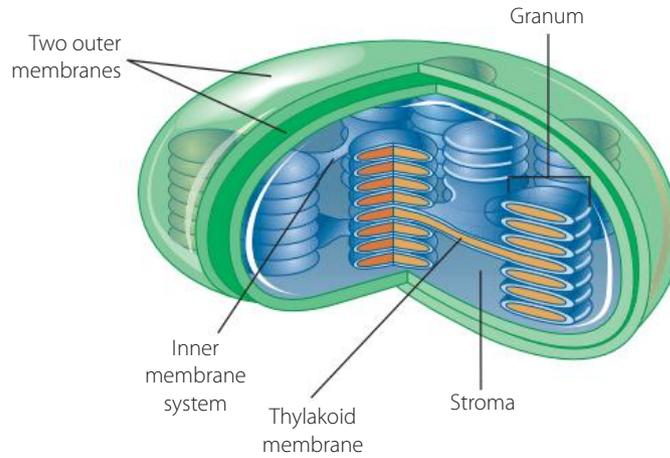


FIGURE 2.3.2 (a) A eukaryotic plant cell showing its plasma membrane, cell wall and other organelles; (b) a line drawing of the cell

FIGURE 2.3.3

A generalised sketch showing the grana and stroma of a chloroplast



Chloroplasts have their own DNA and ribosomes, reflecting their evolutionary link with prokaryotes. The starch granules that are commonly seen in the stroma are temporary stores of the products of photosynthesis.

Cellular respiration occurs in mitochondria

Cellular respiration is a series of chemical reactions that produce carbon dioxide and water from glucose and oxygen. In eukaryotic cells, the first stage of cellular respiration takes place in the cytoplasm. The final stage takes place in **mitochondria** (singular: mitochondrion). Mitochondria are small, rod-shaped organelles scattered throughout the cytosol of a cell (Figure 2.3.4). Each mitochondrion consists of an outer smooth membrane and a highly folded inner membrane. The folds in the inner membrane are called **cristae**. 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.



2.3.1 Cellular respiration

mitochondrion

an organelle within the cytoplasm that is the site of aerobic cellular respiration, which releases energy for the cell

cristae

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

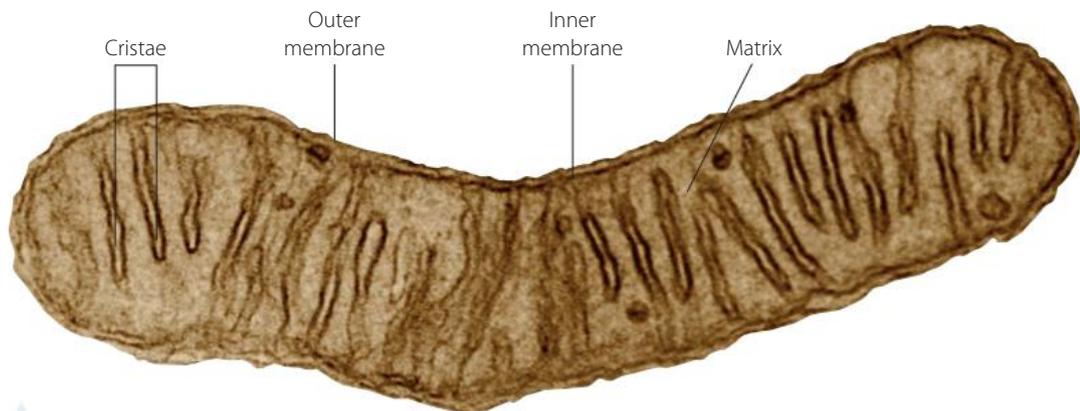


FIGURE 2.3.4 An electron micrograph of a mitochondrion in longitudinal section

Synthesis of complex molecules

Various organelles are involved in the production of complex molecules in cells.

Synthesis of proteins by rough endoplasmic reticulum

Proteins are needed for organisms in order to grow, repair damage and make new cells. In animals, proteins are also important digestive enzymes and hormones. Ribosomes synthesise proteins from their building blocks, amino acids. Some ribosomes are scattered freely throughout the cytoplasm, but in eukaryotes, many ribosomes are attached to the **endoplasmic reticulum** (ER).

The ER is an interconnecting system of thin membrane sheets dividing the cytoplasm into compartments and channels. Much of the ER is studded with ribosomes, giving it a rough appearance, and is known as the **rough endoplasmic reticulum** (rough ER) (Figure 2.3.5). As protein is being made on the rough ER, the growing chain of amino acids is pushed through the rough ER membrane. Some proteins that only move partially through the rough ER membrane remain embedded in it; they become trans-membrane proteins. Others that are water-soluble move across the ER membrane completely and collect within the internal compartment of the ER.

Synthesis of carbohydrates, lipids and steroids by smooth endoplasmic reticulum

In certain parts of some cells, the ER has no ribosomes attached to it and is known as **smooth endoplasmic reticulum** (smooth ER). Smooth ER provides an increased surface area for the storage of key enzymes and their product. It also plays a role in the transport of materials. Smooth ER is responsible for the manufacture and metabolism of lipids and carbohydrates and the synthesis of steroids.

Two important lipids synthesised in the smooth ER are phospholipids and cholesterol, which are the components of cell membranes. Cholesterol is also a precursor for the synthesis by the smooth ER of another group of lipids – the steroids. Steroids are important hormones involved in the transmission of chemical signals both within and between cells. Examples are the sex hormones oestrogen from the ovary and testosterone from the testes.

Synthesis of pigments, tannins and polyphenols by plastids

Plastids are double membrane-bound organelles present in plant cells. They are important sites for the synthesis and storage of a variety of materials. The most well-known plastid is the chloroplast. Not all plastids are coloured; for example, the non-pigmented **leucoplasts** (Figure 2.3.6).

Plastids can interconvert from one type to another. This is seen when chloroplasts bud off small vesicles called **tannosomes**, whose role is to synthesise **polyphenols**.



FIGURE 2.3.5 Rough ER studded with ribosomes

endoplasmic reticulum

an organelle in eukaryotic cells consisting of an interconnecting system of thin membrane sheets dividing the cytoplasm into compartments and channels

rough endoplasmic reticulum

endoplasmic reticulum with ribosomes attached

smooth endoplasmic reticulum

endoplasmic reticulum with no ribosomes attached

plastid

a double membrane-bound organelle involved with the synthesis and storage of materials, found in plant cells

leucoplast

a colourless plastid that does not contain pigments

tannosome

a plastid that produces tannins

polyphenol

a group of compounds formed by plants to protect them from attack by herbivores and pathogens

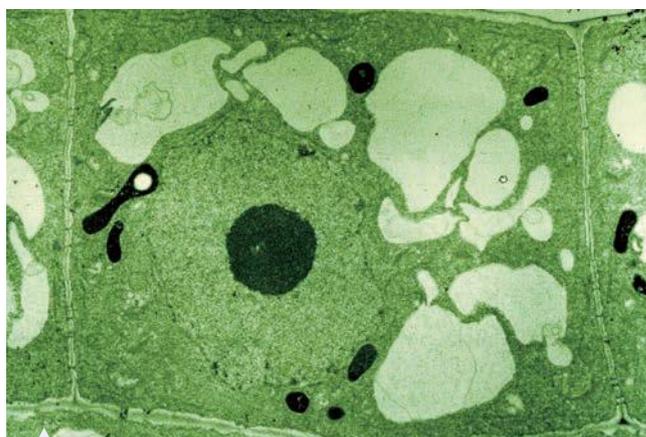


FIGURE 2.3.6 Leucoplasts (the darker, smaller round structures) in onion root cells

Visuals Unlimited/Dr David M. Phillips

INQUIRING FURTHER

Polyphenols are said to have anti-oxidative, anti-inflammatory and anti-carcinogenic actions and are sold as a health food.

Formulate an inquiry question based on the claims of health benefits. For example, is consuming polyphenols good for your health? Is there any evidence that polyphenols prevent cancer?

Research the question, identifying scientific evidence to support the claim.

tannin

a type of polyphenol found in plants; used to tan leather

chromoplast

a plastid that produces and stores coloured pigments

carotene

an orange pigment found in carrots, leaves and flowers

xanthophyll

a yellow pigment found in leaves and flowers

lysosome

a cytoplasmic organelle that contains digestive enzymes

The most abundant polyphenols in plants are the **tannins**, found in virtually all families of plants in leaf, bud, seed, root, and stem tissues. Tannins are valuable in these locations, because they deter herbivores, insects, bacteria and other pathogens.

The vast array of colours seen in the leaves, flowers, fruit and other parts of plants are the result of pigments made in various plastids. Plastids called **chromoplasts** synthesise and store pigments such as orange **carotene**, yellow **xanthophylls** and various red pigments. The main evolutionary purpose of chromoplasts is probably to attract pollinators, such as insects and birds. Coloured fruits attract herbivores, which help disperse seeds once the fruit is digested.

Removal of cellular products and wastes

Inevitably, organelles within the cytoplasm of cells wear out. Mitochondria in liver cells only live for around 10 days and are then broken down. Instead of wasting the raw materials that make up these organelles, the cell has a method of recycling and reuse. This job is carried out by **lysosomes**, special organelles found in the cytoplasm of animal cells.

Lysosomes contain digestive enzymes that are responsible for splitting complex chemical compounds into simpler ones. These simpler subunits can then be used as building blocks for new compounds and organelles. Bacteria phagocytosed by white blood cells and macromolecules taken up by endocytosis are digested by lysosomes when they fuse with the endocytotic vesicle.

SECTION REVIEW

2.3

REMEMBERING

1 Match each structure with its function.

Organelle/structure

- a Nucleus
- b Endoplasmic reticulum
- c Lysosome
- d Mitochondria
- e Chloroplast

Function

- i Breakdown of materials
- ii Photosynthesis and storage
- iii Synthesis and transport
- iv Control centre of the cell
- v Cellular respiration, which releases energy to the cell

2 Name the substances produced by smooth ER.

3 List two pigments found in chromoplasts.

4 Describe the role of lysosomes.

UNDERSTANDING

5 Distinguish between:

- a chlorophyll and a chloroplast
- b rough and smooth endoplasmic reticulum
- c a chloroplast and a leucoplast.

6 If plant cells can make their own food, explain why they still need mitochondria.

APPLYING

7 Explain why you would expect your muscle cells to contain more mitochondria than a cell in your big toe.

2.4

Common features in prokaryotes and eukaryotes

The most obvious distinguishing feature between prokaryotic cells and eukaryotic cells is the presence or absence of a nucleus. Prokaryotic cells contain a single circular chromosome that lies in direct contact with the cytoplasm. By contrast, the chromosomes of eukaryotic cells are separated from the cytoplasm by a double membrane, forming a large nucleus, obvious under a light microscope. While there are many other differences, here we will consider the common features of prokaryotic and eukaryotic cells and their evolutionary journey.

In both prokaryotic and eukaryotic cells, the outer boundary, the cell membrane, encloses the cell cytoplasm. The cytoplasm is made up of cytosol together with cell organelles. The cytosol is the fluid part of the cytoplasm that contains many dissolved substances where chemical reactions occur. Although both prokaryotic and eukaryotic cells contain ribosomes, eukaryotic cells also have a number of membrane-bound organelles with specialised functions. The genetic material, in both prokaryotic and eukaryotic cells, is DNA.

A common evolutionary past

Evidence suggests that the first prokaryotes originated around 3.5 billion years ago, but it was not until 1.8 billion years ago that the first eukaryotes appeared. Eukaryotic cells can carry out many specialised tasks because their cells are divided into various compartments. This leads to the question of how this compartmental organisation evolved from simple prokaryotic cells.

The **endosymbiotic theory** proposes that eukaryote cells were formed when a bacterial cell was ingested by another primitive prokaryotic cell (Figure 2.4.1, page 42). The larger prokaryotic cell would have ingested the smaller bacterial cell by engulfing it in a process known as phagocytosis (see section 1.5). Instead of being digested, the bacteria formed a symbiotic relationship with its host.

Scientists believe that mitochondria and chloroplasts evolved through this process of endosymbiosis, where one species lives inside another. Even now, when they reproduce, mitochondria and chloroplasts make copies of themselves and split in two, just like bacteria. Mitochondria and chloroplasts can only form from pre-existing mitochondria and chloroplasts. They cannot be formed in a cell that lacks them. Both mitochondria and chloroplasts have two membranes. The outer one is probably derived from the host membrane when it engulfed the bacteria and the inner one is probably the membrane of the ingested bacteria.

Mitochondria are similar in size to small bacteria and they have their own genetic material, which, like that in bacteria, is contained in a circular DNA molecule. Mitochondria contain ribosomes and RNA molecules so that they can make their own proteins. It is likely mitochondria evolved from bacteria that could carry out aerobic cellular respiration, living within a host cell.

Scientists believe that chloroplasts arose from primitive cyanobacteria that were ingested by eukaryotic cells already containing mitochondria around 1 billion years ago. This explains why not all eukaryotic cells contain chloroplasts but they all contain mitochondria. Chloroplasts have their own DNA, RNA and ribosomes similar to those of prokaryotic cells. The glucose they synthesise provides energy to the host. The environment within the host cell provides simple compounds, such as carbon dioxide and water, and also protects the chloroplasts from predators and from drying out.

A eukaryotic cell that contains chloroplasts no longer needs to engulf other cells to obtain food. This may explain why plant cells have lost the ability to change shape rapidly to engulf other cells by phagocytosis. Instead, they have developed a tough and protective cell wall.

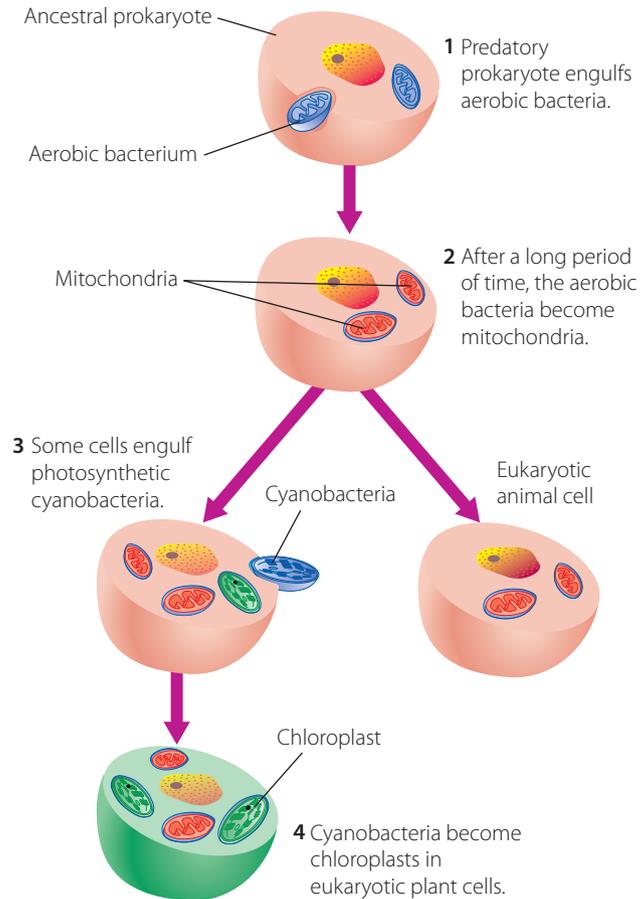
endosymbiotic theory

a theory that suggests that chloroplasts and mitochondria arose from ancient prokaryote cells that were ingested by other prokaryote host cells

2.4.1 Endosymbiotic theory

FIGURE 2.4.1

The theory of endosymbiosis explains how cells may have acquired mitochondria and chloroplasts.



SECTION REVIEW

2.4

REMEMBERING

- 1 List the features that are common to all cells.
- 2 Explain the difference between cytoplasm and cytosol.
- 3 Outline the evidence for a common evolutionary origin of mitochondria and chloroplasts.
- 4 Describe the probable event that triggered the endosymbiotic relationship between primitive cyanobacteria and the eukaryotic cell that ingested it.
- 5 Compare the structure of chromosomes found in prokaryotic and eukaryotic cells.

ANALYSING

- 6 Suggest why it was advantageous for eukaryotic cells to nurture the bacteria that eventually became mitochondria.

2.5 Cell structures under the microscope

In a light microscope, 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 provide magnifications of up to 400 times (Figure 2.5.1). More sophisticated technology is needed to view the smallest parts of cells.

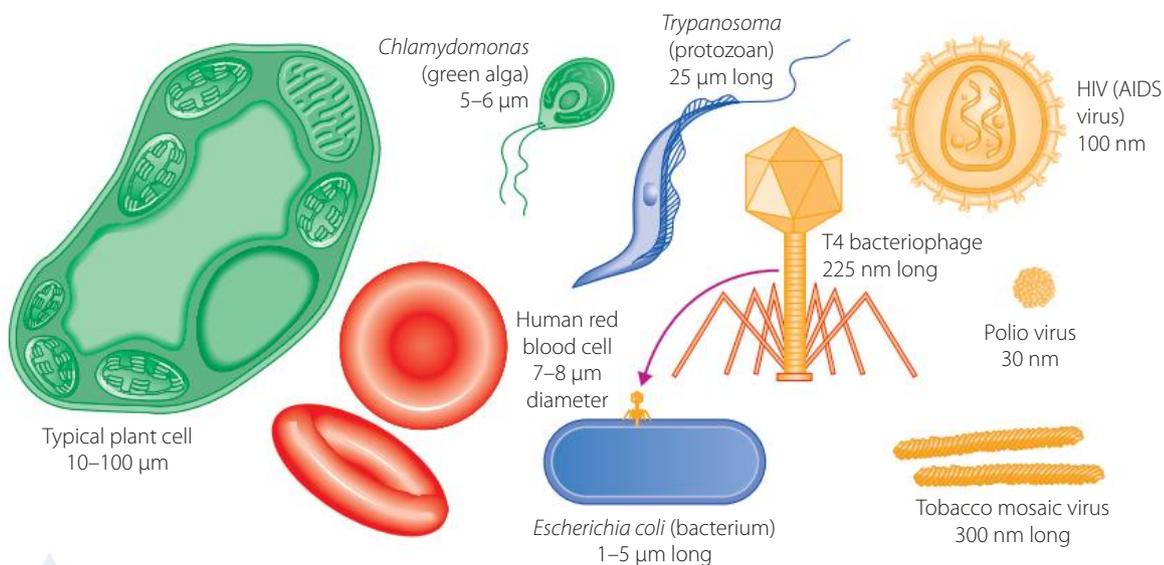


FIGURE 2.5.1 Measurements of biological specimens (not drawn to scale)

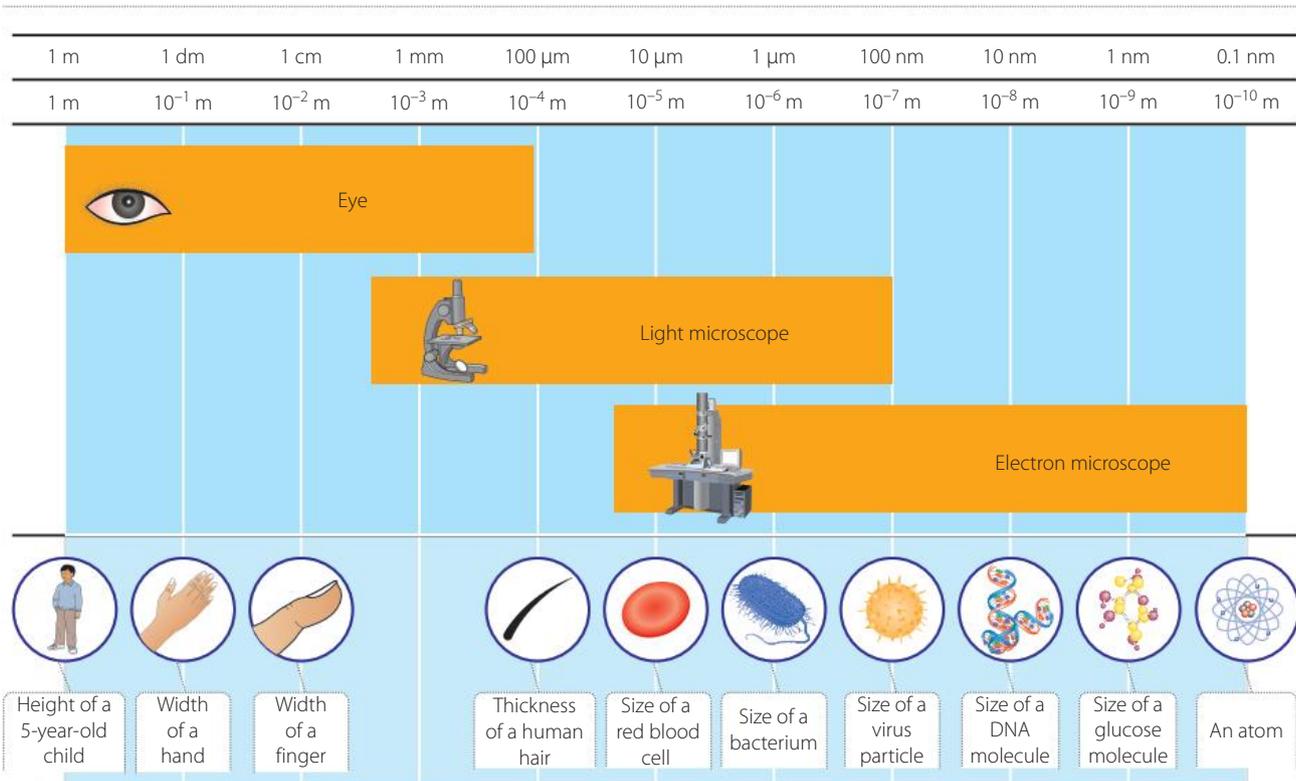


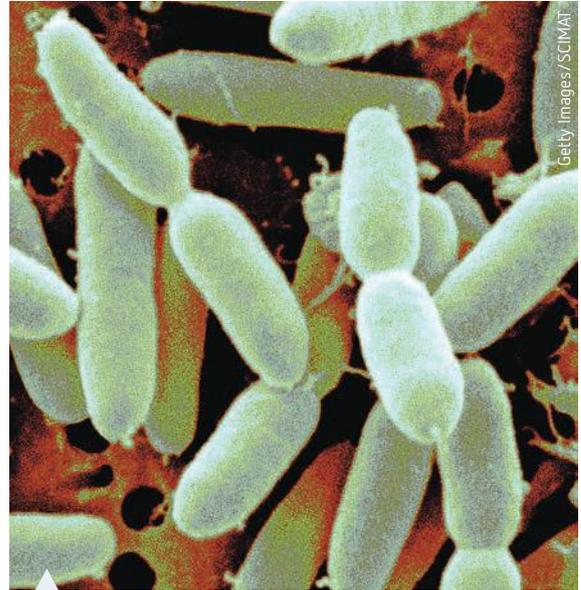
FIGURE 2.5.2 Resolving power of microscopes compared to what can be seen by the naked eye

Adapted from Peter Ball at Southern Biological



Getty Images / Javier Larrea

FIGURE 2.5.3 A TEM currently used in biological research



Getty Images / SCIMAT

FIGURE 2.5.4 An SEM image of *Lactobacillus acidophilus*, a prokaryote

INQUIRING FURTHER

The development of the cell theory has been linked to the development of the microscope. Research the development of each and discuss how they are linked.

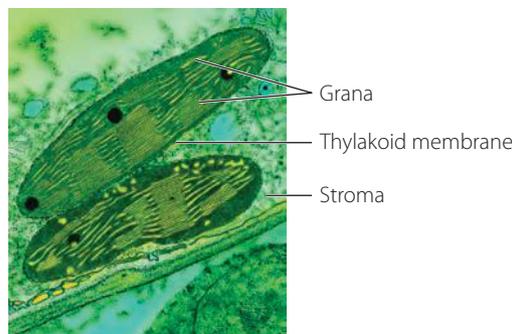
In the 1950s, cell biology was revolutionised by the development of the electron microscope. This instrument uses an electron beam instead of light, and electromagnets instead of glass lenses. The interactions between the electrons and the specimen are recorded as an image on a screen. The electron microscope can give clear pictures of material magnified 1 000 000 times or more. (Figure 2.5.2, page 43)

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 elaborate internal organisation. The electron microscope shown in Figure 2.5.3 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, providing a lower resolution three-dimensional surface view of the specimen (Figure 2.5.4).

Chloroplasts

Chloroplasts are extremely small and invisible to the naked eye. Under the light microscope, they can be seen as round, green structures. Many more details emerge when chloroplasts are viewed with an electron microscope (Figure 2.5.5). Chloroplasts have a double outer membrane. Inside this is the stroma, a semi-gel-like fluid that makes up much of a chloroplast's volume. The thylakoid membrane system floats suspended in the stroma. Thylakoids are arranged in stacks called grana and long, interconnecting thylakoid membranes link the stacks.

FIGURE 2.5.5 An electron micrograph of chloroplasts



Science Photo Library/Dr Kari Lounatmaa

Mitochondria

Mitochondria (Figure 2.5.6) are visible under the light microscope although little detail can be seen. An electron micrograph (Figure 2.5.7) shows the complex internal membrane structure of mitochondria. Mitochondria have two membranes. The inner one forms folds, or cristae, that protrude into the inner space, a protein-rich fluid called the matrix.

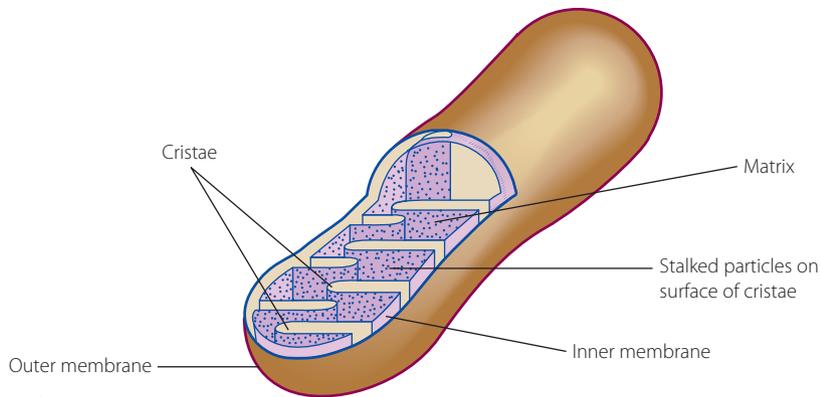


FIGURE 2.5.6 The internal structure of a mitochondrion

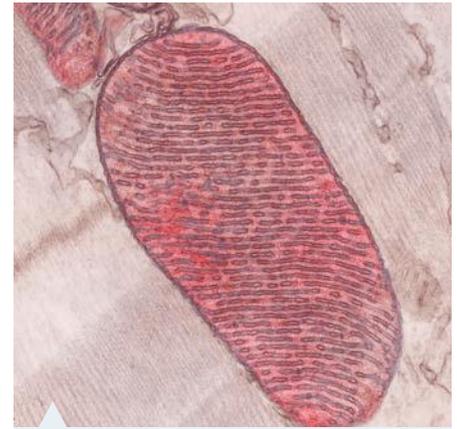


FIGURE 2.5.7 An electron micrograph of a mitochondrion in longitudinal section (magnification $\times 80\,000$)

image folk/Visuals Unlimited/Dr Thomas Deerinck

Rough endoplasmic reticulum

The detailed structure of rough ER can only be seen by using electron microscopes. Ribosomes studding the ER can be distinguished along with the system of membrane sheets, branching tubules and flattened sacs (Figure 2.5.8).

Lysosomes

Lysosomes are membrane-bound organelles in the shape of spherical vesicles varying in size from 0.1 to 1.2 μm . They may have a granular appearance (Figure 2.5.9).

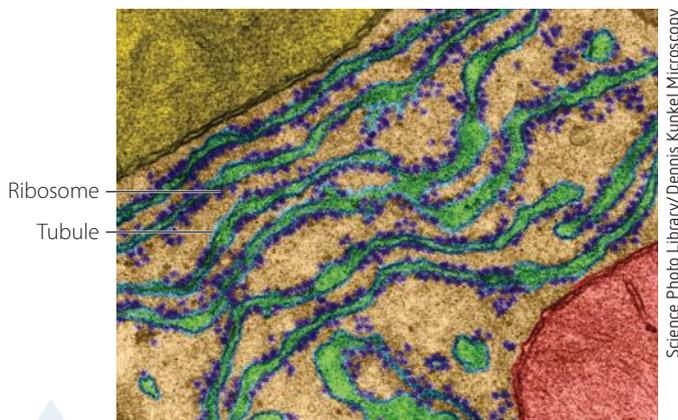


FIGURE 2.5.8 An electron micrograph of a rough ER showing ribosomes on the membranes of the tubules (magnification 19030 when shortest axis printed at 25 mm)

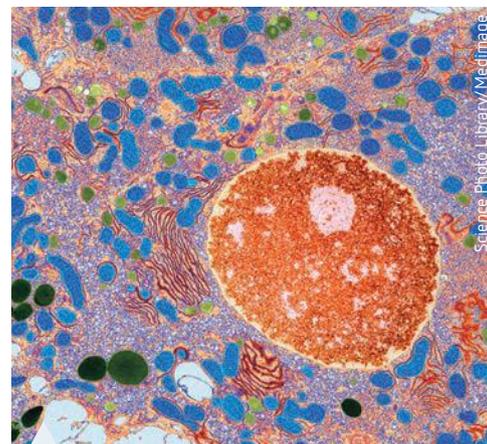


FIGURE 2.5.9 An electron micrograph of a lysosomes

Science Photo Library/Dennis Kunkel Microscopy

Science Photo Library/Medimage

REMEMBERING

- 1 Describe the structure of a chloroplast.

UNDERSTANDING

- 2 Describe two structural similarities and two structural differences between chloroplasts and mitochondria.

ANALYSING

- 3 Look carefully at the photograph of the unidentified cell shown in Figure 2.5.10.
 - a State whether the cell is from a prokaryote or eukaryote. Give reasons for your answer.
 - b Identify whether this photograph was taken of a cell 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 labelled i and ii in Figure 2.5.10.

EVALUATING

- 4 Evaluate the advantages and disadvantages of using different types of microscopes. Include the following types of microscopes.
 - a Light microscope
 - b SEM
 - c TEM

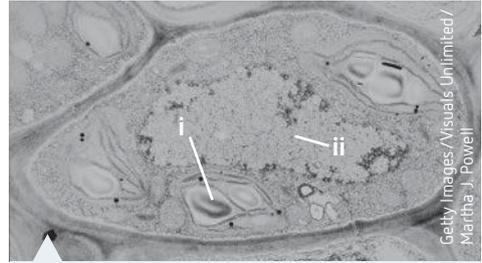


FIGURE 2.5.10 An electron micrograph of an unidentified cell

2.6

Comparing prokaryotes and eukaryotes

Table 2.6.1 compares the structures of prokaryotic and eukaryotic cells.

TABLE 2.6.1 Comparison of prokaryotic and eukaryotic cells

CHARACTERISTIC	PROKARYOTIC CELL	EUKARYOTIC CELL
Organelles	Possess no internal membrane-bound organelles	Possess internal membrane-bound organelles
Chromosomes	Single, circular and free	Multiple, linear and inside the nucleus
Ribosomes	Present	Present but different size from prokaryotic ribosomes
Endoplasmic reticulum	Absent	Present
Microtubules	Absent	Present
Enzymes used for cellular respiration	Attached to plasma membrane	Attached to internal membrane of mitochondria
Chloroplasts	Absent: enzymes of photosynthesis attached to lamellae	Present: enzymes of photosynthesis attached to internal membranes of chloroplasts
Cell wall	Present but not made of cellulose	Present in plants and fungi

SECTION REVIEW

2.6

APPLYING

- 1 Draw up a table to show the ways in which prokaryotic and eukaryotic cells are similar and different.
- 2 Identify features that are unique to:
 - a prokaryotic cells
 - b eukaryotic cells.
- 3 A large cell of 0.3 mm length was observed. Ribosomes were present in the cytoplasm but no other organelles. Could this be a prokaryotic or eukaryotic cell? Justify your answer. Identify further evidence that would be useful in your argument.

2.7 Mandatory practical

INVESTIGATING CELLS

Introduction

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

Aim

- To revise and refine microscope use, including magnification and field of view
- To learn how to prepare living tissue for observation under the light microscope
- 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
- 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 from an aquarium)
- prepared slide of human cheek cells
- prepared slide of bacteria
- prepared slides of plant and animal tissues





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 do not walk around the room carrying it.
Coverslips break easily and can cut.	Take care with coverslips and do not push hard when placing them.
<i>Elodea</i> is a noxious weed.	Dispose of <i>Elodea</i> safely, away from waterways.

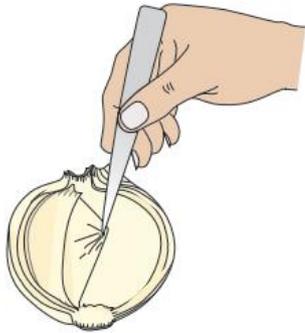


FIGURE 2.7.1 Preparing onion tissue

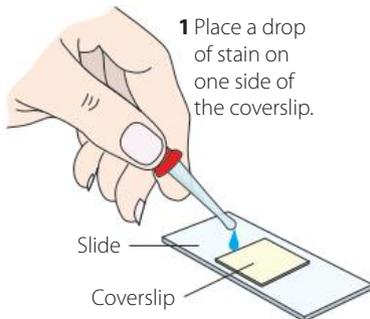
Procedure

FIELD OF VIEW

- 1 Place a mini-grid onto the stage so that you can see it when you look through the microscope. Work out the diameter across the fields of view at different magnifications. Record these measurements.

PLANT CELL: ONION

- 2 Cut off a piece of the onion. Peel a section of 'membrane' from between the two layers of onion. The membrane will be thin and flexible like plastic wrap (Figure 2.7.1).
- 3 Use the knife or razor blade to carefully cut the membrane until it is about the size of a quarter of a fingernail.
- 4 Have a microscope slide ready with a drop of cold water on it.



- 1 Place a drop of stain on one side of the coverslip.

Slide
Coverslip

- 2 Use paper towel placed on the other side of the coverslip to draw the stain under the coverslip.

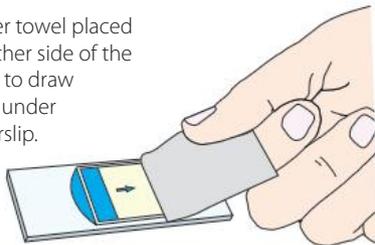


FIGURE 2.7.2 Staining a slide

- 5 Place the small piece of membrane in the drop of water, making sure that it stays flat. Stop it from curling by using tweezers or mounted needles.
- 6 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.
- 7 Focus on onion cells under low power and then switch to high power. Draw a diagram of a few cells, labelling the nucleus, cytoplasm, cell wall and position of the cell membrane.
- 8 Put one drop of methylene blue stain next to one side of the coverslip (Figure 2.7.2). Use some paper towelling on the other side of the coverslip to absorb liquid and so draw the stain across under the coverslip.
- 9 Focus on the cells again and identify whether the stain has made any structures more visible.
- 10 Make a careful diagram of a few cells. Label the nucleus, cytoplasm, cell wall and position of the cell membrane.
- 11 Use the mini-grid to measure the dimensions of an onion cell.

PLANT CELL: *ELODEA* (OR ALTERNATIVE)

- 12 Repeat steps 3–7 using an *Elodea* leaf from the tip of the plant. Float the tissue in warm water instead of cold water.
- 13 View the *Elodea* leaf under low and then high power. Watch it for a few minutes. What do you see happening to the cell contents? What does this suggest?
- 14 Make a careful diagram of one cell. Label the cell wall, nucleus, chloroplasts, cytoplasm and position of the cell membrane.
- 15 Stain the *Elodea* cell using methylene blue by following the instructions in step 8. What differences do you see occurring within the *Elodea* cell? What does this suggest?



» ANIMAL CELL

- 16 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.
- 17 Use a mini-grid to measure the diameter of a cheek cell.
- 18 Your teacher may have prepared other animal and plant tissue slides for you. Look at each slide using the light microscope and see if there are any different cell structures that you can identify.

PROKARYOTIC CELL

- 19 Place a prepared slide of bacterial cells onto your microscope stage.
- 20 Use a mini-grid to estimate the dimensions of a bacterial cell.
- 21 Draw a bacterial cell.

Results

- 1 Create a table and record the diameter of the fields of view for each of the magnifications you used.
- 2 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).
- 3 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 Describe what you observed happening to the chloroplasts inside the *Elodea* cell. Name this process and explain why it is happening.
- 3 Note any differences you noticed in the *Elodea* cell once the cell had been stained with methylene blue. Account for these differences.
- 4 When a specimen is viewed under a microscope, it appears larger than it really is. Explain how you can determine exactly how much it has been enlarged.
- 5 State how many micrometres there are in a millimetre.
- 6 Compare the size of a bacterial cell to the plant and animal cells you have seen.
- 7 Outline what cell detail you can see inside the bacterial cells.
- 8 From your observations, suggest two differences between prokaryotic and eukaryotic cells.
- 9 Describe how the prepared slides that you used in this investigation compare to the ones that you prepared yourself from fresh materials. Explain whether one was better to use than the other.
- 10 Copy and complete Table 2.7.1.

TABLE 2.7.1 Results table

OBJECTIVE LENS	TOTAL MAGNIFICATION EYEPIECE LENS $\times 10$	TOTAL MAGNIFICATION EYEPIECE LENS $\times 5$
$\times 4$		
$\times 10$		
$\times 40$		

CHAPTER REVIEW QUESTIONS

DETAIL QUESTIONS

- 1 What places within a plant are associated with photosynthesis?
- 2 Describe two consequences associated with photosynthesis.
- 3 What is the purpose of photosynthesis?

CATEGORY QUESTIONS

- 4 What processes are associated with carbohydrates?
- 5 What processes are associated with fatty acids and glycerol?
- 6 What processes are associated with nucleic acids?

ELABORATION QUESTIONS

- 7 Predict how living organisms would be different if cyanobacteria had not been engulfed by primitive eukaryotes.
- 8 Predict what would happen if lysosomes stopped working.

EVIDENCE QUESTIONS

- 9 Provide evidence to support the statement that plants photosynthesise more than they respire.
- 10 Provide evidence that supports the endosymbiotic theory.



- 1 Eukaryotic cells:
 - A have no membranes
 - B may contain rings of DNA called plasmids
 - C are significantly larger than prokaryotic cells
 - D have a single circular chromosome.
- 2 Which of the following statements provides the best description of the term used?
 - A The cytosol is made up of the fluid part of the cytoplasm together with cell organelles.
 - B The cytoplasm is the fluid part of the cytosol without the cell organelles.
 - C The cytosol is all the structures and materials between the cell membrane and nucleus.
 - D The cytoplasm contains many dissolved substances, such as ions and sugars.
- 3 A student estimated the diameter of a cell to be $8.6\mu\text{m}$. What is the diameter of this cell in millimetres (mm)?
 - A 0.86
 - B 0.086
 - C 0.0086
 - D 0.00086
- 4 An important macromolecule is the:
 - A triglyceride polymer that forms cell membranes
 - B carbohydrate cellulose in the cell wall of animals
 - C monomer glycogen used as an energy source
 - D nucleic acid RNA that is made from nucleotides.
- 5 Heterotrophs, but not autotrophs:
 - A rely on existing organic molecules for their nutrition
 - B release carbon dioxide and water as products of respiration
 - C rely on carbon dioxide and water for their nutrition
 - D manufacture their own organic molecules for their nutrition.
- 6 Name the organelle responsible for the synthesis of steroids.
- 7 Name the theory suggesting that chloroplasts and mitochondria arose from ancient prokaryote cells.
- 8 Predict what would happen to a cell if its ribosomes failed to work.
- 9 Describe the function of glycogen.
- 10 If you were given an unknown cell, explain how you would be able to tell if it were eukaryotic or prokaryotic.

3

INTERNAL MEMBRANES AND ENZYMES

Introduction

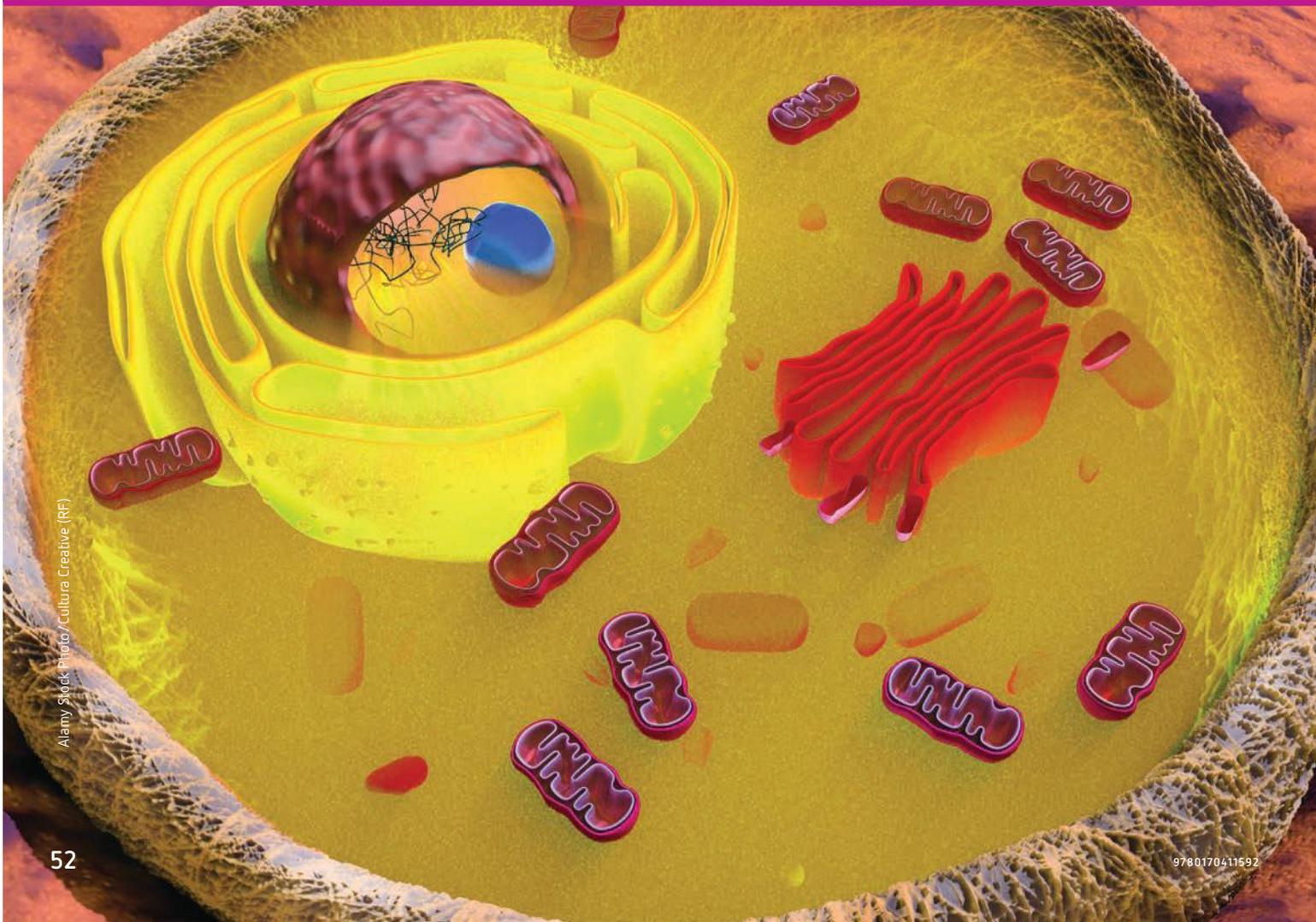
All organisms rely on biochemical pathways to live. Unicellular organisms take in materials (inputs) from their external environment and use these materials inside their single cell. The outputs or products of these activities are biomolecules and inorganic wastes. The biomolecules form the structures that carry out tasks for the organism. For instance, intracellular structures such as ribosomes synthesise proteins. Biomolecules such as carbohydrates provide a cell with the energy to perform these tasks. The waste products produced by working cells must be removed. Each of these essential pathways relies on specific enzymes to function.

Stimulus questions

How does the arrangement of internal membranes of a cell control biochemical processes?

How do enzymes act?

What factors affect enzyme activity?



3.1 Controlling biochemical processes

Compartmentalising a cell by having membrane-bound organelles creates specialised environments for specific functions. This enables a large number of activities to occur at the same time in a very limited space and under different conditions. For example, chemical reactions in lysosomes break down compounds brought into the cell by using strong digestive enzymes in an acidic environment. Enclosing these strong enzymes in a membrane prevents them destroying the cell. Specific chemical reactions can occur using only a handful of enzymes that can be concentrated and recycled in membrane-bound areas. Membrane-bound structures can concentrate reactants and store products.

Some organelles, such as mitochondria, increase their internal surface area by the folding and stacking of internal membranes. The composition of the mitochondrial membranes is similar to that of other membranes. However, mitochondria have a structure distinct from that of other organelles. They contain two membranes: the outer mitochondrial membrane and the inner mitochondrial membrane. Mitochondrial structure can be described as a smooth outer bag enclosing a crumpled inner bag. Two distinct compartments are formed through this arrangement.

Mitochondrial membranes

The outer membrane of mitochondria contains proteins and enzymes involved in transport of substances into and out of the organelle.

The inner folded membrane structure is much more complex. It is studded with enzymes needed for one stage of cellular respiration. The folds of the inner membrane are organised into layers, called **cristae**. The cristae greatly increase the total surface area of the inner membrane.

The space within the inner membrane – the **mitochondrial matrix** – contains enzymes in solution that are responsible for reactions in another stage of cellular respiration. The folding of the cristae means that no part of the matrix is far from the inner membrane (Figure 3.1.1) (see also Figures 2.5.6 and 2.5.7 on page 45).

Compartmentalisation of areas in the mitochondria allows for localisation of enzymes, arranged in order of the steps involved in cellular respiration.

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

mitochondrial matrix
the gel-like substance enclosed by the inner membrane of a mitochondrion



Chapter 4 discusses the process of cellular respiration and the role of mitochondria.

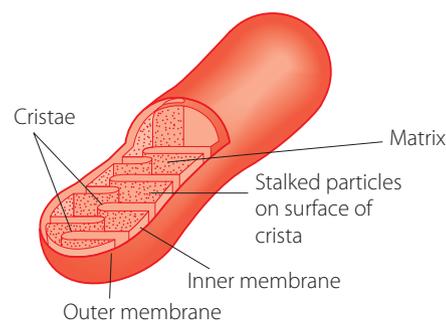


FIGURE 3.1.1 A generalised sketch of a mitochondrion in longitudinal section. The stalked particles on the surface of the cristae are the site of adenosine triphosphate (ATP) synthesis.

SECTION REVIEW

3.1

REMEMBERING

- 1 Define:
 - a organelle
 - b cell membrane
 - c cristae
 - d mitochondrial matrix.
- 2 Describe three advantages of having membrane-bound organelles in a cell.

UNDERSTANDING

- 3 Explain how the structure of a mitochondrion increases enzyme activity.

3.2

Enzymes control biochemical pathways



FIGURE 3.2.1 Thermal imaging reveals the heat emitted from objects. Living organisms with a high metabolism tend to give off more heat, which is why mammals such as sheep glow more brightly than trees and grass.

catalyst

a substance that speeds up a chemical reaction without being used up in the reaction

cellular metabolism

all of the chemical processes occurring in a living cell

intracellular enzyme

an enzyme that functions inside the cell that produces it, to speed up and control metabolic reactions

extracellular enzyme

an enzyme that is produced by cells but functions outside of the cells

activation energy

the energy required to initiate a reaction

Towards the end of the 19th century, the German chemist Eduard Buchner was experimenting to find a way of preventing yeast extracts from going bad. In one trial, he added sugar to yeast extract and, rather than preventing change, he found that the sugar was fermented and converted to alcohol. Louis Pasteur had already demonstrated that yeast was responsible for the fermentation of sugar but Buchner took the research further. He showed that the juice extracted from living yeast cells was responsible for fermentation, not the yeast cells themselves. To describe the active ingredient in the juice that caused the fermentation, he coined the term 'enzyme', from the Greek word 'zyme' meaning leavened. This is now the collective term for the thousands of organic protein molecules extracted from cells and found to act as organic **catalysts**.

The sum of the thousands of chemical reactions that occur constantly in each living cell is known as **cellular metabolism**. The rate of cellular metabolism varies among organisms (Figure 3.2.1). The metabolic reactions that occur in cells do not take place randomly; all are controlled and regulated to maintain cell functions and to meet the energy needs of the cell. These reactions need to occur at a rate that allows the cell to function. Each step in the pathway is controlled by an enzyme, the protein described by Buchner that speeds up the rate of chemical reactions without undergoing any change itself.

Enzymes

Enzymes are one of the most important groups of proteins. Without enzymes, the reactions that occur in living organisms would be so slow as to hardly proceed at all; this would be incompatible with the maintenance of life.

Enzymes do more than speed up reactions; they also control them. Over 1000 different reactions can take place in an individual cell. The functional organisation that this demands is achieved by a specific enzyme being in a particular place within the cell acting as a catalyst for each individual reaction.

Enzymes are divided into two broad groups: intracellular and extracellular. **Intracellular enzymes** occur inside cells, where they speed up and control metabolic reactions. **Extracellular enzymes** are produced by cells but achieve their effects outside the cells. They include digestive enzymes, which break down food in the small intestine.

Inputs, outputs and biochemical processes

Atoms and molecules in a cell do not stay still; they are constantly in motion and colliding. A reaction will only occur between reactants A and B if they receive enough energy for collisions between them to give rise to the products C and D. The amount of energy needed to strain and break the reactants' bonds is called the **activation energy**. When enough activation energy is available to break the chemical bonds of the reactants, new bonds form between the atoms, thus generating one or more products:



reactants products

For cells to continue functioning, enough energy must be provided to maintain the process of generating products from reactants. Cells must control the rate of energy released so they do not burn up.

All chemical reactions are reversible under certain conditions. It is important that products are removed from a cell so that they do not accumulate and slow down vital metabolic reactions. To achieve this, chemical reactions in cells occur in a series of regulated steps collectively called **biochemical pathways**. The product of one step becomes the reactant for the next step (Figure 3.2.2). In this way, a product from one reaction is continually removed by being the reactant for the next reaction.

biochemical pathway
chemical reactions in cells that occur in a series of enzyme-regulated steps

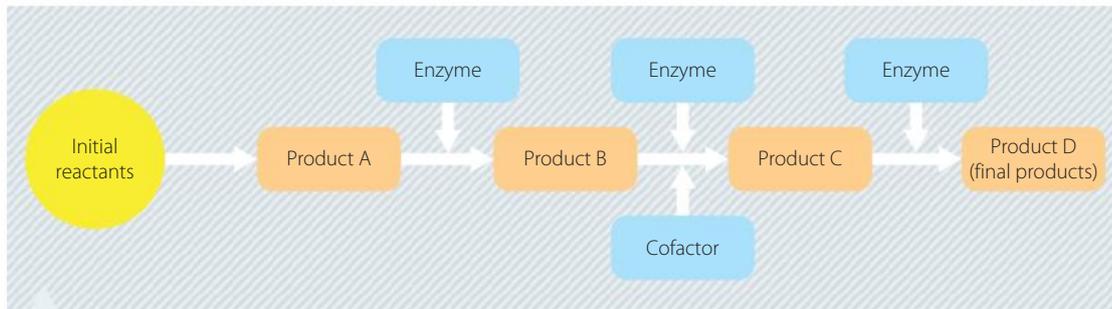


FIGURE 3.2.2 A biochemical pathway. The products or outputs of the first step become the reactants or inputs in the next step until the final products are reached. Each step is regulated by a specific enzyme. Other chemicals called cofactors may also be involved.

3.2.1 Activation energy

SECTION REVIEW

3.2

REMEMBERING

- 1 Define:
 - a cellular metabolism
 - b biochemical pathway.

UNDERSTANDING

- 2 Compare intracellular and extracellular enzymes.
- 3 a Explain why chemical reactions in cells proceed in a series of steps called a biochemical pathway.
 - b Predict what would happen to the reaction if the final product was not removed.

3.3 Active sites of enzymes

Effect of active site on specific functions

Enzymes are proteins. Like all proteins, enzymes have a specific shape. It is this shape that allows it to bind with a specific reactant (**substrate**). Enzymes are generally named according to the substrate they catalyse, or the reaction, and they usually end in '-ase'; for example, sucrase, lipase, maltase. The properties of enzymes suggest that when an enzyme-controlled reaction takes place, the enzyme and substrate molecules join for a short time to form an **enzyme-substrate complex**. The substrate is converted to the end product by the action of the enzyme. The enzyme is unchanged by the reaction and can be used again. This means enzymes are often only needed in small quantities within a cell:



substrate
a substance that enters a reaction; also called reactant or precursor

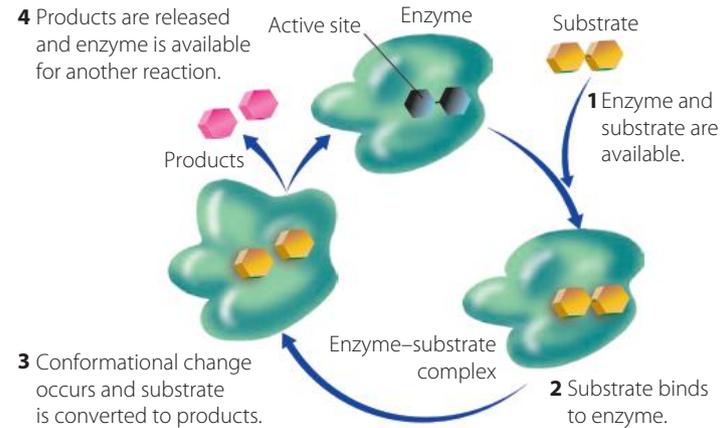
enzyme-substrate complex
a substance formed when an enzyme and a substrate molecule join

active site
the place on the surface of an enzyme molecule where substrate molecules attach

It is thought that each enzyme has a precise place on its surface to which the substrate can become attached. This is called the **active site** (Figure 3.3.1). All enzymes are substrate-specific. For instance, sucrase can only catalyse the substrate sucrose. There are two models for how an enzyme–substrate complex is formed at the active site.

FIGURE 3.3.1

Enzymes are highly specific molecules. A small part of the enzyme, called the active site, has the correct shape, or conformation, to bind with a specific reactant (substrate). The conformational change that results prepares the substrate for reaction.



lock-and-key model
a model suggesting that the shape of a substrate molecule is an exact fit to the shape of an enzyme's active site

Lock-and-key model

One model of enzyme action is known as the **lock-and-key model** (Figure 3.3.2). The folding of an enzyme protein forms a fixed groove or pocket-shaped active site. This groove can accommodate one or more particular substrate molecules. The active site is highly specific for a particular substrate. The substrate must be of a compatible shape for binding to occur.

induced-fit model
a model to explain that the shape of an enzyme's active site undergoes specific changes, induced by the substrate, to achieve a high degree of specificity with the substrate

Induced-fit model

The other model of how an enzyme–substrate complex is formed is known as the **induced-fit model** of enzyme action (Figure 3.3.3). This model is more widely accepted. In this case, the enzyme shape is not fixed. The bonds that form between an enzyme and its substrate are thought to modify the shape of the enzyme so that the substrate can be fully accommodated by the enzyme.

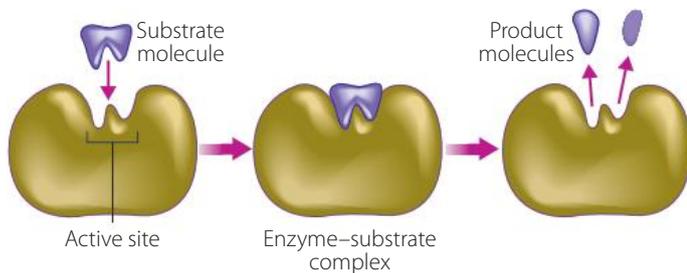


FIGURE 3.3.2 The lock-and-key model. The substrate fits into a specific active site on the surface of the enzyme, where the reaction takes place.

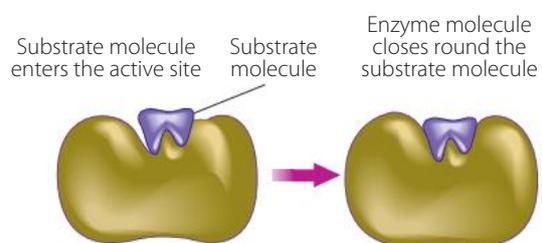


FIGURE 3.3.3 The induced-fit model. The substrate molecule enters the enzyme's active site, causing the enzyme molecule to change its shape so that the two molecules fit together more closely.

In this situation, the bonds within the substrate molecule are stretched and bent by the molecular interactions with the amino acid groups that line the active site. As a result of these stresses on the substrate, the activation energy required to initiate the reaction is dramatically lowered and new product molecules are formed at a faster rate.

MODELS OF ENZYME ACTION

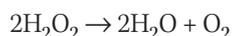
In 1894, Emil Fischer proposed the lock-and-key model to describe how enzymes worked. As new experimental techniques developed, a number of observations that did not fit with the lock-and-key model emerged. A more precise model was proposed by Daniel Koshland in the late 1950s. It was called the induced-fit model.

Conduct research into and compare and contrast the induced-fit and lock-and-key models of enzyme action.

SCIENCE AS
A HUMAN
ENDEAVOUR

Enzymes reduce activation energy

One of the fastest acting enzymes is catalase. This enzyme is found in several organs and tissues, including the liver, where its role is to speed the breakdown of hydrogen peroxide (H_2O_2) into water and oxygen:



hydrogen peroxide \rightarrow water and oxygen

Hydrogen peroxide is a toxic by-product of metabolism, so it is essential that the cell removes it as fast as possible. This reaction has a high activation energy, which means that the energy input required before hydrogen peroxide breaks down into oxygen and water is high. In living cells, the enzyme catalase lowers the activation energy for hydrogen peroxide to decompose by binding hydrogen peroxide at its active site. The decomposition of hydrogen peroxide in the presence of catalase can proceed up to 100 million times faster than without it. The action of enzymes in reducing the activation energy of reactions is represented in Figure 3.3.4.

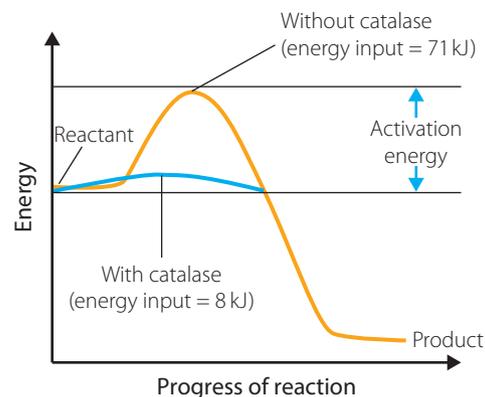


FIGURE 3.3.4 Catalase reduces the activation energy needed to break down hydrogen peroxide. Enzymes are powerful because they reduce the activation energy for chemical reactions.

Enzymes are not destroyed or altered by reactions

Enzymes are not destroyed or altered by the reactions they catalyse, so they can be used again. The product molecules are not specific to the active site of an enzyme, so when they are released, the active site becomes available for another substrate molecule. However, a given molecule of an enzyme cannot necessarily be used indefinitely, because the action of an enzyme depends critically on its shape. The shape of an enzyme is readily affected by changes such as temperature and acidity.

Enzymes can work in either direction

Enzyme-controlled reactions can work in either direction because metabolic reactions are generally reversible. The direction in which the reaction proceeds at any given time depends on the relative amounts of substrates and products present.

If there are a lot of reactants compared with products, an enzyme-controlled reaction will go from reactants to products until equilibrium between them is reached. One direction may be favoured more than the other, but the unfavourable direction of the reaction can occur using a different enzyme-controlled reaction. These types of reactions can also be referred to as **equilibrium reactions**.

equilibrium reaction

a chemical reaction in which the forward and reverse reactions occur at equal rates

REMEMBERING

- 1 Summarise the features of an enzyme.
- 2 Describe what happens to an enzyme after it has catalysed a reaction.
- 3 Recall how enzymes affect the activation energy required for a reaction to occur.

UNDERSTANDING

- 4 List the main properties of enzymes. Relate each property to the lock-and-key model.

APPLYING

- 5 Explain the induced-fit model of enzyme action. Describe how this is different from the lock-and-key model.

3.4 Factors affecting reaction rates of enzymes

Enzymes are involved in the processing of inputs both inside and outside cells. The intracellular and extracellular environments that enzymes work in are regulated to ensure that enzymes perform in a manner suitable to the cell's needs. Enzymes are sensitive to changes in temperature, pH, substrate and product concentrations, and other substances that may compete with a substrate for an active site.

Temperature

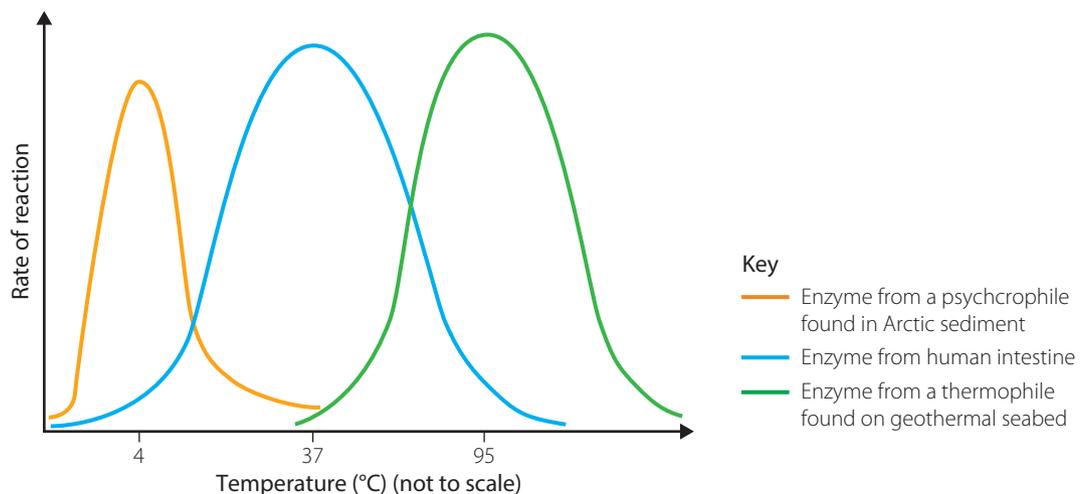
Enzymes are affected by temperature and have an optimal range in which they operate. The temperatures that enzymes work best in are the temperatures of the environment they can be found in. For example, enzymes in the human body work best at temperatures of around 37°C (Figure 3.4.1), which is the relatively constant core temperature of the body. **Psychrophiles** (or cryophiles) are micro-organisms that live in near-freezing environments such as the wind-blasted rocks of snow-covered mountain summits. Their enzymes can operate at very low temperatures. The ability to operate at these temperatures may be due to the loss of some of the bonds that keep the protein rigidly folded. Having a more flexible structure means that enzymes require less energy to work. The micro-organism *Pyrodictium* exists in geothermal-heated areas of the sea floor. It is a thermophile and its enzymes operate best at temperatures of around 95–105°C.

Enzymes from another thermophile, *Thermus aquaticus*, are utilised in biotechnology. The enzyme *Taq* polymerase is used in a technique called the polymerase chain reaction, which is used to make

psychrophile
an organism that can grow and reproduce at low temperatures, ranging from –20°C to +10°C

FIGURE 3.4.1

Activity gradually increases until the optimum temperature for enzyme activity is reached. As temperature continues to increase, enzymes become denatured so the reaction rate decreases.



millions of copies of DNA, because it operates at the required reaction temperature of 70°C and is not denatured at elevated temperatures of 90°C.

As temperature increases, molecules move more and collide more often. These more frequent collisions increase the opportunity for a substrate to bump into its enzyme so that it binds at the active site. Therefore, the rate of reaction increases. If the temperature gets too high, the protein loses its functional shape and the substrate can no longer bind with the active site. This change in shape is called **denaturation**. If the shape has changed enough to break the bonds between the connecting units of amino acids, proteins cannot return to their original shape when conditions revert to normal. In this case, the protein is destroyed.

Repercussions of temperature change

Denaturation of enzymes can be both dangerous and useful to us. If our body temperature rises too much during an infection, critical enzymes in our brain could denature, leading to seizures and possible death. On the other hand, heating meat denatures the proteins and the meat becomes easier to chew and digest. Raw meat is difficult to chew because of fibrous proteins contained in the muscle cells.

Enzymes are not denatured at low temperatures. As with all chemical reactions, lowering the temperature reduces the rate of activity and, therefore, the rate of reaction.

pH

The pH of the solution surrounding enzymes, whether it is acidic, basic or neutral, can have a profound effect on the structure and activity of the active site of an enzyme and its interactions with a substrate. Each enzyme operates at an optimum pH (Figure 3.4.2). Some enzymes can work in a broad range of pH environments, while others are very sensitive and will only work in a narrow pH range. Most enzymes work most effectively around a neutral pH of 7.

denaturation

the process by which the structure of a protein is changed by factors such as pH and temperature; the change in structure often destroys the shape of the active site of the molecule and results in a loss of function

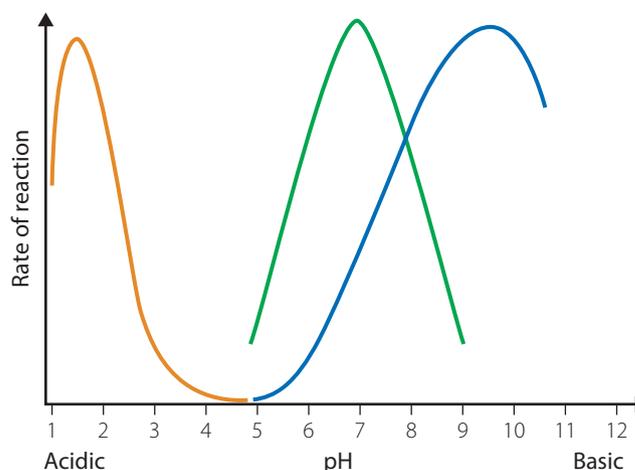
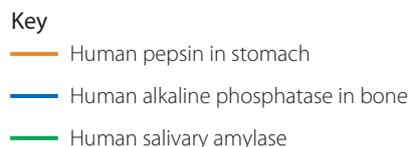


FIGURE 3.4.2

The optimum pH range for three different enzymes. Pepsin digests proteins in the acidic juices of the stomach, alkaline phosphatase catalyses reactions in the relatively alkaline environment of the bone and salivary amylase digests carbohydrates in the mouth at a neutral pH.

The optimal pH of an enzyme relates to the environment in which it is found. The enzyme pepsin, which operates in acidic gastric juices, has an optimal pH of 1.5. Catalase, which works in the neutral environment of cells in the liver, has an optimal pH of 7. Alkaline phosphatase, which is found in the relatively alkaline environment of the bone, has an optimal pH of 9.5.

Some enzymes change shape in response to changes in pH. In some cases, such as excessive acidity or alkalinity, the active site shape can alter so much that the enzyme becomes denatured and can no longer catalyse a reaction, or the substrate may change shape so it no longer fits into an active site.

Substrate and enzyme concentration

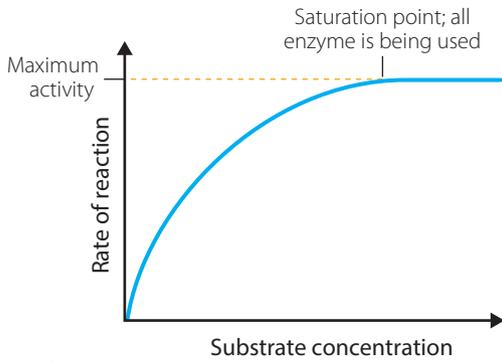


FIGURE 3.4.3 The effect of increasing substrate concentration on the rate of an enzyme-catalysed reaction. At saturation, further increases in substrate concentration do not increase the rate of the reaction.

The amount of substrate or enzyme present in a reaction mix can limit the amount of product produced. Increased amounts of substrate will result in more products being made until all the enzyme molecules are working at their maximum capacity (Figure 3.4.3).

When the amount of enzyme in a system is increased, the amount of product increases exponentially. This keeps occurring until the product starts to inhibit enzyme action or the substrate is depleted. The rate of reaction is proportional to the enzyme concentration, provided there is excess substrate present.

Enzyme concentrations are regulated in response to the needs of a cell. This regulation is achieved by controlling the production of the protein, breaking down the enzyme or activating the enzyme in response to a stimulus. For example, pepsinogen is an inactive form of the enzyme pepsin. When it enters the acidic environment of the stomach, pepsinogen is activated to catalyse the digestion of proteins.

Inhibitors

Some enzymes have two or more active binding sites. These enzymes can change from their active to inactive state when inhibitor or activator molecules bind with them. The activity of almost every enzyme in a cell is regulated by feedback inhibition, in which the product of a reaction can inhibit enzyme activity. If a large amount of product is present in the cell, it will act as an inhibitor by binding to a site on the enzyme, other than the active site, thus slowing the rate of reaction. When the inhibitor binds to the enzyme, the active site of the enzyme changes shape so that it no longer has an affinity for its substrate. If the product is removed, inhibition will be reduced and the product will be produced again. This helps cells keep the concentration of products within a certain range. In this case, the inhibitor does not bind with the enzyme's active site so it is said to be a **non-competitive inhibitor**.

Other inhibitors compete with the substrate for space in the active site and are said to be **competitive inhibitors**. For example, arsenic is an irreversible inhibitor that cannot be detected by the senses. Arsenate molecules resemble the phosphate substances used by cells for energy and signalling, and compete with them to bind to an enzyme's active site. Once arsenates are bound to an active site, the normal substrate is permanently excluded. Over time, less and less of the active enzyme remains to catalyse the reactions that produce energy for the cell. Thus, arsenic is called a chronic poison (Figure 3.4.5).

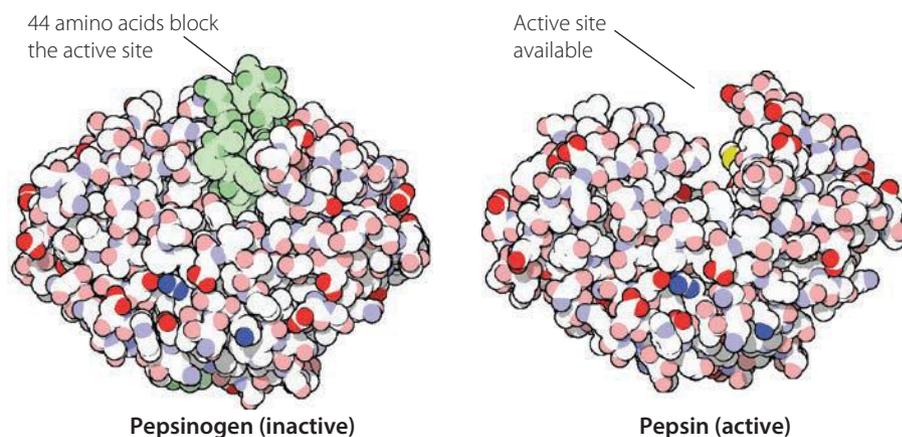
non-competitive inhibitor

a molecule that binds to an enzyme at a site other than the active site; this changes the shape of the enzyme so that the substrate can no longer bind to the active site

competitive inhibitor

a substance that competes with a substrate for an enzyme's active site

FIGURE 3.4.4 In the stomach, protein chains bind in the deep groove of the active site of pepsin so they are digested. Part of the polypeptide (shown in green) is removed from pepsinogen, the inactive form of pepsin. This then exposes the active site groove where proteins will bind.



David S. Goodsell, Research Collaboratory for Structural Bioinformatics

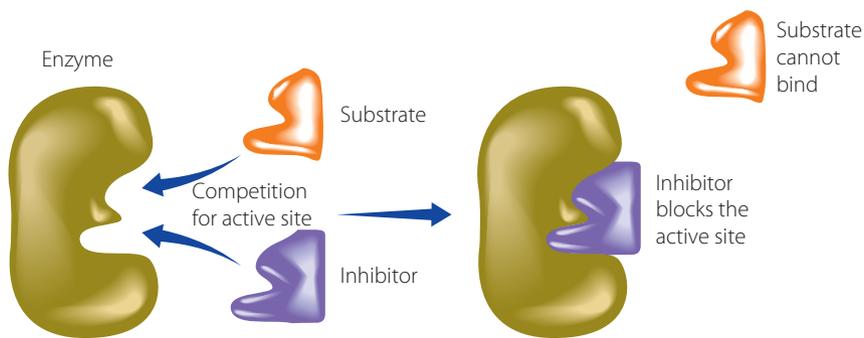


FIGURE 3.4.5

A competitive enzyme inhibitor blocks the active site of an enzyme so that the substrate can no longer fit in. Some inhibitors (poisons) bind irreversibly so the enzyme can no longer perform its specific function.



3.4.1 Cofactors and coenzymes
3.4.2 Beri-beri

Cofactors and coenzymes

Some enzymes are inactive until they bind with other molecules or ions that change their conformation. This alters the shape and the charge of the enzyme's active site so that it can capture substrate molecules and catalyse reactions more efficiently. Two classes of substances bind to enzymes, or to the substrate, to activate the enzyme: **cofactors** and **coenzymes**. Cofactors are small inorganic substances, such as zinc ions and magnesium ions. Coenzymes are non-protein organic substances, and are relatively small molecules compared to the enzyme. Many are made by organisms from dietary vitamins and act as carriers of substances to and from reactions that are catalysed by enzymes. Coenzymes play a major role in metabolic pathways.

Beri-beri is a disease that causes brain damage and affects short-term memory. It is caused by a deficiency of the vitamin thiamine, also known as vitamin B1. Thiamine is converted to the coenzyme thiamine pyrophosphate. This aids in the breakdown of glucose during cellular respiration. Without thiamine, there is an insufficient amount of energy available. Beri-beri affects the brain because the brain depends on the breakdown of glucose for energy.

cofactor

a small inorganic substance that is required in addition to an enzyme to catalyse a certain reaction

coenzyme

a small non-protein organic substance that is required in addition to an enzyme to catalyse a certain reaction

INQUIRING FURTHER

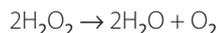
Menkes disease is a rare and fatal genetic disorder resulting in abnormal copper transport. Numerous enzymes need copper as a cofactor. Investigate the symptoms of Menkes disease and how copper, as a cofactor, plays an important role in central nervous system development.

PRACTICAL ACTIVITY 3.4.1

Conditions needed for effective enzyme action

INTRODUCTION

Catalase is an enzyme that works very rapidly. It is found in several organs and tissues, including the liver, where its role is to speed up the decomposition of hydrogen peroxide (H_2O_2) into water and oxygen:



AIM

To investigate the effect of surface area on the rates of enzyme reaction

MATERIALS

- liver (fresh) finely cut
- three test tubes
- 3% hydrogen peroxide
- mortar and pestle
- Bunsen burner/hotplate
- detergent
- sand
- 100 mL beaker



WHAT ARE THE RISKS IN DOING THIS EXPERIMENT?

Hot water baths can burn.

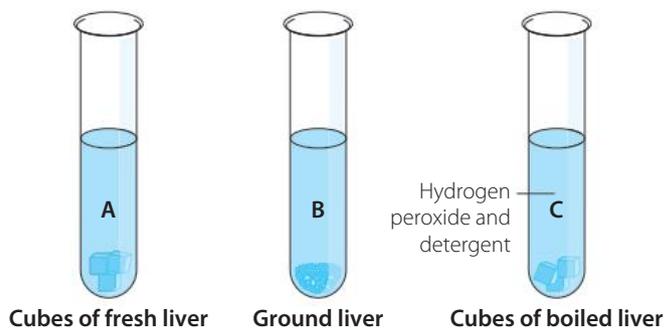
HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?

Do not touch the water bath container or the water in it.

PROCEDURE

- Write a hypothesis about what you think is going to happen in this activity.
- Collect nine small pieces of liver.
- Place three pieces of liver in a beaker half-filled with water and allow it to boil strongly for 5 minutes.
- Place three pieces of liver in a mortar with a little sand and grind with the pestle.
- Label the test tubes A, B and C and place 5 mL of hydrogen peroxide and 3 drops of detergent into each.
- Place the fresh liver into tube A, the ground liver into tube B and the boiled liver into tube C (Figure 3.4.6).
- Record the height of the bubbles produced in each test tube on the diagram in Table 3.4.1.
- Beneath each tube, record any further observations in your table.

FIGURE 3.4.6
Measuring
catalase activity



» OBSERVATIONS AND RESULTS

Table 3.4.1 Results table

TEST TUBE A	TEST TUBE B	TEST TUBE C
		
OBSERVATIONS		

DISCUSSION

- 1 Comment on the relative enzyme reaction rate of the three samples.
- 2 Explain why you would estimate the amount of activity of catalase by observing the amount of bubbling in the test tubes.
- 3 State the control in this experiment. Outline the variables that were being tested in the other two test tubes.
- 4 What effect does grinding up the liver have on enzyme activity? Explain why.
- 5 Account for the reaction rate in test tube C.

CONCLUSION

Relate the surface area to the rate of enzyme reaction.

INQUIRING FURTHER

Design a method that allows the oxygen produced in the reaction to be collected. Explain how this method leads to a more accurate calculation of enzyme reactivity.

SECTION REVIEW

3.4

REMEMBERING

- 1 Define:

<ol style="list-style-type: none"> a psychrophile b denaturation c competitive inhibitor 	<ol style="list-style-type: none"> d cofactor e non-competitive inhibitor f coenzyme.
---	--
- 2 Identify two factors that can affect the activity of an enzyme.

UNDERSTANDING

- 3 Explain what happens to an enzyme when it is denatured.
- 4 Describe how the amount of product produced in a reaction can affect an enzyme's activity.
- 5 Distinguish between a non-competitive inhibitor and a competitive inhibitor.

APPLYING

- 6 Interpret why a doctor would get worried if their patient developed a temperature in excess of 42°C.

CHAPTER REVIEW QUESTIONS

DETAIL QUESTIONS

- 1 Where is the active site of an enzyme?
- 2 What is the structure of the active site?
- 3 How does an active site and substrate fit together?
- 4 What happens to a substrate after joining with an active site?

CATEGORY QUESTIONS

- 5 What are the general properties of enzymes?
- 6 What are the general roles of enzymes?
- 7 What factors affect enzyme reaction rates?
- 8 How are enzyme reaction rates related to their properties and roles?

ELABORATION QUESTIONS

- 9 Why does one type of enzyme only form an enzyme–substrate complex with a specific substrate?
- 10 Why are enzyme reaction rates affected by various factors?
- 11 What would happen if a similar-shaped molecule to a substrate was added to a solution of specific enzyme and its substrate?

EVIDENCE QUESTIONS

- 12 What, if any, external sources did you use to support your answers to Questions 9–11?
- 13 Explain the reasoning behind your answers to Questions 9–11.
- 14 What alternative models of enzyme action are possible?
- 15 How could your answers to Questions 9–11 be improved?
- 16 What further evidence could be used to support your answers to Questions 9–11?



- 1 The primary function of an enzyme is to:
 - A decrease the activation energy
 - B increase the activation energy
 - C keep products from interacting
 - D act as substrate molecules.

- 2 The following reaction is catalysed by a series of enzymes (E1, E2 and E3). What will be the effect of denaturing enzyme E2?
 $A-E1 \rightarrow B-E2 \rightarrow C-E3 \rightarrow D$
 - A Each product, A, B, C and D, will still be produced.
 - B A, B and C will be produced.
 - C A and B only will be produced.
 - D Only A will be produced.

- 3 Which of the following best describes the action of enzymes?
 - A The part of the substrate that binds to an enzyme to bring about the reaction is called the active site.
 - B In the lock-and-key model, the lock is the substrate and the key is the enzyme. Only the correctly sized key fits into the keyhole (active site) of the lock.
 - C In the induced-fit model, bonding of the enzyme to its substrate changes the shape of the enzyme so that the substrate and enzyme fit together.
 - D Because the substrate fits tightly into the active site, most enzyme-catalysed reactions are not reversible.

- 4 The shape of the active site of an enzyme can be altered by:
 - A the presence of molecules with a shape similar to the active site
 - B excess alkalinity
 - C the presence of molecules with a shape complementary to that of its substrate
 - D an increase in activation energy.

- 5 In an enzyme-catalysed reaction, as temperature increases, the rate of reaction will:
 - A not change
 - B increase and then level off
 - C decrease and then level off
 - D increase and then decrease rapidly.

- 6** Name the folding of the inner membrane into the matrix of a mitochondria that increases the total surface area.
- 7** Name two classes of substances that bind to enzymes, or to the substrate, to activate the enzyme.
- 8** List one factor that can alter the speed of an enzyme-controlled reaction.
- 9** Describe the structure and role of the active site of an enzyme.
- 10** Explain why enzyme action is said to be highly specific.
- 11** A human protease works best at 37°C.
 - a** Predict what would happen to the enzyme's activity at very low temperatures.
 - b** Propose how this may differ from the activity of the enzyme at very high temperatures.
 - c** Describe what has happened to the active site in both cases.
- 12** The pH of human blood and body fluids (excluding gastric juices) is approximately 6.8–7.0. Explain why maintaining this level of pH is important.

4

ENERGY AND METABOLISM

Introduction

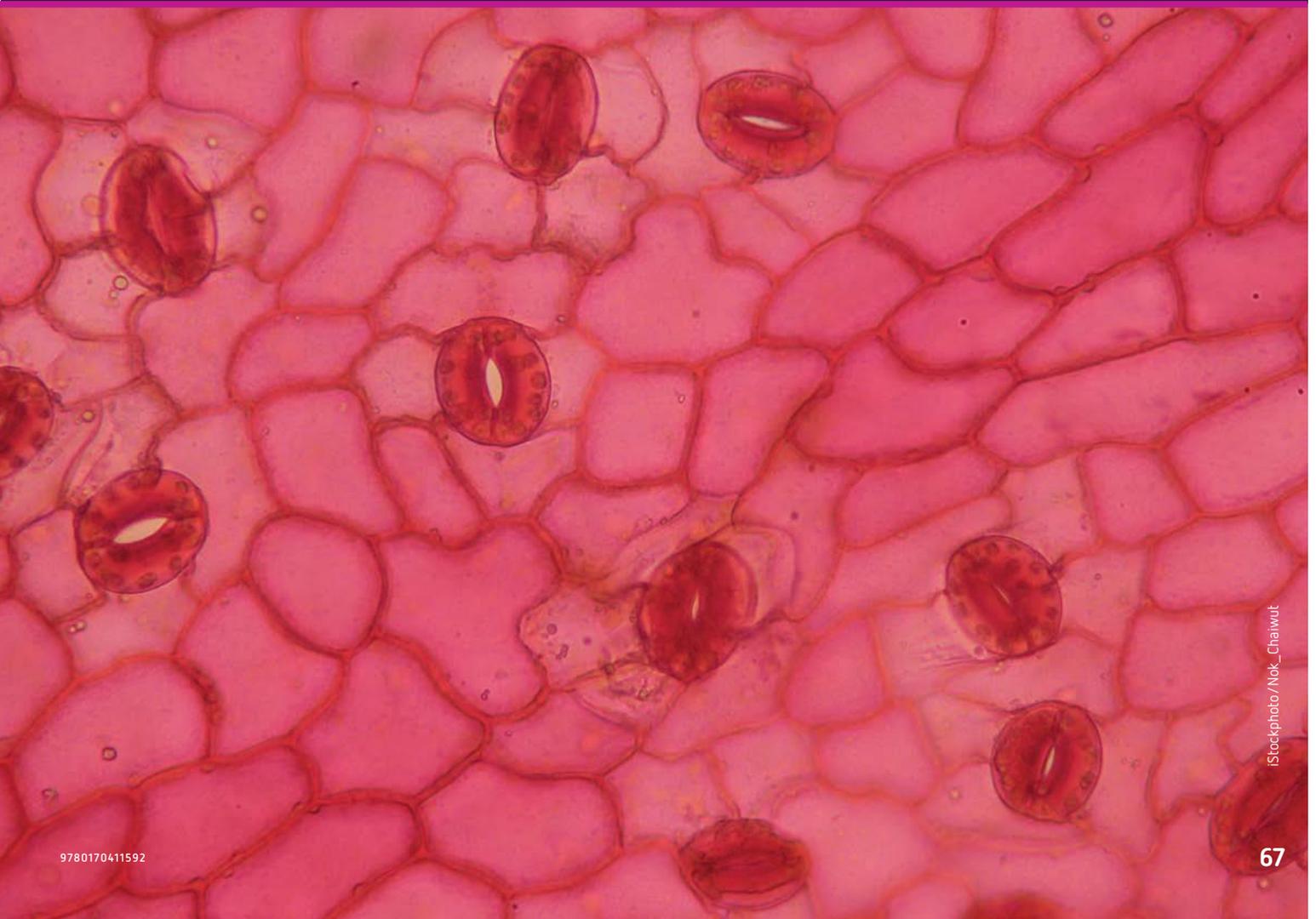
For life to continue, two conditions must be met: matter must be recycled and energy must be added. All things that are currently living contain atoms that have been recycled from other organisms. Although atoms may be restructured into new and different molecules, matter is continuously exchanged between living and non-living things. Energy is added to the planet through sunlight. An organism's metabolism transforms matter and energy. Plants are the key to maintaining energy flowing by the process of photosynthesis. Cellular respiration releases the energy from the products of photosynthesis.

Stimulus questions

How does energy flow through cells?

What are the chemical reactions of photosynthesis?

What are the chemical reactions of cellular respiration?



4.1 Energy transfer in cells

adenosine triphosphate (ATP)
the short-term energy storage molecule of cells



Chapter 2 describes the structure of prokaryotic cells, which include those of the domain Archaea.

INQUIRING FURTHER

Research the different methods Archaea use to synthesise ATP.

exergonic reaction
a chemical reaction that releases energy

endergonic reaction
a chemical reaction that requires 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



4.1.1 Cellular respiration

4.1.2 BBC: Cellular respiration

Organisms require energy to carry out the processes associated with life. 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 a molecule called **adenosine triphosphate (ATP)**. Energy is transferred between reactions. The process of cellular respiration allows cells to capture the energy stored in the chemical bonds of glucose to create ATP ready for use by the cell.

Energy transfer between reactions

Cells use the chemical energy released from **exergonic reactions** to fuel **endergonic reactions**. The two reactions 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. ATP is readily moved around the cell.

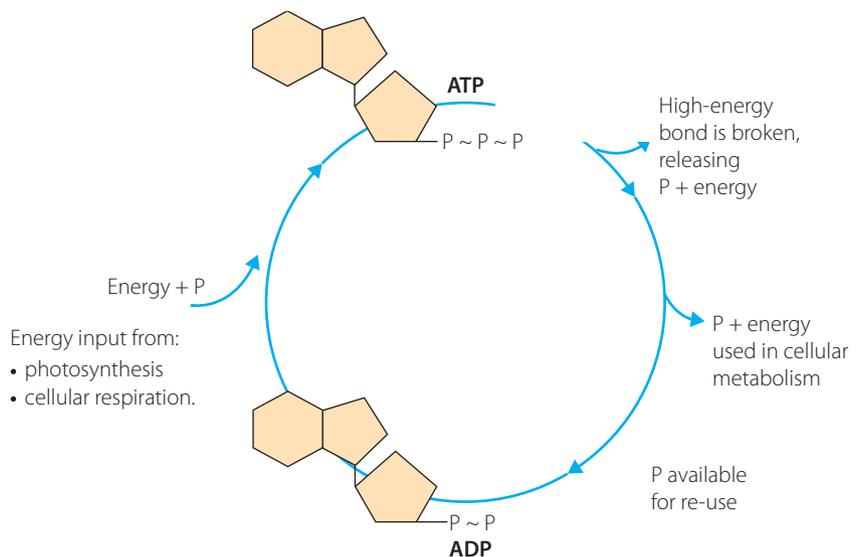
ATP is an energy carrier in all living cells. It couples energy-releasing reactions with energy-requiring ones. ATP is a nucleotide containing adenosine attached to a sugar group (ribose), which is bound to a chain of three phosphate groups.

The structure of ATP makes it very suitable as a renewable energy source. When a cell requires energy to drive a reaction, the high-energy chemical bonds attaching the last phosphate group 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)**. This reaction is sped up by the enzyme ATPase.

Free energy obtained from a reaction 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 (Figure 4.1.1). It provides the cell with an efficient linking or coupling of energy-yielding processes to energy-requiring processes within the cell by conserving, transferring and releasing energy.

FIGURE 4.1.1
The ATP–ADP cycle is the cell’s way of renewing its supply of immediate energy.



SECTION
REVIEW

4.1

REMEMBERING

- 1 Draw a diagram of an:
 - a ATP molecule
 - b ADP molecule.

UNDERSTANDING

- 2 Explain the relationship between ADP, ATP and ATPase.
- 3 ATP is an energy carrier molecule. Explain how its structure is related to its function.

APPLICATION

- 4 Compare a battery to ATP. Describe how they are similar.

4.2 Photosynthesis

If a pot plant growing in soil at a suitable temperature is put in the light and watered, the plant's mass increases over time. The rate of photosynthesis in the plant is greater than the rate of cellular respiration. If the plant is enclosed in an airtight container, the amounts of oxygen and carbon dioxide in the air can be measured. While the photosynthetic rate is greater than the cellular respiration rate, the amount of oxygen would increase and the amount of carbon dioxide would decrease. If the plant is kept in the dark, the plant is undergoing cellular respiration only and the amount of carbon dioxide would increase and oxygen would decrease in the surrounding container. The plant would gradually lose mass. This knowledge is not observable by simply looking at a plant growing in the garden.



FIGURE 4.2.1 Plants exposed to light increase in mass. Pineapple plants (*Ananas comosus*) would not be able to grow large fruit in the dark.

Photosynthesis reactions

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

Word equation: carbon dioxide + water $\xrightarrow{\text{light energy}}$ glucose + oxygen + water

Balanced chemical equation: $6\text{CO}_2 + 12\text{H}_2\text{O} \xrightarrow{\text{light energy}} \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 + 6\text{H}_2\text{O}$

This equation shows only the initial reactants and the final products. Photosynthesis occurs as a series of steps in a biochemical pathway, each catalysed by specific enzymes. It requires light as an energy source, which is captured by the pigment **chlorophyll**.

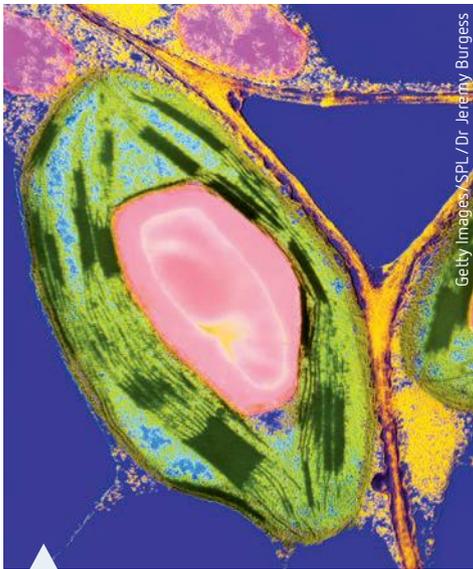
KEY
FORMULA

Photosynthesis

Word equation: carbon dioxide + water $\xrightarrow{\text{light energy}}$ glucose + oxygen + water

Balanced chemical equation: $6\text{CO}_2 + 12\text{H}_2\text{O} \xrightarrow{\text{light energy}} \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 + 6\text{H}_2\text{O}$

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



Getty Images/SPL/Dr. Jeremy Burgess

FIGURE 4.2.2 A false-colour transmission electron micrograph of a green chloroplast from a leaf of a coleus plant (*Plectranthus scutellarioides*). 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 $\times 5000$).

Chloroplasts

Chloroplasts are the site of photosynthesis. Chloroplasts have an outer and an inner membrane. The **stroma** is a gel-like matrix rich in enzymes and is enclosed by the inner membrane. Suspended in the stroma is a membrane system, the **thylakoid membranes** (Figure 4.2.2). 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.

Light-dependent stage

Light energy is absorbed by different pigments within the thylakoid membranes. These pigments 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. ATP molecules are formed in this stage.

Light-independent stage

The light-independent reactions occur in the stroma of the chloroplast. In the light-independent 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 formed in the light-dependent stage provide the chemical energy for the conversion of carbon dioxide to glucose molecules.

Relationship between light-dependent and light-independent reactions

Many chemical reactions are involved in both the light-dependent and light-independent stages of photosynthesis (Figure 4.2.3).



See Chapter 2 for information on the evolutionary origin of chloroplasts.

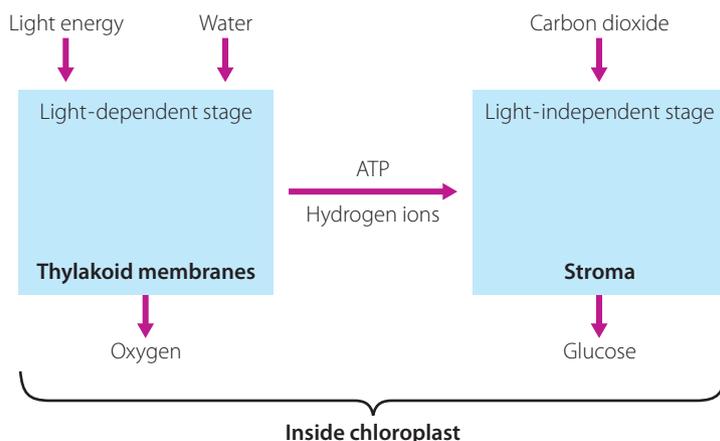
stroma
the jelly-like, semifluid interior of a chloroplast

thylakoid membrane
the interconnected, folded membranes within chloroplasts

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

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

FIGURE 4.2.3 Photosynthesis is a series of reactions occurring in two stages: the light-dependent and the light-independent stages.



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. Starch is the most common storage form. 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.

Tables 4.2.1 and 4.2.2 summarise the light-dependent and light-independent stages of photosynthesis.

Light-independent stage

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



4.2.1 The simple story of photosynthesis
4.2.2 Photosynthesis

TABLE 4.2.1 Summary of inputs and outputs for the light-dependent stage of photosynthesis. The data represents 12 cycles of the light-dependent reactions

INPUTS	TOTAL NUMBER OF MOLECULES	OUTPUTS	TOTAL NUMBER OF MOLECULES
Water	12	Oxygen	6
ADP	12	ATP	12
Inorganic phosphate	12		

TABLE 4.2.2 Summary of inputs and outputs for the light-independent stage of photosynthesis. The data represents six cycles of the light-independent reactions

INPUTS	TOTAL NUMBER OF MOLECULES	OUTPUTS	TOTAL NUMBER OF MOLECULES
Carbon dioxide	6	Water	6
ATP	12	ADP	12
		Inorganic phosphate	12
		Glucose	1

NEW SOURCES OF FUEL

Scientists have been studying biofuels as an alternative to fossil fuels. Plants are already being used as an alternative fuel in the form of bioethanol. Bioethanol requires a large input of solar energy, meaning the amount of land required to cultivate the plants is also quite large. The large energy and land requirements have led scientists to question the efficiency of producing bioethanol.

In Australia, bioethanol is produced by the fermentation of sugar, starch and cellulose; in the United States, it is predominantly produced from fermented corn; and in a number of Asian countries, palm oil is used.

Alternatives to traditional bioethanol include biofuels such as algae, which the Commonwealth Scientific and Industrial Research Organisation (CSIRO) is researching. The research being conducted by CSIRO also includes using the bacteria *Geobacteri* to conduct electricity.

Research one form of biofuel from plants. Identify how the fuel is produced and used. Discuss and evaluate the efficiency of the production process. Make recommendations about the fuel's use in Australia.

SCIENCE AS
A HUMAN
ENDEAVOUR

SECTION REVIEW

4.2

REMEMBERING

- 1 Name the products or outputs of the light-dependent reaction that are used as inputs for the light-independent reaction of photosynthesis.
- 2 Name the product of photosynthesis that contributes to the growth of plants.
- 3 Write a balanced equation for photosynthesis.

UNDERSTANDING

- 4 Do all living plant cells carry out photosynthesis? Explain your answer.
- 5 Distinguish between the light-dependent and the light-independent stages of photosynthesis in terms of location, requirements and products.

4.3 Cellular respiration

aerobic cellular respiration

a metabolic reaction that requires oxygen to produce energy for the cell

aerobe

an organism that requires oxygen

anaerobe

an organism that does not require oxygen

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

pyruvate

the end product of glycolysis

Krebs cycle

a biochemical pathway that requires oxygen and takes place in the mitochondria as part of cellular respiration; the second stage of aerobic cellular respiration

The process of breaking down chemical bonds in glucose, resulting in the release of free energy in the form of ATP, is known as **aerobic cellular respiration**. It can be summarised by the following equation.

Word equation: glucose + oxygen → carbon dioxide + water + energy

Balanced chemical equation: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 36-38ATP$

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, many micro-organisms live in environments without oxygen and can use other molecules. These organisms are called **anaerobes**. For all organisms, 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**.

KEY FORMULA

Aerobic cellular respiration

Word equation: glucose + oxygen → carbon dioxide + water + energy

Balanced chemical equation: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 36-38ATP$

Glycolysis

Glycolysis takes place in the cytosol of cells. The biochemical pathway of glycolysis is made up of ten 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 they are not sufficient for multicellular organisms. 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. This points to glycolysis being one of the earliest reactions to produce energy for the cell. The presence or absence of oxygen determines what occurs after glycolysis in prokaryotic and eukaryotic cells.

Cellular respiration with oxygen

In eukaryotic cells that are supplied with oxygen, the two molecules of pyruvate formed in glycolysis enter the mitochondrion (Figure 4.3.1). Mitochondria are small, regularly shaped structures scattered throughout the cell's cytosol. Mitochondria are often described as the 'energy powerhouse' of the cell because large numbers of ATP molecules are produced in them.

Pyruvate molecules undergo a series of reactions involving a cyclic biochemical pathway called the **Krebs cycle**. Carbon dioxide molecules are produced as a by-product of this second stage of aerobic respiration.

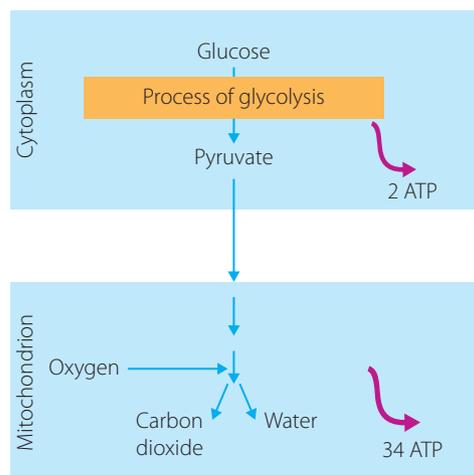


FIGURE 4.3.1 Glycolysis, the first stage of cellular respiration, occurs in the cytoplasm. The Krebs cycle and electron transfer chain stages of aerobic cellular respiration occur in the mitochondria.

The **electron transfer chain** is the third and final stage of aerobic cellular respiration. The process is a stepwise movement of electrons from high energy to low energy. A large amount of energy is released during this stage to drive most of ATP formation. At the end of the chain, electrons are taken up by oxygen molecules, which join with hydrogen to make water.

From all the reactions associated with aerobic cellular respiration, it is possible to produce a net 36–38 ATP molecules in one cycle.

electron transfer chain

the third and final stage of aerobic respiration involving the stepwise transport of electrons

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. They produce ATP using anaerobic pathways. Such organisms have evolved biochemical pathways that allow glycolysis to continue in the cytosol 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 and some bacteria, carry out anaerobic cellular respiration. The products of alcohol fermentation are carbon dioxide and ethanol, an alcohol. The overall summary for alcohol fermentation is given below.

Word equation: glucose → ethanol + carbon dioxide + adenosine triphosphate

Balanced chemical equation: $C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2 + 2ATP$

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

alcohol fermentation

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

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



4.3.1 Alcohol or ethanol fermentation

KEY FORMULA

Alcohol fermentation

Word equation: glucose → ethanol + carbon dioxide + adenosine triphosphate

Balanced chemical equation: $C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2 + 2ATP$

Yeast is a classic example of an anaerobic organism that is used in the brewing and wine-making industries. However, yeast grows much better under aerobic than under 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 to not let the conditions become too anaerobic. It is commercially beneficial to develop new strains of yeast that are tolerant to high concentrations of ethanol.

INQUIRING FURTHER

Yeast is commonly used to transform corn and other plant materials into biofuels such as ethanol. However, because large concentrations of ethanol are toxic to yeast, production capacity has been limited.

Research how microbiologists are finding new ways to increase yeast tolerance to ethanol.

Lactic acid fermentation

Lactic acid is the end product of anaerobic respiration in animals. Even though our body generates most of its energy by aerobic methods, sometimes we require energy production faster than our bodies can supply oxygen. For example, during strenuous exercise, our working muscles generate energy anaerobically with a build-up of lactic acid. Once the muscles slow down, oxygen is available again and lactic acid reverts to pyruvate, allowing continued aerobic metabolism and energy for the body's recovery from the strenuous event.

Aerobic respiration produces a lot of energy. Anaerobic respiration produces less energy because glucose is not broken down as completely as it is in aerobic respiration. 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. Aerobic and anaerobic respiration are summarised in Figure 4.3.2.

Word equation: glucose → lactic acid + adenosine triphosphate

Balanced chemical equation: $C_6H_{12}O_6 \rightarrow 2CH_3CH(OH)COOH + 2ATP$

KEY FORMULA

Anaerobic respiration

Word equation: glucose → lactic acid + adenosine triphosphate

Balanced chemical equation: $C_6H_{12}O_6 \rightarrow 2CH_3CH(OH)COOH + 2ATP$

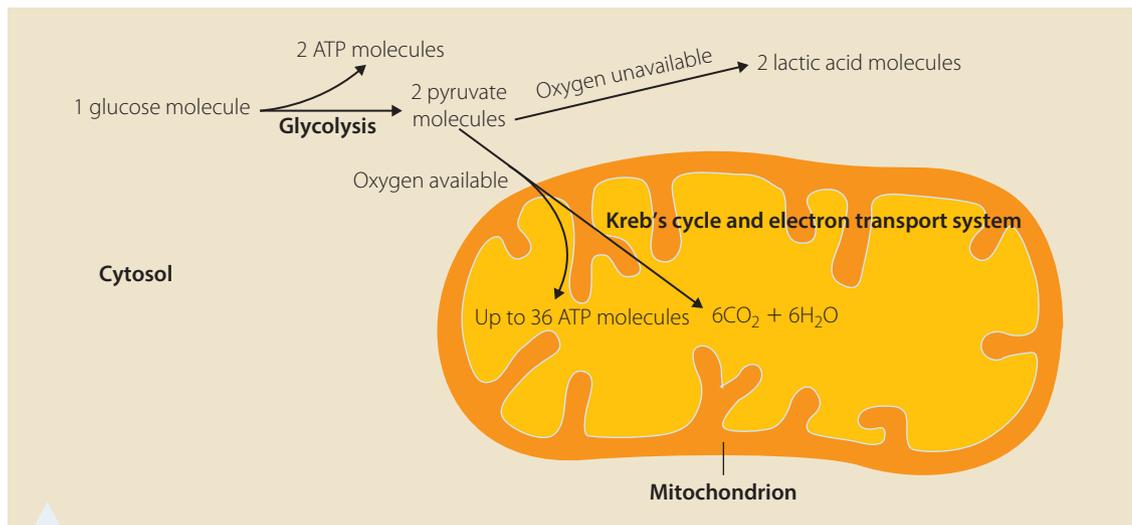


FIGURE 4.3.2 A summary of aerobic and anaerobic respiration in an animal cell

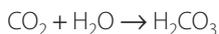
PRACTICAL ACTIVITY 4.3.1

Effect of light on photosynthesis

INTRODUCTION

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) according to the following equation:



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

- 2 *Elodea* healthy leaf shoots (or an alternative freshwater oxygenator available from the local aquarium or biological supplier)
- 5 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 spill 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.
Phenol red indicator can irritate skin and eyes.	Take care to avoid contact with skin and eyes.
<i>Elodea</i> is a noxious weed.	Dispose of <i>Elodea</i> safely, away from waterways.





PROCEDURE

- 1 Half-fill a test tube with tap water and add 2–3 drops of phenol red indicator. Note the colour.
- 2 Add 5 drops of 0.1 M ammonia solution. Note any colour change.
- 3 Add 5 drops of 0.1 M hydrochloric acid. Note any colour change, and then add a further 5 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 5–6 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 4.3.1 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 4.3.2 and record the colour of tubes A–D.

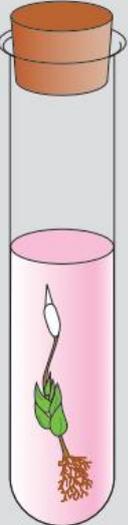
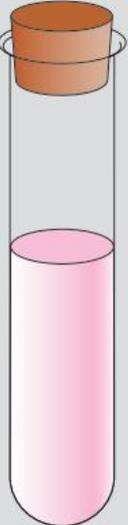
TABLE 4.3.1 Reference indicator colours

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 4.3.2 Measuring 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 wrapped 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.

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 the effect light has on the rate of photosynthesis compared to the rate of cellular respiration.

INQUIRING FURTHER

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

SECTION REVIEW

4.3

REMEMBERING

- 1 Write a balanced equation for aerobic cellular respiration.
- 2 Identify the initial substrate and the final product in the glycolysis pathway.
- 3 Describe where glycolysis takes place in all cells.
- 4 List two differences between aerobic respiration and fermentation.

UNDERSTANDING

- 5 Compare the products of anaerobic respiration with those of aerobic respiration in animals and plants.
- 6 Name the source of the by-product carbon dioxide in aerobic cellular respiration.

ANALYSING

- 7 Discuss why alcohol fermentation is used in bread-making rather than lactic acid fermentation.
- 8 'Muscle cells cannot contract when deprived of oxygen.' Evaluate this statement by using your knowledge of pathways for cellular respiration.

CHAPTER REVIEW QUESTIONS

DETAIL QUESTIONS

- 1 How is energy transferred in a cell?
- 2 What process converts light energy to chemical energy in the form of organic compounds (glucose)?
- 3 What process transfers energy from glucose to ATP?

CATEGORY QUESTIONS

- 4 How does the ATP–ADP cycle transfer energy in a cell?
- 5 What are the reactions of photosynthesis?
- 6 Where do the reactions of photosynthesis take place?
- 7 What are the reactions of cellular respiration?
- 8 Where do the reactions of cellular respiration take place?
- 9 How do the inputs and outputs of photosynthesis and cellular respiration compare?

ELABORATION QUESTIONS

- 10 Why does all life on Earth depend on the process of photosynthesis?
- 11 Why do all cells undergo cellular respiration?
- 12 What would happen to the rates of photosynthesis and cellular respiration if the amount of sunlight decreased?

EVIDENCE QUESTIONS

- 13 What, if any, external sources did you use to support your answers to Questions 10–12?
- 14 Explain the reasoning behind your answers to Questions 10–12.
- 15 What other energy transfer processes are available to cells?
- 16 How could your answers to Questions 10–12 be improved?
- 17 What further evidence could be used to support your answers to Questions 10–12?

- 1 Select the best description out of the following.
 - A The enzyme ATPase catalyses the reactions of glycolysis.
 - B Endergonic reactions are used to fuel exergonic reactions.
 - C ATP is an energy carrier in living cells.
 - D When ADP is converted to ATP, the energy released drives cellular reactions.
- 2 A human male will use approximately 8000 grams of ATP per hour. However, the body will have only 50 grams available at any given time. The ATP needed can be supplied because:
 - A more ATP is broken down than is synthesised
 - B some cells use less ATP than other cells
 - C ATP is recycled
 - D ATP can be used in more than one reaction simultaneously.
- 3 Fill in the gaps: In photosynthesis, the light-dependent reactions occur in the _____, while the light-independent stage occurs in the _____.
 - A stroma; thylakoid membranes
 - B thylakoid membranes; stroma
 - C cytoplasm; stroma
 - D stroma; cytoplasm
- 4 The *least* productive wavelength of light to a plant during photosynthesis is:
 - A green
 - B blue
 - C red
 - D orange.
- 5 The products of photosynthesis are water and:
 - A glucose and carbon dioxide
 - B carbon dioxide
 - C oxygen
 - D glucose and oxygen.
- 6 In animals, including humans, the following substance is produced anaerobically during strenuous exercise.
 - A Lactic acid
 - B Glucose
 - C Glycogen
 - D Ethanol
- 7 A cell that has a high proportion of mitochondria is most likely to be specialised to produce:
 - A starch for storage
 - B ATP to drive endergonic reactions
 - C glucose from the light-independent reactions
 - D specific enzymes to release fermentation products.
- 8 Write a balanced chemical equation for:
 - a photosynthesis
 - b aerobic cellular respiration.
- 9 Name the output of the:
 - a light-dependent stage of photosynthesis
 - b light-independent stage of photosynthesis.

- 10 Describe one advantage of aerobic respiration compared to anaerobic respiration.
- 11 Name the three stages of aerobic cellular respiration and where in the cell they occur.
- 12 Explain what Figure 4.5.1 represents.

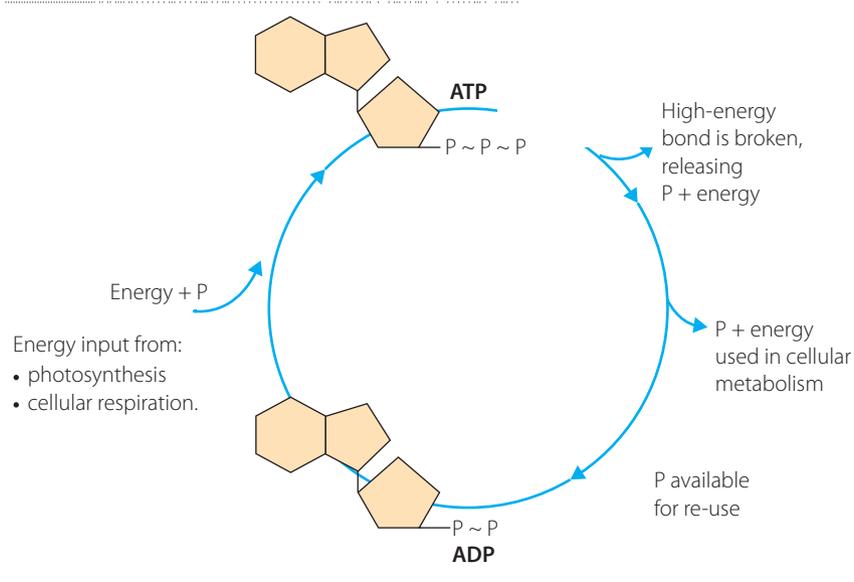


FIGURE 4.5.1
Describe what this diagram represents.

- 13 Relate the structure of ATP to its function.
- 14 Figure 4.5.2 shows the relationship between net carbon dioxide production and uptake by a green plant over time.
- Determine at what time the rate of photosynthesis would be equal to the rate of respiration.
 - Decide if the plant was put under light or dark conditions for the first 10 minutes of the experiment. Explain why you think so.
 - Predict what happened after 10 minutes to cause the change.
 - Suggest a reason why the carbon dioxide uptake levelled off at 30 minutes. Predict some limiting factors.
 - Predict what would happen to cellular metabolism if the temperature surrounding the plant increased beyond the plant's limit.
 - Explain why the carbon dioxide concentration in the air surrounding the plant can be used as a measure of the rate of photosynthesis.

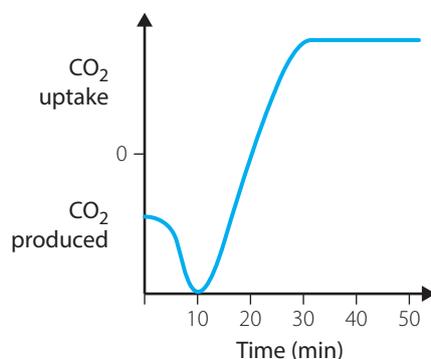


FIGURE 4.5.2
The relationship between net carbon dioxide production and uptake by a green plant

» UNIT ONE

CELLS AND MULTICELLULAR ORGANISMS



iStockphoto/chuvipro

A large, semi-circular graphic on the right side of the page, with a dark blue background and a yellow border. The number '2' is circled in yellow. The background of the page is a close-up of a pink flower with water droplets.

Topic 2: Multicellular organisms

The vast majority of organisms are multicellular. Cells are massed together in specialised tissues, organs and systems. All specialised cells originate from undifferentiated stem cells. Similar to individual cells, multicellular organisms need a way of exchanging gases, nutrients and wastes with their surroundings. Specialised structures are needed to do this. In animals, the respiratory and transport systems function to exchange and transport gases and the digestive and excretory systems function to exchange nutrients and wastes. Specialised structures in the leaf, stem and roots of plants function to exchange and transport gases.

SCIENCE AS A HUMAN ENDEAVOUR

Students should be given the opportunity to investigate the ethical treatment of animals, issues surrounding organ and tissue transplantation and bioartificial tissues and organs.

5

CELL DIFFERENTIATION AND SPECIALISATION

Introduction

There is an amazing diversity of cell shape and structure among all the living things that have evolved to currently inhabit the Earth. In multicellular organisms, these differences in cell structure relate to the specific function of the cells. This specialisation of cells allows the whole organism to function more efficiently in its environment, and thus survive to reproduce and ensure the continuation of the species.

Stimulus questions

How can all the different specialised cells in our bodies develop from just one cell that has just one set of genetic instructions?

What is the structural organisation of cells in multicellular organisms?

5.1 Properties of stem cells

The human species is highly evolved with approximately 200 different types of cells. In each individual organism, this huge variety of cells originates from just the first cell, the **zygote**, formed by the union of an egg and a sperm cell from two parents. Cells that are able to change or **differentiate** into different **specialised** types are called **stem cells**. Figure 5.1.1 shows undifferentiated embryonic stem cells growing together in a cluster.

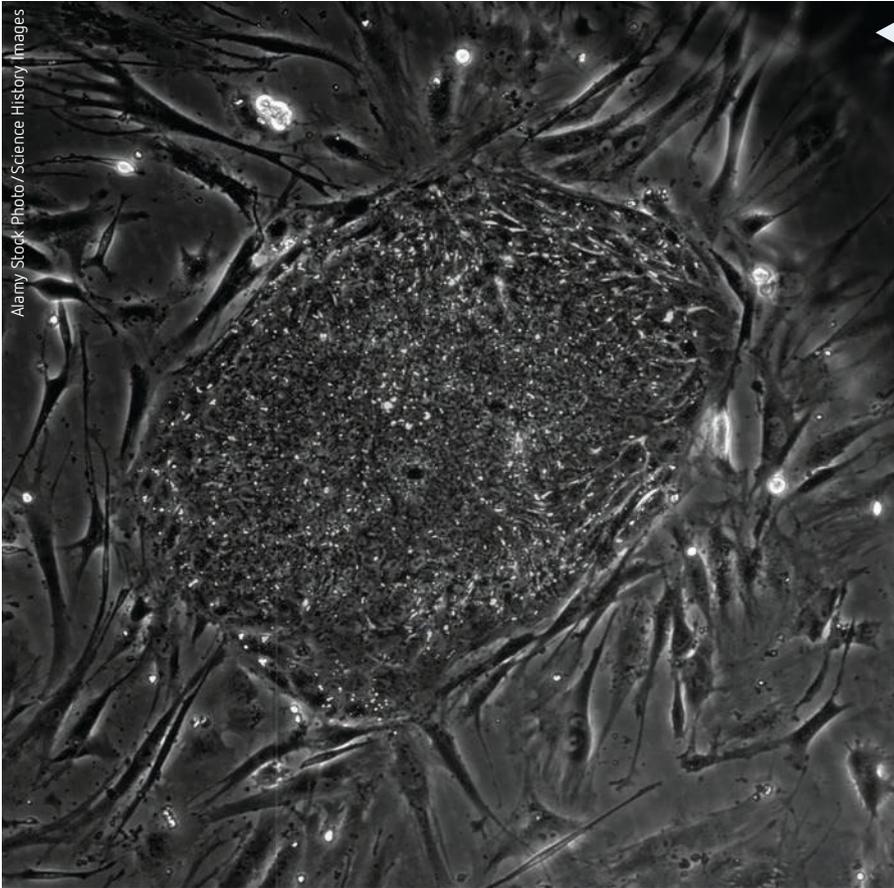


FIGURE 5.1.1
A magnified image ($\times 200$) of thousands of human embryonic stem cells growing together as a colony (the silver cluster of cells in the centre of the image) on top of mouse feeder cells (the dark filamentous structures). These cells can become any cell type in the body and divide indefinitely.

zygote
a cell formed by the union of two sex cells; usually fertilisation of an egg cell by a sperm cell

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

specialise
to develop specific features suited to specific function

stem cell
an unspecialised, immature cell capable of differentiating into a specialised cell



5.1.1 What are STEM cells?

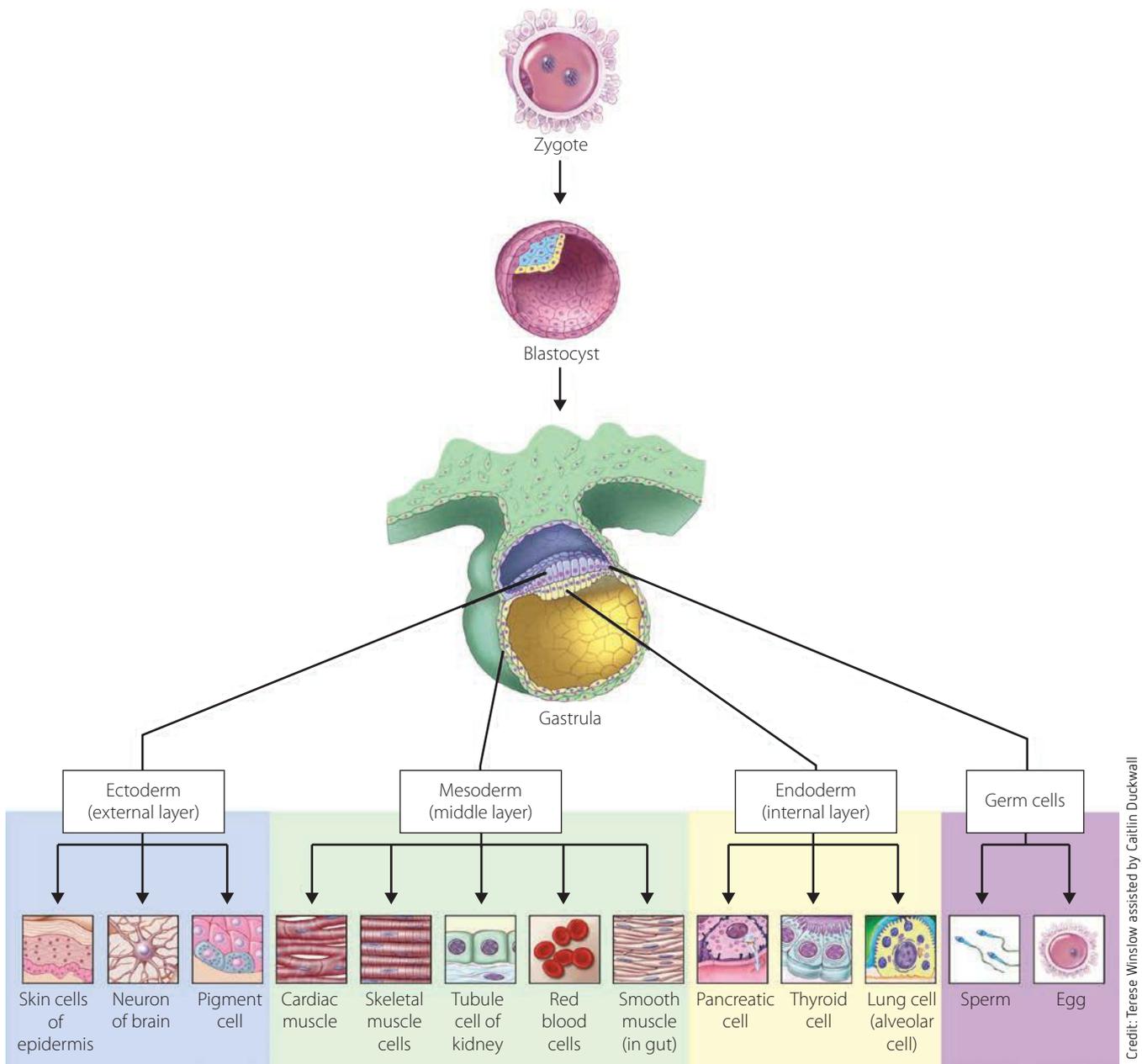
All specialised cells originate from stem cells. Stem cells differ from other cells in three important ways.

- 1 Stem cells are unspecialised; that is, they have not yet developed into a particular type of cell.
- 2 Stem cells have the potential to divide and replicate for long periods of time.
- 3 Although stem cells are relatively unspecialised cells, they can differentiate to form different specialised cells.

Potency of stem cells

Stem cells are categorised and named according to their potential to differentiate. A fertilised egg has the potential to develop into a complete embryo. At this point, the fertilised egg, or zygote, is a **totipotent stem cell**. (Totipotent means total potential.) Totipotent stem cells have the potential to develop into any type of cell necessary for embryonic development, including the embryo itself, and all the membranes associated with embryonic development (Figure 5.1.2, page 86).

totipotent stem cell
a stem cell that can develop into any of the types of cells necessary for embryonic development



Credit: Terese Winslow assisted by Caitlin Duckwall

FIGURE 5.1.2 A human zygote cell, the primary stem cell, develops into the multitude of different cell types that make up the human body.

pluripotent stem cell

a stem cell that can develop into many, but not all, of the cell types necessary for foetal development

embryonic stem cell

a stem cell that is cultured from an embryo

multipotent stem cell

a stem cell that can develop into a limited number of cell types

The zygote is the original totipotent stem cell that gives rise to all other cells in the human body. The zygote divides to form two identical totipotent cells, which divide to form four, then eight, and so on. Because these cells are still totipotent, any one of them has the potential to develop into an entire human being. Identical twins are formed when a small cluster of totipotent cells separates and two genetically identical embryos develop.

Approximately 5 days after fertilisation, the totipotent stem cells start to specialise to become **pluripotent stem cells**. At this stage, the ball of cells has an outer layer that develops into the placenta, and a distinct small inner cell mass of pluripotent cells, generally referred to as **embryonic stem cells** because they will become the embryo.

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 (**adult stem cells**), the best understood adult 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 cells and platelets. Adult stem cells in the human body function in the repair of damaged cells and to replenish those cells, such as blood, skin and intestinal lining cells that have a short life span. Table 5.1.1 summarises the potency of the different types of stem cells, and Figure 5.1.3 shows the sequential process of cell differentiation.

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

TABLE 5.1.1 Potency of stem cells

STEM CELL TYPE	POTENTIAL DIFFERENTIATION
Totipotent stem cells	Can give rise to all the cell types that make up the human body and 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 <i>not</i> the cell types that make up the embryonic membranes
Multipotent stem cells	Develop into more than one of the cell types that make up the body but <i>not</i> all cell types, i.e. different cells of a particular tissue type

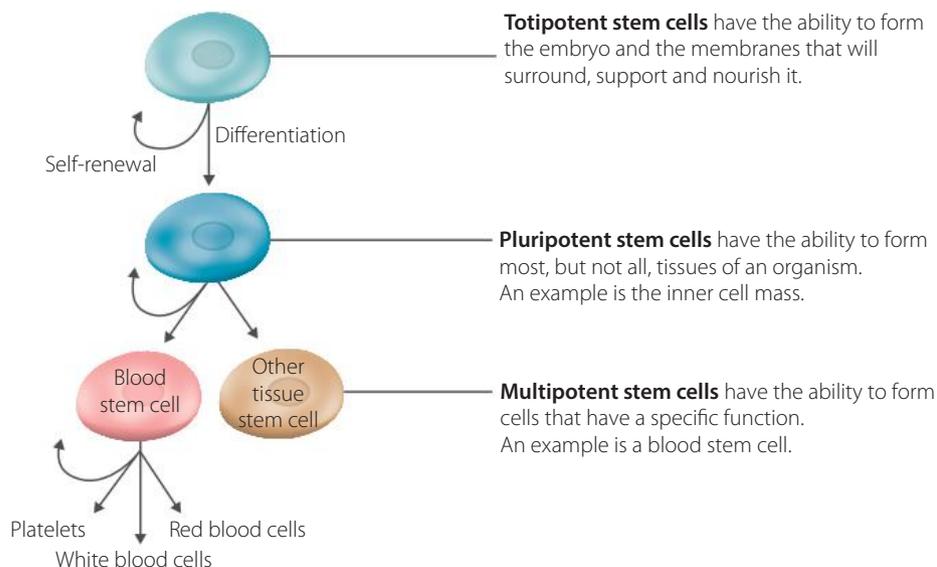


FIGURE 5.1.3 The process of cell differentiation

STEM CELL RESEARCH

Research by cell biologists has led to the discovery that certain cues found naturally in the environment of adult stem cells *in vivo* (inside an organism) cause them to develop into organised tissues. When the adult stem cells were placed in laboratory-produced culture media (*in vitro*), organised tissues did not develop. This led tissue-engineering scientists to add physical scaffolding and stimulatory chemicals such as growth factors and hormones to stem cells *in vitro* to guide the development of a three-dimensional tissue configuration.

Research the use of adult stem cells. The medical use of adult stem cells is much less controversial than that of embryonic stem cells. Explain why you think this is the case.

Suggest how the use of synthetic scaffolding and 3D printing, with *adult* stem cells, may help solve some of the ethical dilemmas in stem cell research and development, and therefore allow scientific advancements to proceed more quickly.

SCIENCE AS
A HUMAN
ENDEAVOUR

REMEMBERING

- 1 State whether each of the following is true or false. Justify your decisions.
 - a The process of specialisation in cells is called cellular differentiation.
 - b Different types of specialised cells contain different DNA.
 - c All specialised cells originate from stem cells.
- 2 Outline three ways in which stem cells are different from other cells in the body.

UNDERSTANDING

- 3 Consider the different types of stem cells. Explain how their names fit their potency.
- 4 Explain why a zygote is considered to be a stem cell.
- 5 Name the category of stem cell you consider the zygote to be. Explain why.

5.2 Stem cell differentiation

mitosis

a type of cell division in which a parent cell produces two daughter cells with exactly the same genetic material as each other and as the parent cell

Mitosis is a process of cell division. It is the process by which living things produce more cells for development, growth and repair. All cells are produced by mitosis except sex cells, such as eggs and sperm.

Mitosis produces daughter cells that are genetically identical to each other and to the original parent cell. This means that all of the non-sex cells within a multicellular organism are genetically identical to each other.

Formation of specialised cells

Even though the various specialised cells of a multicellular organism contain the same genetic instructions, they don't all look the same and they perform different functions. This is because not all of the genetic information is used in every cell. Only a small portion is actively 'switched on' in each cell; therefore, each cell's function depends on which of the many genetic instructions are actively expressed.

The cell's location in the developing organism, and its immediate environment, determine which genes will be activated in the developing cell. The activated genes cause the cell to manufacture particular proteins for the cell to differentiate. As a specialised cell, it will have a specific structure that suits its function.

Interdependence of specialised cells

Within a multicellular organism, this specialisation brings about the need for communication and coordination between cells. Specialised cells are totally dependent on activities of other cells to perform tasks that they cannot perform. For example, nerve cells in humans can transport nerve impulses, but they need red blood cells to deliver oxygen, heart muscles to pump the oxygenated blood to them and other cells to provide nutrients and remove their wastes. If a nerve cell was isolated, it would not be able to function on its own and would die.

Advantages of cell specialisation

The specialised cells in multicellular organisms are thought to increase the efficiency of the organisms as a whole, allowing them to carry out a wider variety of biochemical functions, without too much duplication of tasks by cells. Therefore, multicellular organisms are able to perform more complex physical and cognitive functions.

SECTION
REVIEW

5.2

REMEMBERING

1 Briefly describe the advantages of cells becoming specialised.

UNDERSTANDING

2 All cells within a multicellular organism contain the same genetic information, but the structure and function of specialised cells differs. Explain how this is possible.

APPLYING

3 Discuss whether you consider there to be any disadvantages in cell specialisation.

5.3

Structural hierarchy in multicellular organisms

There are patterns in how cells of multicellular organisms are organised and how they work together. Groups of specialised cells working together to perform a similar function make up **tissues**. Likewise, a collection of different types of tissues working together to perform a particular function is called an **organ**. For example, your heart is an organ. It consists of cardiac **muscle tissue**, in which **nervous tissue** directs its contractions. Chambers of the heart are lined with **epithelial tissue** that prevents leaking, and **connective tissue** that adds strength and elasticity.

A collection of organs that work together to perform a particular function in the body forms a **system**, the highest level of the hierarchical organisation. Figure 5.3.1 illustrates this hierarchical pattern. Figure 5.3.2 (page 90) shows a hypothetical organism and the interdependence of its different organ systems.

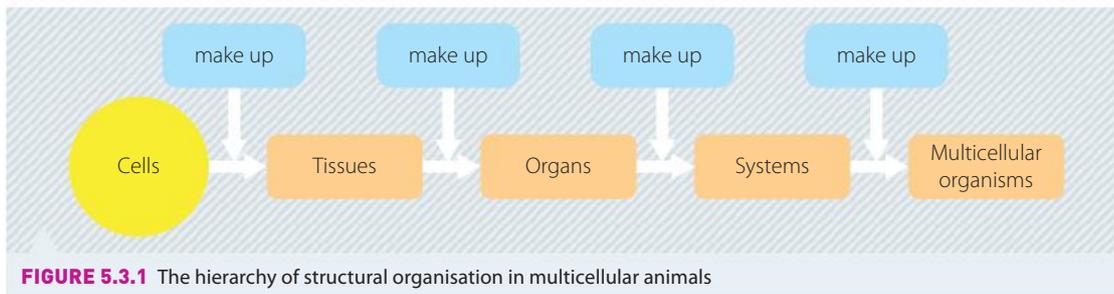


FIGURE 5.3.1 The hierarchy of structural organisation in multicellular animals

Each organ system contributes to the survival of all living cells in the body. For example, muscles and bones help each small, individual cell stay alive. The interactions between the skeletal system and the muscular system allow us to move towards sources of nutrients and water. Parts of these organ systems help keep blood circulating to cells, such as when contractions of leg muscles help move blood in veins back to the heart. The circulatory system rapidly transports oxygen and other substances dissolved in blood to cells, and moves metabolic products and wastes away from them. The respiratory system swiftly delivers oxygen from the air to the circulatory system and takes up carbon dioxide wastes from it. Skeletal muscles assist the respiratory system, and so it goes throughout the entire body.

While the skeleton helps support and gives shape to your body, and allows movement, it is merely one of the many systems that work together to keep you alive. Each of these systems is made up of different organs, which are made up of different types of tissues, which are made up of collections of specialised



Chapters 6–8 discuss the roles of various systems in animals and plants.

tissue

a group of specialised cells working together to perform a specific function

organ

a collection of different types of tissues working together to perform a particular function

muscle tissue

a type of tissue made up of thin, very long thread-like cells called muscle fibres that contract when stimulated

nervous tissue

a type of tissue containing cells that are highly specialised for transmission of nerve impulses

epithelial tissue

a type of tissue containing cells that line internal and external surfaces such as blood vessels, digestive organs and airways

connective tissue

a type of tissue that supports, strengthens and protects structures of the body

system

a collection of organs that work together to perform a particular function

cells. Although they share some features with other cells in the body, the cells in the skeleton also have different features that suit them to their specific function. These cells have become so specialised that they cannot live independently of other types of cells of your body.

Each different part of a cell has a specialised function, which can give rise to new abilities due to interactions among components with increasing organisation. These new abilities can be seen in multicellular organisms when individual cells cooperate to form tissues, tissues work together in organs, organs work together to carry out a particular function in systems, and these combined systems cooperate to maintain life. The interaction and cooperation between cells, tissues, organs and systems provide multicellular organisms with abilities that are beyond the limitations of a single cell.

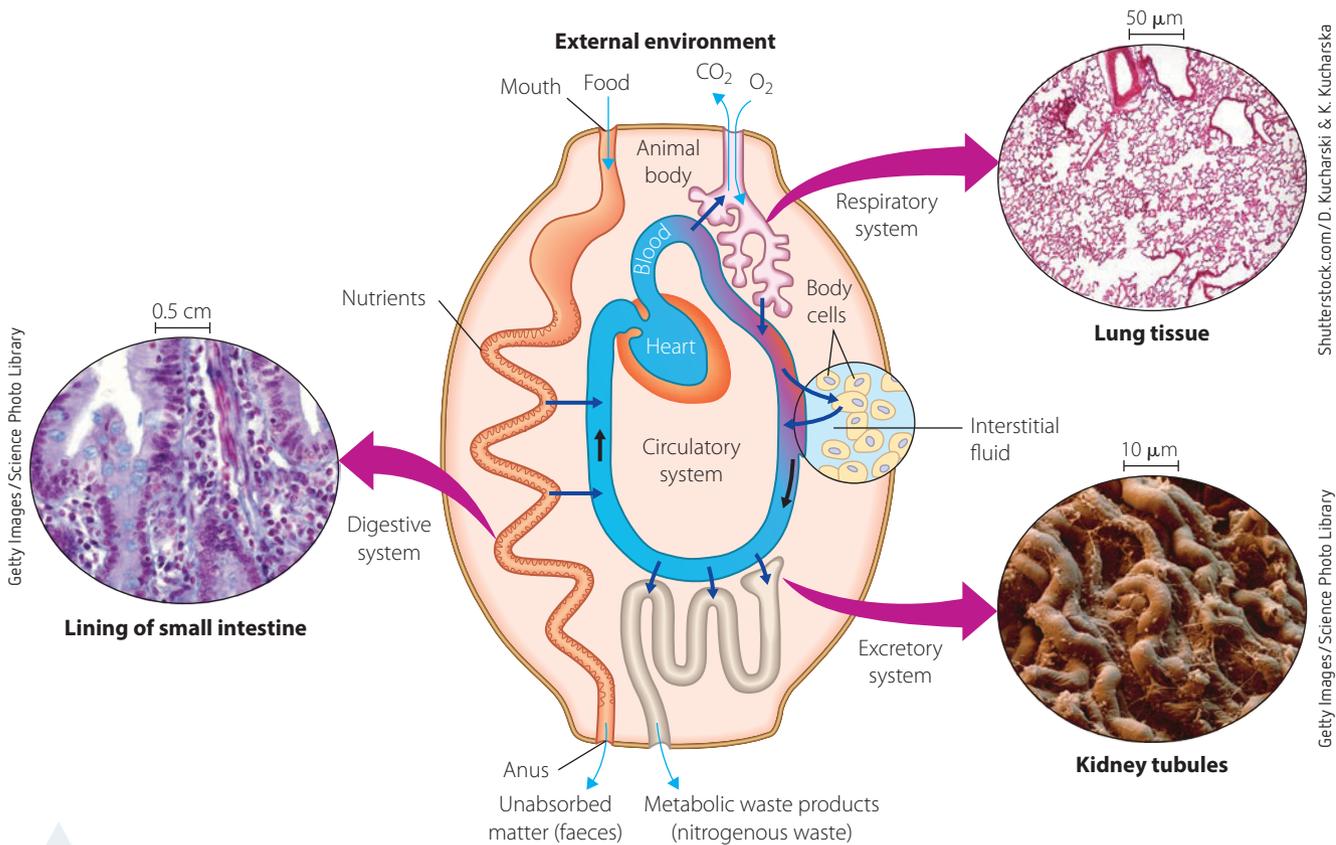


FIGURE 5.3.2 A schematic diagram showing the interaction between different systems of a hypothetical organism

SECTION REVIEW

5.3

REMEMBERING

- 1 Starting with cells, draw a simple flowchart showing the hierarchy of organisation within a complex multicellular organism.

UNDERSTANDING

- 2 Describe the relationship between specialised cells, tissues, organs and systems.
- 3 Explain the need for connections and communication between cells of a multicellular organism.

CHAPTER REVIEW QUESTIONS

DETAIL QUESTIONS

- 1 What properties do stem cells have that other cells do not?
- 2 What is an embryonic stem cell?
- 3 What are the different levels in the structural hierarchy of multicellular organisms?

CATEGORY QUESTIONS

- 4 Describe what it means to say that a cell differentiates into a specialised cell.
- 5 Choose a system of the human body that you are reasonably familiar with and try to name each of the organs in that system.

ELABORATION QUESTIONS

- 6 Explain why a zygote can be considered as the original stem cell of any human being.
- 7 Explain how two cells that have identical genetic material can each differentiate to become different specialised cells.
- 8 Explain why systems, each containing their own specialised cells, are dependent on each other.

EVIDENCE QUESTIONS

- 9 Describe an example of a particular function or process that occurs in the human body, where specialised cells from different organ systems are all involved to complete the process.
Ensure you use the names of the systems, the organs and the particular cells or tissues involved, and explain the contributory part played by each of these in the overall function or process.



- 1 Choose the correct statement, with respect to stem cells.
 - A Specialised cells have differentiated from stem cells.
 - B Stem cells have become differentiated from embryonic cells.
 - C Differentiated cells are totipotent.
 - D Zygote cells have become differentiated from unspecialised stem cells.
- 2 Different specialised cells within an organism:
 - A have different genetic material from each other
 - B have the same genetic material as each other
 - C initially had the same genetic material as each other but it changed with development to become different in each of the cells
 - D initially had genetic material from both parents but some of the parental genetic instructions was lost and the cells became different.
- 3 Advantages to complex multicellular organisms of having different types of specialised cells include:
 - A the ability to perform a wider variety of biochemical functions
 - B having a simpler body plan with more duplication of functions among cells
 - C an increased efficiency due to duplication with increased number of cells performing the same functions
 - D an increased chance of mutations causing further differences between cells.
- 4 The hierarchical levels of structural organisation in multicellular organisms, in order, are:
 - A *cells* make up *tissues*, which make up *organs*, which make up *systems*
 - B *tissues* make up *cells*, which make up *organs*, which make up *systems*
 - C *systems* make up *cells*, which make up *organs*, which make up *tissues*
 - D *atoms* make up *molecules*, which make up *compounds*, which make up *chemicals*.
- 5 Briefly describe the characteristics of stem cells that make them different from other cells.
- 6 Describe the differences between these three types of stem cells: totipotent, pluripotent and multipotent.
- 7 Briefly describe how it is possible for different types of cells to differentiate from stem cells all with the same genetic instructions.
- 8 Explain, by specifically naming an organ system and briefly describing its function or functions, how all of the parts of the body are dependent on each other.

6

GAS EXCHANGE AND TRANSPORT

Introduction

All cells require inputs so that they can perform the chemical reactions required to function. Some of these inputs are gaseous molecules. In unicellular organisms, essential input gases can simply diffuse across the cell membrane from the external environment into the cell. Gaseous molecules that are produced in cell reactions but which are not required can diffuse out. In the bodies of multicellular organisms, whole systems are deployed to allow this exchange of molecules between the inside and outside environments.

For both groups, the actual surfaces across which gaseous molecules move have special properties.

Stimulus questions

Why can't relatively large mammals, such as whales or even humans, exchange gases with the external environment directly through their skin surface, as can much smaller amphibians, such as frogs?

If whales obtain their oxygen through lungs, why can't fish?



6.1

Structure and function of gaseous surfaces

6.6.1 Circulatory and respiratory system

concentration gradient

the difference in concentration of a substance between two different regions

alveolus

a tiny air sac located on the end of a bronchiole

epithelial cell

a cell in a sheet of cells covering any external or internal surface in a multicellular organism

capillary

a very narrow blood vessel found between arteries and veins; part of a branching network that reaches to within a very small distance of every body cell

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

The mechanism of gas exchange between the external environment and the internal environment is similar for all living things. The surface across which the gas exchange occurs must:

- ▶ be moist, because the gases dissolve in water to 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 volume of the organism, to adequately supply the gaseous requirements and efficiently remove gaseous waste
- ▶ have a greater concentration of gas to be transported on one side of the membrane than on the other, so that the **concentration gradient** is maintained.

Gas exchange in mammals

In larger terrestrial animals, the gas exchange structures are inside the body to prevent the exchange surfaces dehydrating. The animals obtain the oxygen needed for cellular respiration from the air. Carbon dioxide is a product of cellular respiration and needs to be eliminated from the body.

Mammals have a high demand for oxygen to provide energy for their active lifestyles and maintain their body temperatures. The mammalian lung structure within the respiratory system has evolved to perform this gas exchange function very efficiently. Air passes into the lungs through the nose and mouth and into the trachea (windpipe), which branches into two bronchi (singular: bronchus) leading into the lungs. Inside the lungs, each bronchus continually divides into smaller tubes called bronchioles, each of which ends in a cluster of tiny air sacs called **alveoli** (singular: alveolus), as shown in Figure 6.1.1.

The alveoli 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 approximately equal to that of a tennis court. The single, flat layer of **epithelial cells** forming the alveolar wall is covered internally with a thin layer of fluid in which the gases can dissolve.

A network of **capillaries** surrounds each alveolus (Figure 6.1.1). The very thin wall of the alveolus is the body's boundary with the external environment, even though it is deep within the lung. The wall of the capillary, also only one cell thick, is the body's boundary with the internal environment; that is, the blood within the capillaries. Gaseous exchange between the two environments occurs naturally by diffusion: there is a higher concentration of oxygen in the air drawn into the alveolus than in the capillaries, and so oxygen enters the capillaries. Conversely, there is a higher concentration of carbon dioxide in the capillaries than in the inhaled air, and so carbon dioxide molecules diffuse out into the alveolus. The distance the oxygen and carbon dioxide molecules travel is much less than 1 micrometre (1 μm), which is one-thousandth of 1 millimetre (1 mm).

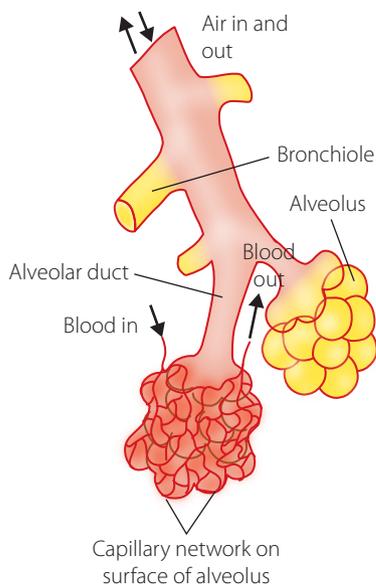


FIGURE 6.1.1 Each alveolar sac is surrounded by a network of capillaries.

Gas exchange in fish

Aquatic animals also require a constant oxygen supply. Although they don't have the challenge of keeping the respiratory surface moist, aquatic animals have the complication of extracting oxygen dissolved in the water surrounding them.

They need specialised adaptations to extract the dissolved oxygen, which occurs at less than 4–8 parts per million (ppm) compared to approximately 21%, or 210 000 ppm in air. Fish can exchange carbon dioxide and oxygen with their environment through their **gills**, which have all four necessary features of gas exchange surfaces that are listed at the beginning of this section.

Experimental data collected across different fish species has shown that gills are approximately four times as efficient at extracting oxygen from water as mammalian lungs are at extracting oxygen from air. Fish require less oxygen than mammals do because they don't need to maintain their internal body temperature; a fish's body temperature changes with its environment.

Bony fish have a hard, outer cover over their gills called an **operculum** that can be opened and closed. This helps to move water into the opercular cavity. Water is passed over the gills when it enters the mouth and exits through the operculum.

Each gill is composed of many layers of feather-like filaments, projecting out from the bony gill arches that form the basic structural framework. Inside each gill arch, a blood vessel delivers deoxygenated blood, and branches into a huge number of tiny capillaries inside the hundreds of fine filaments. Because the water flowing over the gill has a higher concentration of oxygen than in the capillaries, and a lower concentration of carbon dioxide, oxygen diffuses into the blood capillaries of the gill and carbon dioxide diffuses out. The oxygenated blood is then carried away by another larger blood vessel that the capillaries lead into, and is delivered to every cell of the body by more branching capillary networks further along in the closed circulatory system. The excess carbon dioxide is washed away from the gill by the water flowing over and past it.

Neighbouring filaments on each gill arch touch each other, as do the multiple filament layers on overlying gill arches, for maximum contact with the water flow passing over. The gill structure relies on the buoyancy of the water in which it is immersed to 'float' and thus spread out to expose its massive surface area, so that more of the internal blood supply is only a microscopic distance away from the water. This blood supply is easily seen as red in colour in Figure 6.1.2, through the extremely thin outer epithelial cell layers of the gill filaments.

If fish are taken out of water, their gills collapse because air does not provide the support that water does. Although air contains more oxygen than water, the fish will die because the surface area available to exchange gases decreases dramatically and the gills are no longer kept moist.

Oxygenated water flows over the gills in the opposite direction to which the deoxygenated blood flows through the capillaries inside. This **counter-current exchange** ensures maximum gaseous diffusion by maintaining a high concentration gradient.

gill
the gas exchange structure of a fish

operculum
a protective covering over the gills in bony fish



FIGURE 6.1.2 The operculum of a bony fish fully open to expose the gills. Out of water, the filaments bunch together.



Chapter 7 discusses a counter-current exchange system in the structures inside the human kidneys.

counter-current exchange
the mechanism observed in various systems in living things, and mimicked in engineering, where there is an exchange of particles or energy (heat) between two bodies flowing in opposite directions to each other

SECTION REVIEW

6.1

REMEMBERING

- 1 List the characteristics of an efficient gas exchange surface.
- 2 Name the gas that must be:
 - a taken *into* the body from the external environment
 - b expelled *from* the body to the external environment, in the cellular respiration process.
- 3 Name the structures between the internal and external environments through which gases move in:
 - a mammals
 - b bony fish.





UNDERSTANDING

- 4 Explain why living things need to continually exchange gases with their external environment.
- 5 Describe features of alveoli that suit them to their function as a gas exchange surface.

ANALYSING

- 6 Design and create a table to briefly describe how each of the characteristics of an efficient gas exchange system, as listed in Question 1, is achieved in mammals and bony fish.

6.2 Structure and function of capillaries

circulatory system

blood, blood vessels and heart working together to ensure all necessary materials are carried around the body to and from cells

closed circulatory system

a type of circulatory system in which blood is confined to a series of paths or vessels

artery

a blood vessel that takes blood away from the heart

vein

a blood vessel that carries blood to the heart



Chapter 1 discusses diffusion as one of the methods for movement of substances across the cell membrane

endothelial cells

a single layer of flattened cells that lines internal surfaces of body structures containing fluid

A transport system must be able to reach every cell in the body to facilitate the necessary exchange of materials between the cells and the external environment, without disrupting the functioning of other systems. The human **circulatory system** does this by having a:

- 1 fluid (blood) in which materials are transported
- 2 closed system of tubes (blood vessels), in which this fluid travels, that reaches all cells of the body
- 3 pump (heart) that pushes the fluid through the vessels.

The bloodstream in mammals is said to be a **closed circulatory system**. The blood is confined to a series of paths or vessels. The driving force behind the blood flow around the body is the heart, so all vessels must be connected to this organ. There are three main types of blood vessels. Large diameter blood vessels with thick elastic walls are called **arteries**. These vessels carry blood away from the heart. Large diameter vessels, but with much thinner and non-elastic walls, called **veins** carry blood back to the heart. Capillaries are found between these two blood vessels.

The capillaries branch extensively inside every organ of the body. Parts of these branching networks reach to within a microscopic distance of every cell in the body, to deliver the cellular requirements and take away cellular wastes. For example, the capillaries inside the lung branch to surround each tiny alveolus. In the small intestine, a network of capillaries facilitates efficient absorption of nutrients and ions. A tight ball of capillaries within each functioning unit of the kidney helps facilitate the removal of waste materials from the blood within, and reabsorption of water from urine (to be eliminated) is increased due to an extensive network of capillaries surrounding kidney tubules.

Unlike arteries and veins, capillaries have very thin walls and are very narrow. In fact, their walls are only one cell thick (Figure 6.2.1). This makes it possible for all the inputs that a cell needs, such as glucose and oxygen, to diffuse out of the capillaries to the cells. Wastes, such as carbon dioxide and urea, can also

pass from the cells to the blood inside the capillaries. The diameter of capillaries is similar to or less than that of a red blood cell, which further increases the diffusion rate of gases, due to the extremely small distance across which the molecules need to diffuse.

The capillary wall structure, composed of a jigsaw-puzzle-like single layer of flat **endothelial cells**, definitely suits its essential function as an exchange surface. Not only does it have a very thin wall, but also both inner and outer wall surfaces are bathed in fluid. Like other

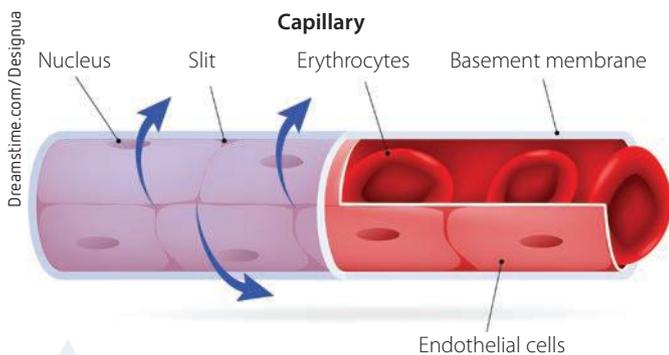


FIGURE 6.2.1 A diagram of a human capillary, illustrating the thin, flattened, jigsaw-puzzle-like endothelial cells that fit together to form the capillary wall

components of the human circulatory system, the capillary also functions to transport materials around the body, for which its tubular shape, with very smooth inner surface, is perfectly suited.

In the capillaries, red blood cells function extremely effectively to deliver oxygen molecules to body cells. Normally only about 0.3 millilitres (mL) of oxygen gas can dissolve in 100 mL of blood. However, red blood cells contain a pigment called haem and a special protein called globin, which combine to form **haemoglobin**, which enables red blood cells to carry about 20 mL of oxygen per 100 mL of blood – about the same as the proportion in air.

When there is a high concentration of oxygen, as in the capillaries carrying blood from the lungs, the oxygen atoms combine with the haemoglobin molecules to form **oxyhaemoglobin**. In areas where there is a low concentration of oxygen, as in the cells, where it is constantly used up in cellular respiration, the oxygen **dissociates** from the haemoglobin in the blood, and diffuses out through the red blood cell membrane, and then through the plasma within the capillary, and out through the capillary wall cell membrane to cells.

haemoglobin
the iron-containing protein molecule in red blood cells that attracts and binds with oxygen and gives blood its red colour

oxyhaemoglobin
the molecule in red blood cells formed by the combination of oxygen and haemoglobin

dissociate
to separate; dissociation is the chemical process where oxygen separates from haemoglobin

PRACTICAL ACTIVITY 6.2.1

Using data to predict direction of gaseous exchange

If the relative difference in concentrations of molecules in two different regions is known, it is possible to predict the direction of movement of these molecules: from the region where the molecules are in higher concentration to the region where they are in lower concentration.

PART A: GAS EXCHANGE BETWEEN ALVEOLI AND CAPILLARIES

Examine Figure 6.2.2. By convention, in diagrams red depicts oxygenated blood and blue depicts deoxygenated blood. In Figure 6.2.2, the gradation in colouring of the red blood cells as blood moves along in the capillary, from blue through purple to red, illustrates the increasing concentration of oxygen, as it diffuses into the blood cells of the capillary.

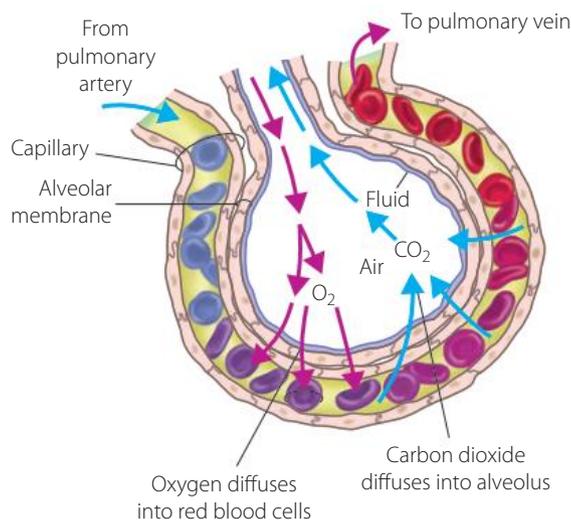


FIGURE 6.2.2
A diagram illustrating structural detail at cellular level of an alveolus and a capillary, and the gas exchange occurring between them

6.2.1 Oxygen movement from alveoli to capillaries



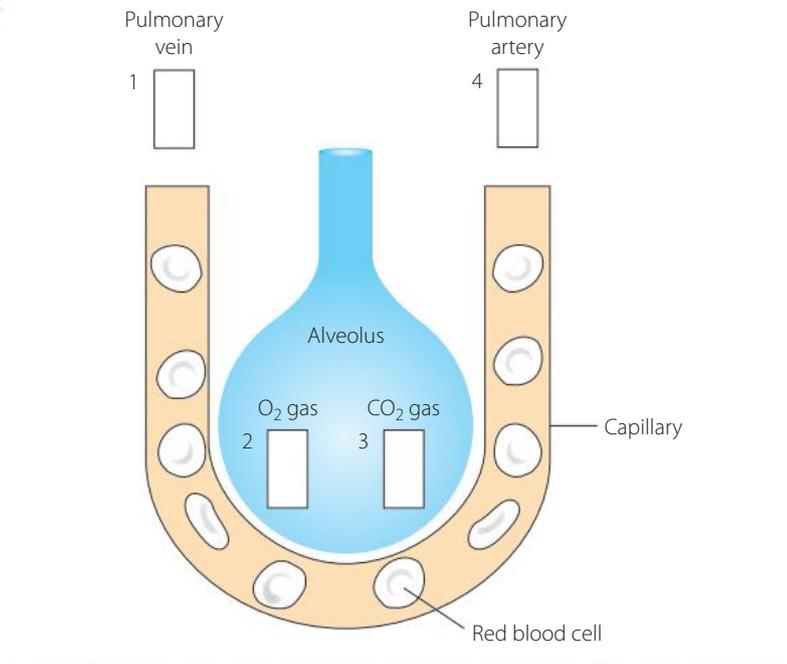
The direction of diffusion of the gases in Figure 6.2.2 can be determined because it is shown that deoxygenated blood inside the entering capillary is delivered from the pulmonary artery to the alveolus of the lung. After becoming oxygenated in the alveolus of the lung, blood is returned to the heart by the pulmonary vein.

Predicting direction of gaseous exchange and blood flow

Examine Figure 6.2.3.

FIGURE 6.2.3

A schematic diagram depicting the basic structure of an alveolus and a capillary



Answer the following guidance questions to predict the direction of blood flow and gaseous exchange in Figure 6.2.3.

- 1 Does the blood enter the capillary from the pulmonary vein or pulmonary artery?
- 2 Using your answer from Question 1, should rectangle 4 contain an up arrow or a down arrow?
- 3 At this point of entry, is the capillary carrying oxygenated or deoxygenated blood?
- 4 Therefore, is there a higher concentration of oxygen in the air in the alveolus, or in the capillary?
- 5 Therefore, in which direction will the oxygen diffuse?
- 6 Using your answer from Question 5, should rectangle 2 contain an up arrow or a down arrow?
- 7 Is there a higher concentration of carbon dioxide in the alveolus or in the capillary?
- 8 Using your answer from Question 7, should rectangle 3 contain an up arrow or a down arrow?
- 9 Should rectangle 1 contain an up arrow or a down arrow?

Check your answers against the following.

- 1 Pulmonary artery. Deoxygenated blood is moved away from the heart and into the lungs to be oxygenated, and all blood leaving the heart travels in arteries.
- 2 Down arrow
- 3 Deoxygenated blood: has previously been returned to the heart from body tissues and is now being sent to the lungs to become oxygenated



- 4 In alveolus, because a lot of oxygen has diffused *out* of blood to body cells previously
- 5 From the alveolus into the capillary
- 6 Down arrow
- 7 In the capillary, because a lot of carbon dioxide has diffused *into* blood from cells previously
- 8 Up arrow
- 9 Up arrow

Part B: Predicting direction of blood flow in capillary

Examine Figure 6.2.4.

6.2.2 Capillaries

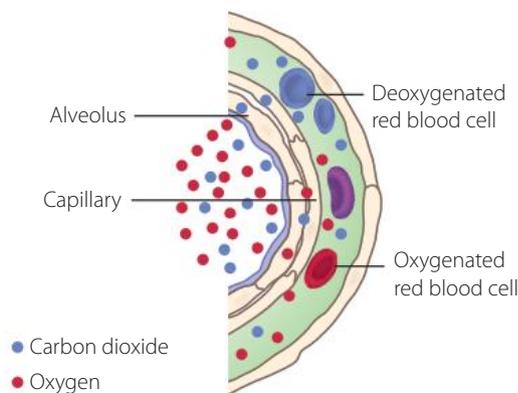


FIGURE 6.2.4

A schematic diagram showing oxygen and carbon dioxide molecules, depicted as small red and blue discs, in that order, at the site of gaseous exchange in the alveolus. Red blood cells inside the capillary are also shown, with their colours indicating the quantity of oxygen carried by the cell; red carrying the most oxygen and blue carrying the least.

Answer the following question to predict the direction of blood flow in Figure 6.2.4.

- 10 In which direction is blood flowing in the capillary: from top to bottom or from bottom to top?

Check your answer against the following.

From top to bottom. The red blood cells are changing from blue to red from top to bottom, because oxygen molecules are starting to diffuse *into* the capillary from the alveolus.

PART C: GAS EXCHANGE BETWEEN CAPILLARIES AND MUSCLES

After the blood becomes oxygenated via the alveoli of the lungs, it is transported back to the heart to be pumped out, to deliver oxygen to all the cells of the body, including to muscle cells.

Using data to determine relative differences in concentrations

In Figures 6.2.2–6.2.4, measured quantities of oxygen and carbon dioxide molecules in particular illustrated regions were not given. However, it was still possible to predict the direction of movement of gaseous molecules (and blood) from the supplied qualitative information, by applying knowledge of this topic, and knowing that diffusion of molecules occurs from higher concentration to lower concentration.

Using data to predict direction of gaseous exchange

Examine Table 6.2.1 (page 100), which lists the partial pressures of oxygen $P(\text{O}_2)$ and carbon dioxide $P(\text{CO}_2)$ gases in the body in kilopascals (kPa) (kPa is also the metric unit of measurement used to measure the air pressure in car tyres). Partial pressures, relative to each other, indicate the relative proportions or relative concentrations of those gases in the total body of gas. With the numerical data supplied, it becomes obvious which gas occurs in the highest concentration in each of the regions, by simply reading off the highest partial pressure measurement given. Therefore, it is possible to predict the direction of diffusion of the gases between pairs of regions listed in the table.



Answer the following questions about predicting the direction of gaseous diffusion, using the information in Table 6.2.1.

TABLE 6.2.1 Partial pressure measurements of oxygen and carbon dioxide gases at various sites around the human body

	PARTIAL PRESSURE (kPa)						
	EXTERNAL AIR	ALVEOLUS AIR	PULMONARY VEIN (BLOOD EXITING LUNGS)	CAPILLARY ENTERING MUSCLE TISSUE	MUSCLE TISSUE	CAPILLARY LEAVING MUSCLE TISSUE	PULMONARY ARTERY (BLOOD ENTERING LUNGS)
$P(O_2)$	160	104	100	90	39	38	38
$P(CO_2)$	0.3	40	40	41	46	46	46

- 11** What is the difference in $P(O_2)$ between the capillary entering muscle tissue and in the muscle tissue itself?
- 12** Using your answer from Question 11, in which direction would you expect O_2 molecules to diffuse?
- 13** What is the difference in $P(O_2)$ between the muscle tissue and the capillary leaving it?
- 14** Using your answer from Question 13, would you expect any diffusion of O_2 between these two tissues? Why or not?
- 15** What is the difference in $P(CO_2)$ between the external air and alveolus air?
- 16** Using your answer from Question 15, in which direction would you expect CO_2 molecules to diffuse?
- 17** Do you think the size of the difference in pressures has an effect on the *quantity* of gas molecules diffusing? Why or why not?
- 18** Do you think the size of the difference in pressures has an effect on the *speed* of gas molecules diffusing? Why or why not?
- 19** What does no difference in pressures between capillary leaving muscle and pulmonary artery indicate?
- 20** Comment on the differences between $P(O_2)$ and $P(CO_2)$ in the pulmonary artery and in muscle tissue, and try to explain your observations.

Check your answers against the following.

- 11** $90 - 39 = 51$ kPa
- 12** From the capillary to the muscle tissue.
- 13** $39 - 38 = 1$ kPa
- 14** No. There is almost no difference in concentrations between regions; O_2 is in equilibrium between the two regions.
- 15** $40 - 0.3 = 39.7$ kPa
- 16** From alveolus to air outside.
- 17** Yes. The more molecules there are on the highly concentrated side of membranes compared to the other side, the more molecules will randomly pass through compared to movement in opposite direction.
- 18** Yes. The more molecules there are on the highly concentrated side of the membranes compared to the other side, the *faster* the molecules will randomly pass through from higher to lower side, compared to lower to higher side.

- 19 No more exchange of gases occurs in blood vessels on the rest of blood's journey from capillary back to the lungs.
- 20 There is (virtually) no difference between gaseous concentrations in the pulmonary artery and the muscle tissue. Blood returned to the heart from the muscles, via the vena cava, is forwarded through the pulmonary artery to the lungs to be oxygenated. No gaseous exchange takes place until the blood reaches the alveoli of the lungs.

INQUIRING FURTHER

Oxygen–haemoglobin dissociation curves show the relationship between partial oxygen pressures on the horizontal axis (*x*-axis) and a percentage measurement of how much oxygen is attached to haemoglobin in the red blood cells on the vertical axis (*y*-axis).

- 1 Investigate the shape of these curves and try to explain why they have this shape.
- 2 What conditions can change the shape of the curves?
- 3 What is a foetal oxygen–haemoglobin dissociation curve, and how is it useful?

SECTION REVIEW

6.2

REMEMBERING

- 1 List the three major components of the human circulatory system.
- 2 Explain why the bloodstream in mammals is described as a closed circulatory system.
- 3 Compare the diameters of capillaries, arteries and veins.
- 4 Describe the structure of a capillary.

UNDERSTANDING

- 5 Explain how the capillary structure suits it to facilitating the exchange of materials.

CHAPTER REVIEW QUESTIONS

DETAIL QUESTIONS

- 1 Through which two particular structures, in order, in the human body does:
 - a oxygen gas enter the internal environment?
 - b carbon dioxide leave the internal environment?
- 2 Through which particular structure or structures in the bony fish body does:
 - a oxygen gas enter the internal environment?
 - b carbon dioxide leave the internal environment?
- 3 What structures in the human body allow oxygen gas that has entered the body to be delivered to every cell?
- 4 Do the structures named in Question 3 carry out the same function in bony fish?

CATEGORY QUESTIONS

- 5 Describe the common features of gas exchange surfaces through which oxygen enters and carbon dioxide leaves the body, in both humans and bony fish, that ensure that these surfaces function efficiently.
- 6 Describe the features of the structures delivering oxygen to each individual cell of the body, in both humans and bony fish, that allow them to perform this function so efficiently.
- 7 With respect to obtaining oxygen, which particular aspect of the external environment is a challenge for:
 - a humans, but not for bony fish?
 - b bony fish, but not for humans?

ELABORATION QUESTIONS

- 8 Following on from Question 7, explain how the features of the structure through which oxygen enters the body in:
 - a humans
 - b bony fishallow them to cope with the particular environmental challenge they face.
- 9 Explain how an increased surface area inside the lungs increases the efficiency of diffusion of oxygen into the blood.

EVIDENCE QUESTIONS

- 10 What feature of the lung's gaseous exchange surface would be most negatively affected by all the particles that are inhaled during cigarette smoking?
Explain the 'mechanics' of how this negative effect is caused.

END-OF-CHAPTER EXAM



End-of-chapter test

- 1 Which of the following is *not* an essential feature for a gaseous exchange surface to function efficiently?
 - A Occurs near to the outside of the body
 - B Has a very large surface area
 - C Must be covered with fluid layer
 - D Must be very thin
- 2 The name of the process by which carbon dioxide moves out of body cells and into capillaries for later removal to the external environment is:
 - A active transport
 - B non-active transport
 - C exhalation
 - D diffusion.
- 3 The blood vessels with the smallest diameter and that occur within a very small distance of every cell in the human and bony fish body are:
 - A arterioles
 - B lymph vessels
 - C capillaries
 - D veins.
- 4 Name the individual structures through which gas is exchanged with the *external* environment in:
 - a humans
 - b bony fish.
- 5 Name the individual structures through which gas is exchanged with the *internal* environment in:
 - a humans
 - b bony fish.
- 6 Compare and contrast the structures of gills and alveoli.
- 7 Explain why a gaseous exchange surface in an animal must be kept moist.
- 8 Describe and illustrate the process of gaseous exchange in the alveolus.
- 9 Draw an oxygen–haemoglobin dissociation curve, including labels on the *x* and *y* axes, and describe what it illustrates.

7

EXCHANGE OF NUTRIENTS AND WASTES

Introduction

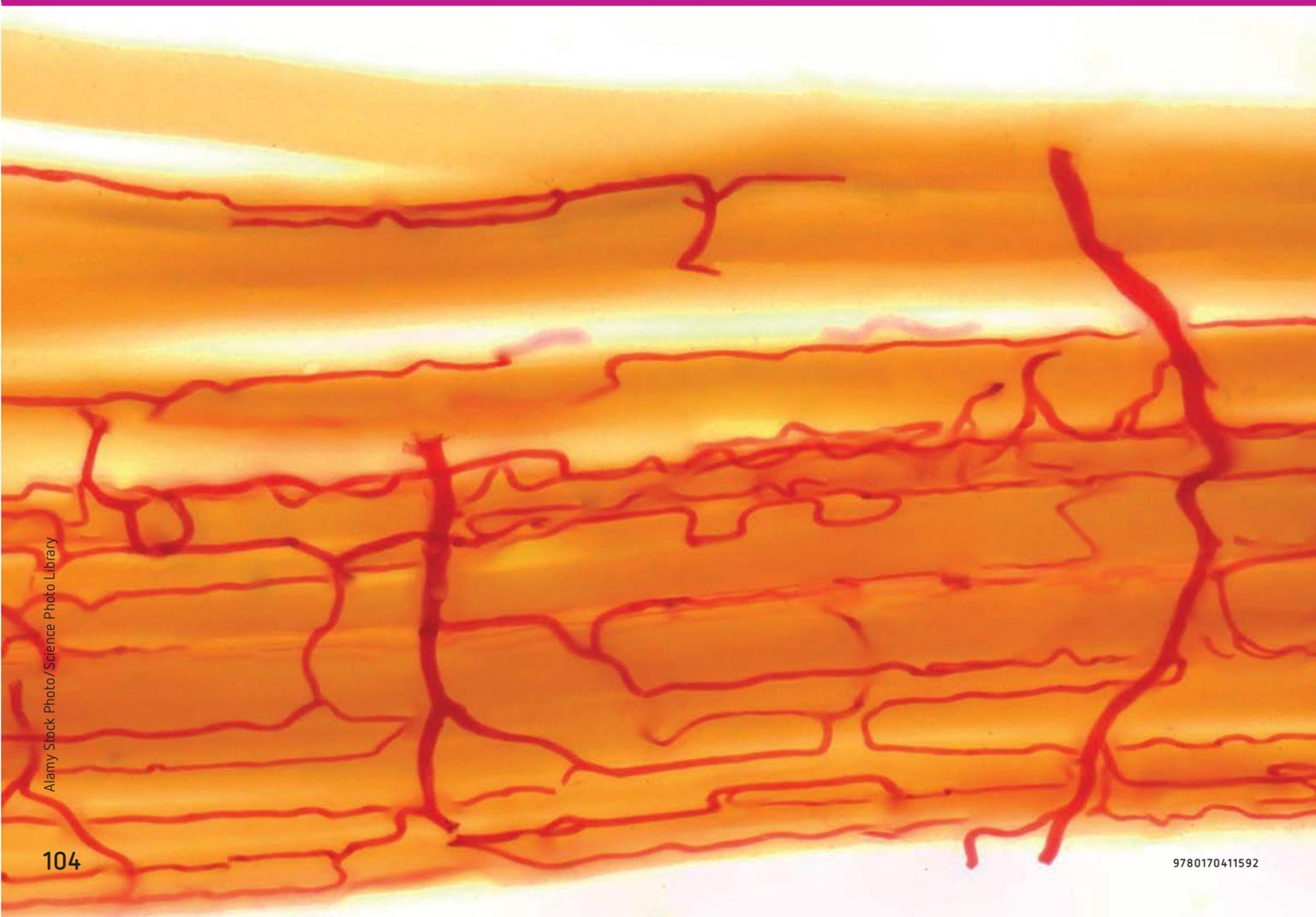
Animals take in food, in the form of other living things, to supply energy-containing molecules to use in cellular respiration. Chemical respiration then releases usable energy for all life functions. Food taken in must provide all the necessary inputs for the millions of different chemical reactions occurring constantly in the body cells of animals, including humans. Cells in the human brain alone carry out over 100 000 different chemical reactions every second.

Unused food, along with any other non-useful or toxic ingested material, and the surplus and waste products from all the body's metabolism need to be excreted to the external environment.

Stimulus questions

How does the food you eat get converted into the chemical reactants required for cells?

How do cells get rid of chemical wastes and eliminate them from your body?



7.1 Absorption of nutrients

The exchange surface through which food particles must pass to enter the internal environment is deep within the body. It is part of a complex digestive system in more advanced multicellular animals. Food delivered to this surface must be in broken down or digested form; that is, in molecules small enough to cross membranes of the cells forming the exchange surface.

Transport of food to exchange surface

Most mammalian digestive systems are basically similar in arrangement to the human digestive system (Figure 7.1.1). Many species, though, have different specialised variations in organ structure that specifically suit their diverse diets.

Food enters through the mouth, where **mechanical digestion** first occurs, with the teeth chopping and grinding the food into many smaller pieces. This physical chewing action creates a much larger surface



7.1.1 Digestive system
7.1.2 Digestive system: nutrient absorption

mechanical digestion
the physical break down and/or mixing of ingested substances, with no chemical change occurring

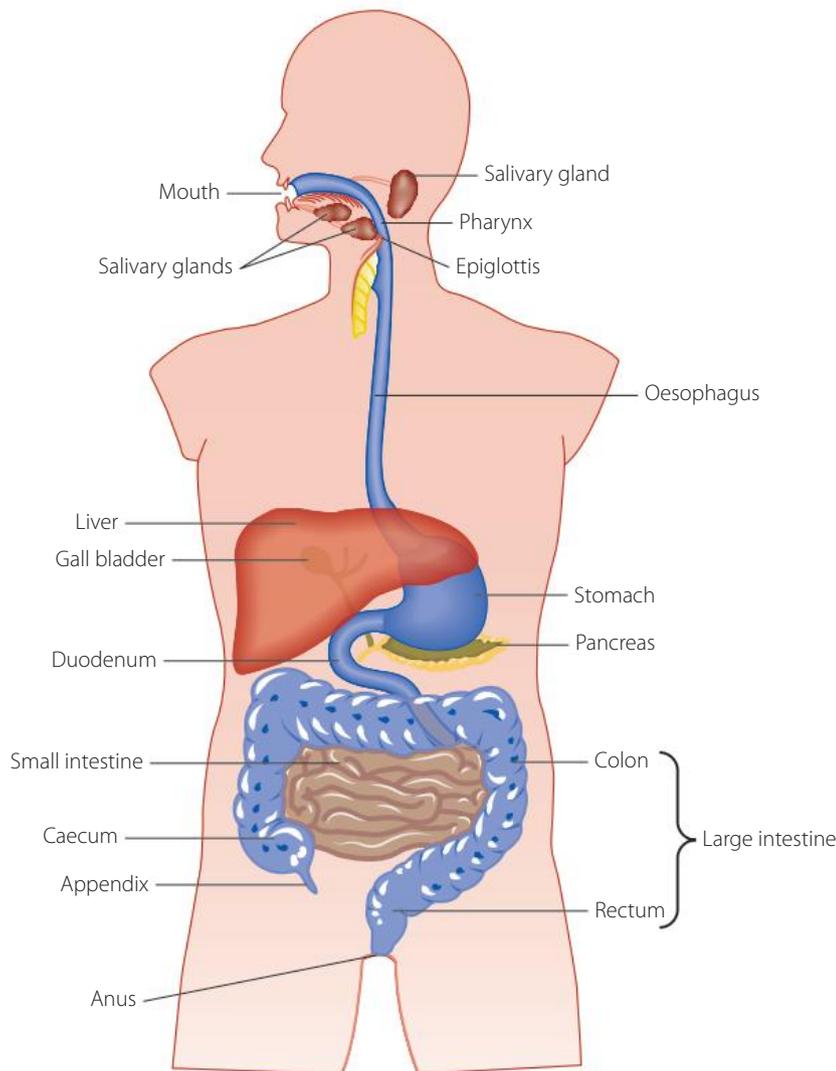


FIGURE 7.1.1 The human digestive system

chemical digestion

the break down of large molecules progressively into different smaller molecules in chemical reactions catalysed by digestive enzymes

area of food material upon which the digestive juices, in watery saliva, can better act, in the first stage of **chemical digestion**. The tongue carries out the mixing, and moves the food to the back of the throat where it is swallowed into the tubular oesophagus.

The wall of the oesophagus contracts in rhythmic waves to move food into the stomach. Both mechanical and chemical digestion continue in the stomach. The partially digested food is then released progressively from the stomach into the small intestine, where the bulk and remainder of the chemical digestion takes place to allow passage of nutrients into the body itself.

Absorption of food from small intestine

In the small intestine, nutrients such as glucose, amino acids, fatty acids and glycerol move from the gut (digestive tube) into the blood by 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.

Special structures, known as villi (singular: **villus**) project from the surface of the small intestinal tissue. Villi are tiny finger-like projections, with walls one cell thick. Villi completely cover the inner intestinal surface. The **epithelial cells** that form the villi boundaries, in turn, have a cell membrane that is convoluted into multitudes of microvilli. The villi and their microvilli massively increase the surface area of the gut lining and facilitate efficient absorption.

villus

an elongated projection from the lining of the small intestine that hugely increases the surface area and thus the capacity for exchange of materials

epithelial cell

a cell in a sheet of cells covering any external or internal surface in a multicellular organism

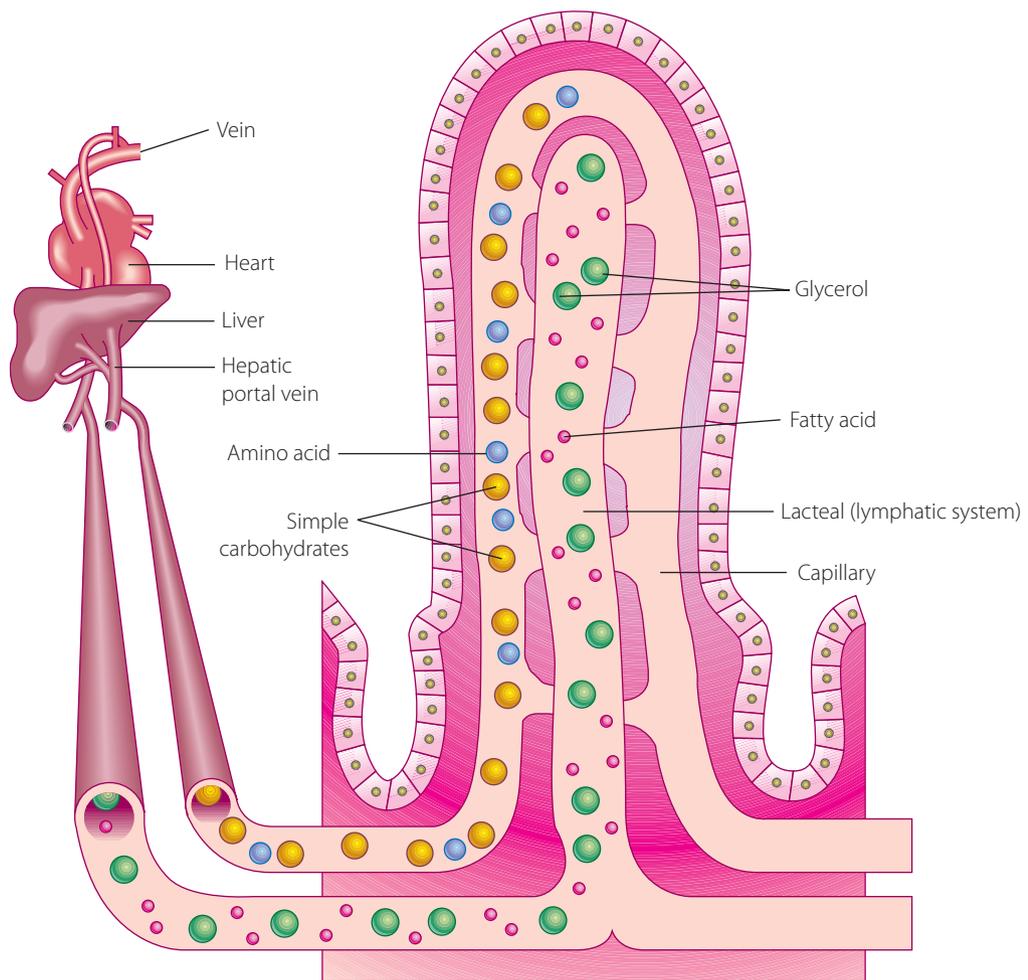


FIGURE 7.1.2 A cross-section of a villus

Each villus is supplied with a network of **capillaries** that intertwine with **lymph vessels** called **lacteals** (Figure 7.1.2). This creates an extremely small distance, equivalent to just the thickness of two cells, across which the digestion breakdown products have to move to be inside the transport vessels, and thus inside the internal environment of the body. Glucose and amino acids are absorbed into the capillary network of the circulatory system; fatty acids and glycerol are absorbed by the lacteals and enter the lymphatic system.

capillary
a very narrow blood vessel found between arteries and veins; part of a branching network that reaches to within a very small distance of every body cell

lymph vessel
a thin-walled tube forming part of the lymphatic system, which collects and transports lymph, a plasma-like fluid, containing cell debris and bacteria, and returns it to the circulatory system

Features common to all exchange surfaces

Absorptive surfaces within the digestive system, including the villi in the small intestine, exhibit the four features characteristic of any exchange surface. They are moist and thin, they have a large surface area, and there is a greater concentration of molecules on one side of the exchange surface than on the other.

SECTION REVIEW

7.1

REMEMBERING

- 1 List the structures, in order, through which food passes before reaching the villi in humans.
- 2 State the function of each of the structures listed in Question 1.
- 3 Name the two structures into which most digestion products enter to leave the small intestine for transportation to all of the body cells.

UNDERSTANDING

- 4 Describe the features of the villi that make them capable of functioning as an exchange surface between the body's internal and external environments.
- 5 State whether the materials passing along the length of the digestive system are part of the internal or external environment of the body. Justify your answer.

ANALYSING

- 6 Explain how the villus structure actually improves the efficiency of absorption of digested molecules.

7.2 Digestion of food

Digestive enzymes eventually break down the ingested food into molecules small enough to pass across the villi, capillary and lacteal walls. These enzymes act progressively along the length of the digestive system. Each species of animal has its own particular diet to supply its nutritional needs; therefore, each species has evolved a digestive system suited for the breakdown of those particular food types. All food ingested by animals consists of organic compounds that can be categorised into four main types of large biological molecules: carbohydrates, proteins, lipids and nucleic acids (DNA, deoxyribonucleic acid, and RNA, ribonucleic acid).

Digestive enzymes, like all enzymes, function most efficiently within an optimal range of pH, concentration of substrate and enzyme, and temperature.

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



Chapter 3 discusses the nature and function of enzymes in general.

Types of digestive enzymes

Table 7.2.1 summarises the categories of digestive enzymes and the types of molecules they act on.

TABLE 7.2.1 Overview of digestive enzymes

TYPE OF ORGANIC MOLECULE	CATEGORY OF DIGESTIVE ENZYME	FINAL BREAKDOWN PRODUCT
Carbohydrates (saccharides): monosaccharides, disaccharides, polysaccharides	Amylases	Simplest sugars (monosaccharides): glucose, galactose, fructose
Proteins (polypeptide chains)	Proteases	Amino acids
Lipids	Lipases	Fatty acids, glycerol

SECTION REVIEW

7.2

REMEMBERING

- State the function of each of the following enzyme groups:
 - amylases
 - proteases
 - lipases.
- List the end products of digestion resulting from the action of:
 - amylases
 - proteases
 - lipases.

7.3 Nitrogenous wastes

Carbon dioxide, the gaseous waste of cellular respiration, is expelled from the lungs of the respiratory system in most higher terrestrial animals, and from gills in most aquatic animals. Undigested food material is passed out of the body through the anus at the end of the digestive tract.

Many other non-useful or excess ingested substances and metabolic waste products must also be excreted to the external environment. Nitrogenous wastes, or wastes containing the element nitrogen, are among these, and are eliminated as different compounds and by various methods by different animal groups.

Mammals, including humans, must include protein in their diet as a source of amino acids. However, amino acids cannot be stored in the body. The nitrogenous part of the amino acid molecule, the amine group, is not useful as a reactant in other metabolic pathways. However, the remaining carbon-containing part is useful as a precursor for glucose or other intermediates in the complex cycle of the energy-producing cellular respiration reactions. The nitrogen-containing amine group is separated from the rest of the amino acid in liver cells in a process called **deamination**.

deamination

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

The removed amine group is converted directly to **ammonia** (NH_3), which is toxic to cells. A build-up of 0.005 mg of ammonia is enough to kill a human, so it must either be removed very quickly or be converted to a less toxic substance that can be safely stored temporarily, prior to elimination.

In mammals, cells in the liver convert ammonia to the less toxic **urea**. The urea is carried to the **kidneys** where it is diluted with water to form **urine**, which is eliminated from the body. Fish excrete their waste nitrogen as ammonia, while birds, reptiles and insects excrete it as **uric acid**, a whitish semi-solid substance.

Ammonia is the simplest of the nitrogenous wastes produced by protein breakdown. It is extremely toxic, so large quantities of water are required to dilute the ammonia and dissolve it for transport out of the body. Fish are totally surrounded by water in their environment, so they can excrete nitrogenous waste in this form.

In a terrestrial environment, where water may be scarce, extra energy is expended by liver cells to very quickly convert ammonia to urea. Urea is much less toxic to cells than ammonia. Therefore, it can be stored longer in the body and in a more concentrated form, so that less water is lost when it is eliminated.

Uric acid is the most chemically complex type of nitrogenous waste, having four nitrogen atoms in its molecules. Therefore, it requires the most metabolic energy for its production in the liver cells. However, it also rids the body of the most nitrogen per molecule, is completely non-toxic and requires very little water for elimination because it is excreted as a paste.

ammonia (NH_3)
a product of amino acid breakdown that is extremely toxic in humans

urea
a nitrogenous waste that is a less toxic breakdown product of ammonia in mammals; it is excreted in urine

kidney
an organ that excretes the urea dissolved in the blood out of the body

urine
a fluid containing water, urea and uric acid, which is expelled from the kidneys

uric acid
a nitrogenous waste produced by desert animals, birds, reptiles and insects



FIGURE 7.3.1 An X-ray photograph showing a 17 cm kidney stone

INQUIRING FURTHER

Humans excrete uric acid in urine as a waste product from nucleic acid metabolism. Uric acid is only slightly soluble in water and easily precipitates out of solution in tissue fluid, forming needle-like crystals. These crystals can cause excruciating pain when deposited in the joints – a medical condition called gout.

Uric acid can also contribute to the formation of kidney stones, an extraordinarily large example of which is seen in Figure 7.3.1.

- 1 Some people develop gout or kidney stones while most people don't. Research these medical conditions to try and decide whether, in your opinion, their occurrence is caused by lifestyle or genetics or a combination of both.
- 2 Some kidney stones are too large to be passed naturally. List and briefly describe medical methods by which such kidney stones could be removed.
- 3 Although uric acid can cause gout and kidney stones in humans, most of it is actually reabsorbed back into the blood in the kidneys. It can be assumed that the presence of uric acid must be an adaptation in some way. Try to find out what advantage, if any, the presence of uric acid in the blood provides in human cellular function.

SECTION REVIEW

7.3

REMEMBERING

- 1 State why ammonia has to be chemically changed before being excreted in humans, and what it is converted to.
- 2 What are the other nitrogen-containing chemical compounds excreted by animals other than humans?

APPLYING

- 3 Suggest why different animals have evolved different ways to eliminate their nitrogenous waste.

7.4 Nephrons

7.4.1 How do your kidneys work?

nephron

a specialised structural and functional unit within the kidney where elimination of waste molecules from the blood and regulation of solute and water levels occurs

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 each kidney

The membranes across which waste molecules pass are situated well inside the human body. This is the case with all exchanges of materials between the external and internal environments of many terrestrial animals, including oxygen and carbon dioxide gas exchange, and absorption of digested food molecules. In humans, these membranes are inside an extremely specialised structure called the **nephron**, which is part of the kidney, an organ of the excretory system.

Human kidneys

The kidneys are two bean-shaped organs, each about as big as a fist, located against the body wall of the back upper abdomen at either side of the spinal column (Figure 7.4.1). Branches of the aorta, the **renal arteries**, deliver 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. Each renal artery branches progressively into smaller and smaller vessels until millions of capillaries are formed. Each capillary enters a nephron where filtration of the blood occurs.

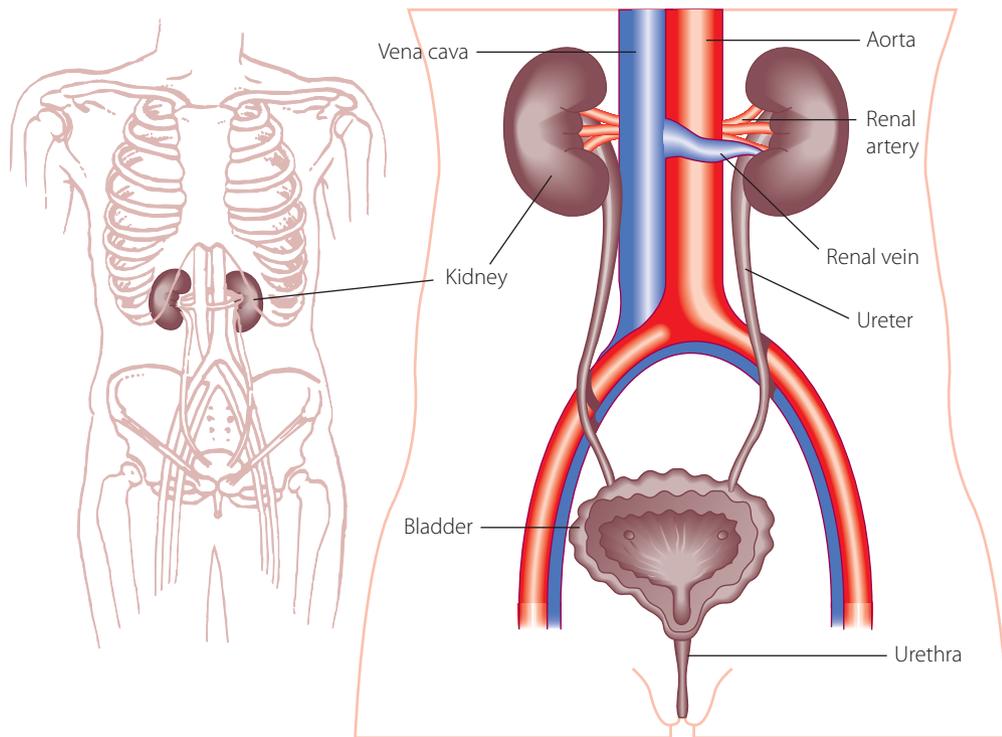


FIGURE 7.4.1 The human excretory system

Nephron structure

The multitude of nephrons in each kidney extend from the cortex of the kidney down into the medulla (Figure 7.4.2). Within the nephrons, water and solutes, such as nitrogenous wastes, are filtered from the blood. The amounts of these materials filtered out are adjusted to suit the body's requirements for those materials at that particular time.

The first structure of the nephron through which blood enters consists of a ball of capillaries called a **glomerulus**. The glomerulus is situated inside the **Bowman's capsule**, which looks like a hollow rubber ball that has been pressed in on one side. The capillaries that form the glomerulus are tightly bound into the smaller Bowman's capsule, and the blood pumped into them by the renal artery is under very high pressure. This pressure forces some of the water, along with all its solutes except large proteins and blood cells, out of the blood through the one-cell-thick glomerulus wall and into the Bowman's capsule, through its one-cell-thick wall. The liquid in the capsule is referred to as **filtrate**.

The Bowman's capsule connects to the **proximal tubule**, then to a hairpin-shaped **loop of Henle**, extending down into the medulla, and finally to the **distal tubule**. A **collecting duct**, the last structural component of the individual nephron, collects the filtrate, now containing wastes, from the distal tubule. The collecting duct passes down through the medulla, and empties the waste filtrate (urine) into an extensive drainage collection system channelling into the kidney's central cavity (**renal pelvis**). From here, urine passes into the ureter, then the bladder and finally into the urethra, which opens to the outside of the body (Figure 7.4.1). Once the filtrate enters the Bowman's capsule, it becomes part of the external environment.

All of the useful components of the blood that were forced out of circulation into the Bowman's capsule are not lost to the external environment. The substances left inside the glomerulus capillaries, including the remaining water, then flow on into a branching network of capillaries threading around the nephron's tubular parts (Figure 7.4.2). Water and solutes required by body cells are reabsorbed from the nephron tubules into the surrounding capillaries, which converge into a branch of the renal vein.

glomerulus
a network of capillaries, contained within the Bowman's capsule, from which the blood contents are filtered by the structures of the nephron

Bowman's capsule
the nephron structure in which the glomerulus is positioned, and into which the filtrate from the glomerulus blood is forced

filtrate
the liquid that has passed through a filter

proximal tubule
the section of the tubule in the nephron that leads from the Bowman's capsule to the loop of Henle

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

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

collecting duct
a duct in the kidney that collects and transports fluid from several distal tubules to the renal pelvis

renal pelvis
the section of the kidney where urine is collected and directed to the ureter

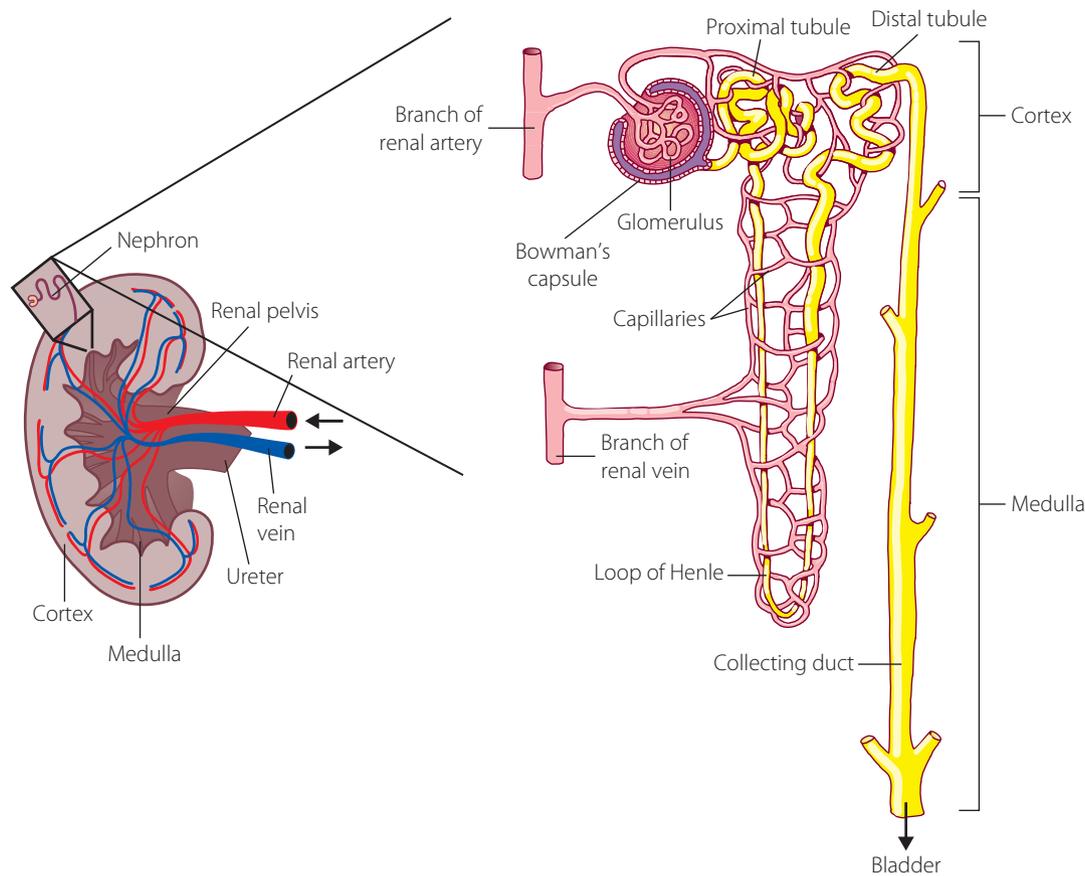


FIGURE 7.4.2 Structure of the human kidney and the functional unit, the nephron

REMEMBERING

- 1 List, in order, the structures through which nitrogenous waste molecules travel, starting with the renal artery carrying blood into the kidney, and ending outside the body.

UNDERSTANDING

- 2 State whether you consider that substances in each of the following structures would be in the internal or external environment of the body, and give reasons for your choice.
 - a Glomerulus
 - b Bowman's capsule
 - c Tubules of the nephron
 - d Capillary network surrounding the nephron tubules
 - e Renal vein
 - f Ureter
- 3 Draw a labelled diagram showing the structure of a nephron.

7.5 Production of urine

On average, about 600 mL of blood flows through each kidney every minute. Approximately 20% of this (120 mL) is filtered through the glomeruli. If all this fluid were excreted, you would have to replace it by drinking at least 1 L of liquid every 10 minutes just to maintain water balance. Fortunately, reabsorption ensures that 119 mL of the water, along with many essential dissolved molecules, is returned to the body's circulatory system.

The remaining 1 mL is urine. Before the urine is expelled from the kidneys, to be stored in the bladder for elimination, secretion occurs. Secretion is the term for the transfer from capillary blood into the nephron tubules of additional nitrogenous wastes, and any minerals or other chemicals in excess of what is required. This could include drugs such as penicillin, or even vitamins that have been consumed in greater quantities than required.

The direction of movement of substances across the tubule and capillary membranes in the nephron is illustrated in Figure 7.5.1. Blood is brought to the nephron in the **afferent** arteriole and taken away in the **efferent** arteriole. The **peritubular capillaries** are located alongside the nephron and allow reabsorption and secretion between the blood and the nephron. Table 7.5.1 outlines the functions of different nephron structures.

afferent
bringing towards, as in blood vessel carrying blood to an organ

efferent
taking away from, as in blood vessel carrying blood away from an organ

peritubular capillary
a capillary in a network surrounding the tubules of the nephron

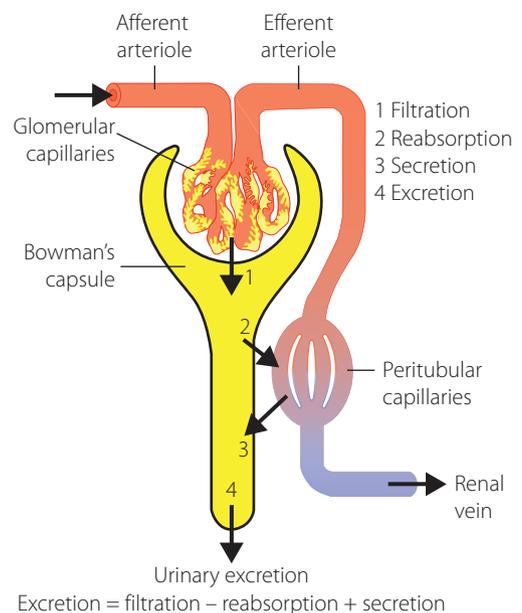


FIGURE 7.5.1 Schematic representation of direction of movement of substances across the membranes of the nephron

TABLE 7.5.1 Functions of nephron structures

NAME AND STRUCTURE	FUNCTION
Glomerulus	Filtration: pressure of blood forces about one-fifth of its plasma out through the capillary walls, along with everything small enough to pass through. This includes urea, glucose, amino acids and mineral ions, such as sodium (Na ⁺), chloride (Cl ⁻) and potassium (K ⁺), but not blood cells, platelets or large proteins.
Bowman's capsule	Filtration: plasma with dissolved materials diffuses across the single-cell thickness of the Bowman's capsule wall and into the hollow space of the capsule and is passed on into the proximal tubule.
Proximal (convoluted) tubule: a winding, large-diameter tube	Reabsorption: water is reabsorbed, as is 100% of glucose and amino acids, and approximately 65% of mineral ions, by both active and passive transport depending on substance, with most of the urea staying inside the tubule.
Loop of Henle – descending limb: extended straight part of small-diameter tubule moving away from the proximal tubule	Reabsorption: water flows out of the tubule and into the interstitial fluid and capillaries passively by osmosis, because the concentration of dissolved ions in the fluid inside the tubule is lower than that in the surrounding interstitial fluid and capillaries. The urea (and other solutes) inside becomes more concentrated in the urine the further down the descending tube it goes.
Loop of Henle – ascending limb: extended straight part of loop leading to the distal tubule	Reabsorption: mineral ions are moved out of the thick-walled section of the tubule initially by active transport, and later out of the thin-walled section, by passive transport and into the interstitial fluid, as part of the overall mechanism for concentrating the urine. Water remains inside because the tubule walls are impermeable to water. Waste concentration in urine is lower by the end of this part of the loop.
Distal (convoluted) tubule: a winding, large-diameter tube	Reabsorption: some useful mineral ions, and water if necessary, are reabsorbed. If the body cells require more water, the permeability of the distal tubule is increased to allow water to move out into the interstitial fluid and capillaries. If there has been a large water intake to the body, 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	Reabsorption: Na ⁺ ions and more water, if necessary, move from collecting ducts into the surrounding interstitial fluid and capillaries. Urea may also be reabsorbed into the interstitial fluid. Secretion: additional wastes as necessary are transferred from the capillary network and interstitial fluid into the ducts.

interstitial fluid
extracellular tissue fluid, fluid in spaces surrounding cells



Chapter 13 discusses the mechanism of water balance in animals.

Counter-current multiplication in the loop of Henle

A very efficient mechanism, called **counter-current multiplication**, occurs in the loop of Henle to concentrate the wastes in urine without a large expenditure of energy. Fluid in the descending limb of the loop of Henle flows in the opposite direction to that in the ascending limb in a counter-current manner. Reabsorption of different materials occurs in the two parts of the loop. Water is reabsorbed from the descending limb and mineral ions are reabsorbed from the ascending limb.

Mineral ions, such as sodium, chloride and potassium, are initially actively pumped from the thick-walled part of the ascending limb, making the solute concentration in the surrounding interstitial fluid high. This multiplies the amount of water that is reabsorbed passively from the descending limb of the loop, by increasing the concentration gradient between the solutes in the

counter-current multiplication
a system operating between two tubes connected by a hairpin bend and with fluid flowing in opposite directions, where energy is used to transport a material across a membrane of one tube, enabling the production of a much greater concentration of solutes in the hairpin bend than could otherwise be achieved

INQUIRING FURTHER

A mechanism that further enhances water reabsorption from the nephron occurs in a process called urea recycling, in which some urea is reabsorbed into interstitial tissues from the collecting tubules to help maintain the difference in concentrations of the tubular fluid and interstitial fluid.

Research this topic and try to explain:

- why reabsorbing urea into the interstitial fluid is not harmful
- whether urea passes across the membrane by active or passive transport
- how this process leads to greater water reabsorption.

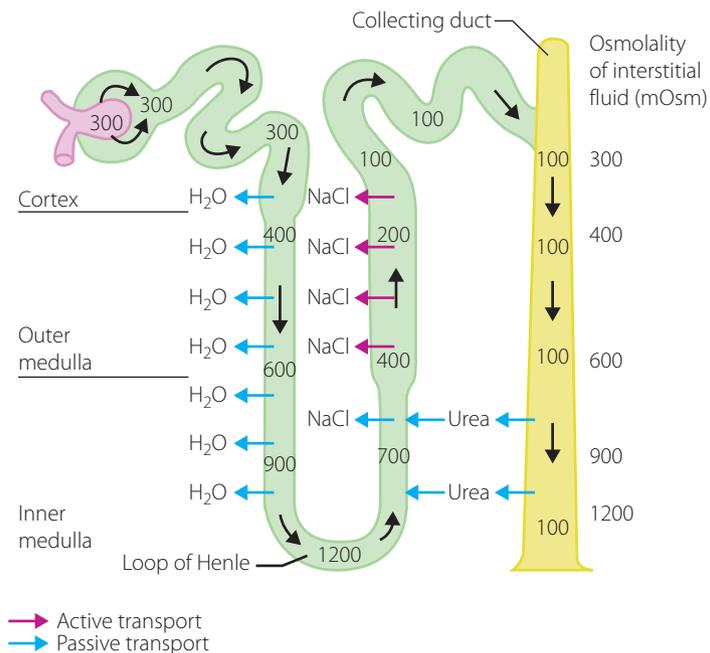
descending tubule and in the interstitial fluid. Therefore, a large quantity of water can be reabsorbed with minimal expenditure of energy. By the end of the descending limb, the solute concentration in the tubule is at its highest (Figure 7.5.2).

These solute concentrations in the loop of Henle are matched by those in the associated and parallel vertical sections of the similarly shaped surrounding capillary network.

Through the adaptation of a counter-current multiplication mechanism, a small amount of energy is initially used to greatly enhance the overall passive reabsorption of water from urine in the loop of Henle back into capillaries for return to the body. In this way, wastes can be eliminated from the blood and body without copious loss of water and necessary water levels are maintained for the functioning of all cells in the body.

FIGURE 7.5.2

The counter-current multiplication mechanism that concentrates urine in the loop of Henle of the human kidney nephron. Osmolality is a measure of urine concentration. The higher the value, the more concentrated the urine is.



SECTION REVIEW

7.5

REMEMBERING

- With respect to nephron function, briefly state what is meant by:
 - filtration
 - reabsorption
 - secretion.
 - State in which structures the above three processes occur.

UNDERSTANDING

- Outline the differences between reabsorption and secretion processes.

APPLYING

- Suggest why the kidney uses more energy proportionally than the heart.

7.6 Mandatory practical

EFFECT OF TEMPERATURE ON ENZYME ACTIVITY

Introduction

Amylase is an enzyme that breaks down starch molecules into separate glucose molecules. Iodine is normally a yellow-brown substance but turns blue-black or purplish in the presence of starch. Therefore, iodine is an indicator of the presence of starch (Figure 7.6.1).

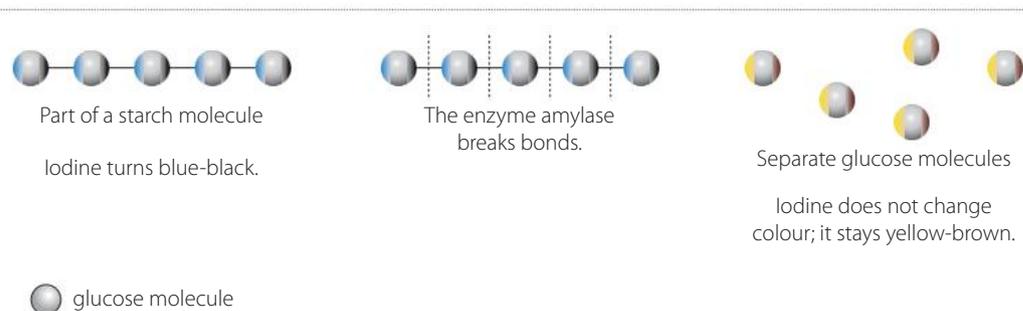


FIGURE 7.6.1 The digestive enzyme amylase chemically breaks down starch to individual glucose molecules. In the presence of starch, iodine is blue-black (or purple) in colour. Iodine does not react with glucose so in the presence of glucose molecules, iodine does not change colour, but stays yellow-brown.

Aim

To investigate the effect of varying temperature on the activity (or reaction rate) of amylase

Materials (for each group)

- 6 test tubes and test tube rack
- beaker or other container to hold 6 test tubes in allocated temperature water bath/ice water
- clock or timer
- permanent marker or stickers and pen
- thermometer
- toothpicks
- 2% amylase solution in dropper bottle
- 5% starch solution in dropper bottle
- distilled water in dropper bottle
- iodine solution in dropper bottle
- 3 × 10 mL measuring cylinders (labelled 'Amylase', 'Starch' and 'Distilled water') or 3 × 5 mL pipettes (labelled 'Amylase', 'Starch' and 'Distilled water')
- 6 Pasteur pipettes
- white tile or spotting tile
- Bunsen burner or hotplate
- ice water





WHAT ARE THE RISKS IN DOING THIS EXPERIMENT?	HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?
Hot water baths can burn.	Do not touch the water bath container or the water within it.
Iodine can stain skin and clothing.	Take care to avoid spilling iodine on skin and clothing.

Procedure

- 1 Your group will be allocated a temperature to investigate (0, 20, 40, 60 or 80°C). Set up a water bath or ice bath at your allocated temperature and use a thermometer to monitor the temperature.
- 2 Label six test tubes 1–3 and A–C, and with your group's allocated temperature.
- 3 To test tubes 1–3, add 5 mL distilled water.
- 4 To test tubes A–C, add 5 mL amylase solution.
- 5 Place the test tubes in a beaker or container in your water or ice bath for 10 minutes.
- 6 During this 10 minutes, place a drop each of amylase, starch and distilled water onto the white tile. Note the location of each.
- 7 Add a drop of iodine solution to each drop and mix them with a clean toothpick. Observe any changes.
- 8 Record the final colour for each combination by copying and completing Table 7.6.1.
- 9 After 10 minutes, remove the test tubes from the water or ice bath and place them in the test tube rack. Allow the solutions to come to room temperature for 5 minutes.
- 10 Add 10 mL of starch to each test tube and mix, using a separate pipette for each test tube. Do not remove the pipettes.
- 11 Use the pipette to remove a drop of starch mixture from each test tube and place the drop on a clean white tile. Note the position of each drop from test tubes 1–3 and A–C. Return the pipette to its test tube.
- 12 Add a drop of iodine to each drop on the tile and mix with a clean toothpick.
- 13 Observe the colour of each drop initially and every 5 minutes for 20 minutes. Record your results by copying and completing Table 7.6.2.

Results

TABLE 7.6.1 Colour of solution when iodine added to amylase, starch and water

MIXTURE	COLOUR
Iodine + amylase	
Iodine + starch	
Iodine + water	

TABLE 7.6.2 Colour after starch added to test tubes at indicated times

TEST TUBE	COLOUR AFTER MIXING WITH STARCH AT INDICATED TIME (min)				
	0	5	10	15	20
1					
2					
3					
A					
B					
C					

» Discussion

- 1 Explain how the colour of the mixture after adding iodine indicates the activity of the enzyme amylase.
- 2 Explain why you added iodine to the distilled water and the amylase, as well as to the starch (and then observed the colour) early in your experimental procedure.
- 3 Explain why you had three samples of distilled water and amylase.
- 4 Explain why you included the three distilled water test tubes.
- 5 Analyse your results in Table 7.6.2 and write a summarising statement for your allocated temperature regarding colour descriptions and times for:
 - a test tubes 1–3, which contained distilled water initially
 - b test tubes A–C, which contained amylase initially.
- 6 Interpret your statement from Question 5 and write a statement explaining enzyme activity at your allocated temperature and times for your test tubes A–C.
- 7 Design and complete a table to record the observed colours of the samples for the whole class across all the tested temperatures.
- 8 Explain why some groups had different results from other groups.
- 9 Analyse the data and give your opinion on whether there are any temperatures at which amylase does not appear to function. Try to explain your answer.

Conclusion

- 10 By analysing the whole class data, propose a conclusion regarding whether or not temperature is an important factor in determining the activity and reaction rate of amylase.
- 11 By analysing the whole class data, compose a summarising statement regarding amylase activity at the different tested temperatures.
- 12 Using your responses to Questions 10 and 11, predict the optimum temperature at which amylase functions.

INQUIRING FURTHER

- 1 Design an experiment that investigates the effect of pH on enzyme activity.
If possible, carry out the experiment.
- 2 As a result of a fever, a person's temperature may rise above the normal level.
Discuss how this could affect cellular activity, and, in turn, the entire body.

CHAPTER REVIEW QUESTIONS

DETAIL QUESTIONS

- 1 What processing is necessary before ingested food can be absorbed into the body?
- 2 **a** Through which particular structures in the human digestive system do nutrients enter the body?
b After entering the body, how are these nutrients delivered to individual cells?
- 3 Name the particular structural units in the human kidney that process chemical waste, including excess nutrients and other metabolic cell products, for excretion from the body.
- 4 Which body system is the kidney organ a part of?
- 5 Once urine is formed in the kidney, how is it excreted to the outside environment?

CATEGORY QUESTIONS

- 6 Enzymes are responsible for breaking down the organic molecules in food, with specific enzymes catalysing the breakdown reactions for each type of compound.

Complete the following table by identifying what the letters **a–c** represent.

Type of organic compound	Digestive enzyme group
Carbohydrates	a
b	Proteases
Lipids	c

- 7 Excess amino acids are broken down, and this process produces nitrogenous wastes that need to be eliminated from the body.
What happens to excess carbohydrate and lipid breakdown products?
- 8 The following table lists three different processes involved in waste elimination from the blood. Identify what the letters represent by either providing a brief description for **a–c**, or naming a structure for **d–f**.

Process occurring in nephron	Brief description of process	Structure(s) in which process occurs
Filtration	a	d
Reabsorption	b	e
Secretion	c	f

ELABORATION QUESTIONS

- 9 Explain why it is necessary for the digestion of organic compounds to be:
a a progressive process occurring along the whole length of the digestive tract
b separated in some cases, with digestion of different compound types occurring in different locations.
- 10 What structural features must all sections of the nephron have in common to function, regardless of whether they are filtering, reabsorbing or secreting body fluids?

EVIDENCE QUESTIONS

- 11** Explain why proteins are the only type of organic compounds that can be digested in the stomach, but in the small intestine the continued digestion of proteins, carbohydrates and fats occurs.
- 12** Despite being the largest living animal on Earth, the blue whale feeds primarily on krill, an extremely small crustacean mainly composed of protein and lipid.
Suggest what differences may exist between the digestive systems of humans and blue whales, and explain why differences exist in:
- a** digestive enzymes produced in the mouth
 - b** overall range of digestive enzymes produced.
- 13** The loop of Henle is a substructure of the nephron that only mammals and some birds have acquired as an adaptation, or advantage to survival, through evolution.
Considering the specialised function of the loop of Henle, achieved by the counter-current multiplication mechanism, suggest *why* and try to explain *how* it suits mammals to their way of life.



1 In Figure 7.7.1, the letter that would represent lipase is:

- A V
- B X
- C Y
- D Z

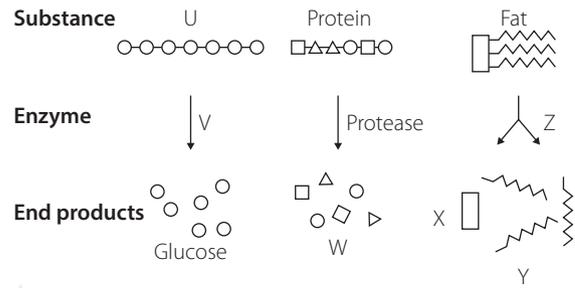


FIGURE 7.7.1

2 In Figure 7.7.1, W would most likely be:

- A starch
- B amino acids
- C fatty acids
- D glycerol.

3 The absorptive surface through which most digested food particles pass to enter the circulatory system of the human body is in the:

- A mouth
- B stomach
- C small intestine
- D large intestine.

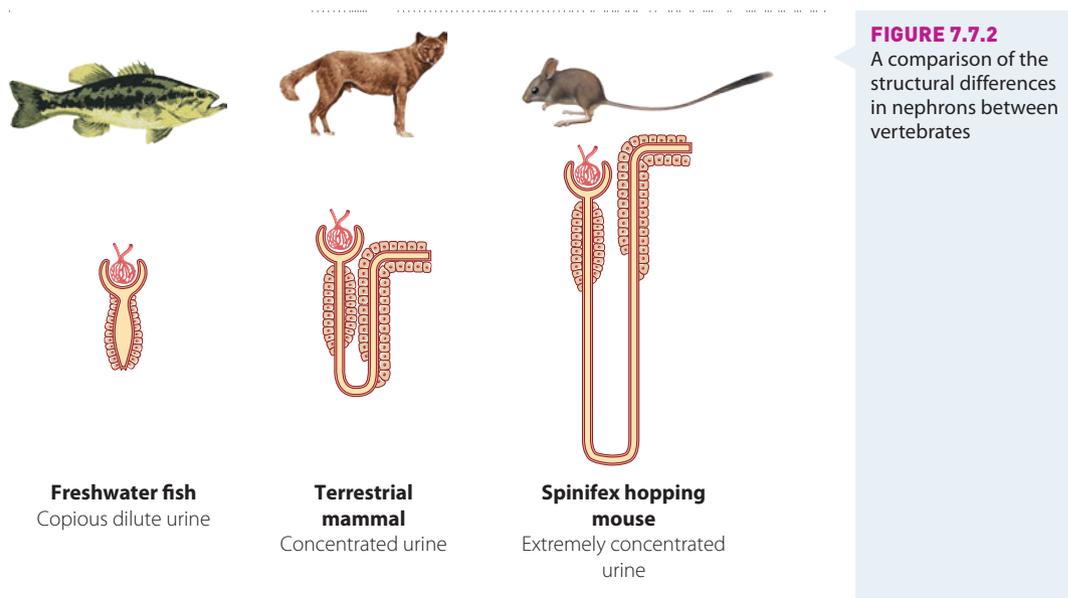
4 The structures through which most digested food particles pass to enter the circulatory system of the human body are the:

- A villi
- B nephrons
- C lacteals
- D lymph vessels.

5 The order of structures through which blood fluid containing wastes passes in a nephron is:

- A loop of Henle, Bowman's capsule, distal tubule, proximal tubule, collecting duct, glomerulus
- B collecting duct, loop of Henle, glomerulus, Bowman's capsule, proximal tubule, distal tubule
- C glomerulus, Bowman's capsule, loop of Henle, proximal tubule, distal tubule, collecting duct
- D glomerulus, Bowman's capsule, proximal tubule, loop of Henle, distal tubule, collecting duct.

- 6 Nitrogenous waste produced by the breakdown of excess ingested protein:
- A is transformed into ammonia from an earlier metabolic product in humans
 - B is transformed into urea from an earlier metabolic product in humans
 - C is always in the form of urea
 - D can be in the form of ammonia, urea, uric acid or nucleic acid.
- 7 Glucose molecules are forced out of the glomerulus and pass through layers of cells that form the boundaries of structures before re-entering the internal environment of the body, that is, the circulatory system. The last of these layers is the epithelial cells of the capillaries, in the circulatory system itself, which transports the nutrients. What other structure(s) must they pass through?
- 8 In a sentence, state whether you consider the inside of the digestive tract, in which food particles are broken down before absorption, to be part of the internal or external environment of the body and explain why.
- 9 State whether you consider the capillaries surrounding the tubules of the nephron to be a component of the kidney, and thus of the body's excretory system, or a part of the circulatory system, or of both. Give reasons for your answer.
- 10 Refer to Figure 7.7.2, which illustrates the structural differences in nephrons between three vertebrate animals. The spinifex hopping mouse lives in an environment with very little rainfall and builds burrows in sandy soil that does not retain moisture well. Use this information, your knowledge of the specialised function of the loop of Henle, and Figure 7.7.2 to discuss how the structural differences of the nephrons shown suit each of the animals to their particular habitat and way of life.



- 11 Discuss the similarities in features of the surfaces through which digested food particles pass from the small intestine into the blood of the internal environment of the body, and the surfaces through which the waste particles in the blood pass from the internal environment to the external environment.

8

PLANT SYSTEMS: GAS EXCHANGE AND TRANSPORT SYSTEMS

Introduction

The redwoods, or sequoias, of California, USA, are famous for being among the tallest trees in the world. One redwood in California has been measured as 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. At some stage in the swamp gum's life, the crown appears to have snapped off and regrown. Because redwoods are classified as conifers, Centurion currently represents the tallest flowering plant, the tallest hardwood tree and the tallest eucalypt 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 the tree to lift many kilograms of water and other substances up distances of 50–100 m, against the force of gravity.

Stimulus questions

How do leaves facilitate gas exchange in plants?

How does the transport system in plants move substances?



8.1 Movement of gases

Plants do not possess all of the same systems that multicellular animals do, but they do have specialised cells that make up tissues with specific functions to assist in their survival. Individual cells are organised into tissues (such as photosynthetic tissue), 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 functions include obtaining energy, producing organic compounds, distributing materials, removing wastes and exchanging gases. The structure of a **vascular** plant ensures that each organ – the leaves, stem, roots, flowers and seeds – receives what it needs.

Oxygen and carbon dioxide are exchanged locally throughout the plant. This means that they do not need to be transported from one part of the plant to another. Gas exchange in plants occurs entirely through the process of passive diffusion. The structure of leaves is well adapted to achieve this. Leaves may be large but are always flat, maximising the surface area available compared to the relatively small volume of each leaf. Leaves contain open air spaces within them. These provide even greater surface area and allow the gases to move freely through much of the leaf without having to pass through cells.

The entry of carbon dioxide and oxygen through the **epidermis** is essential for photosynthesis and cellular respiration. However, a problem arises when water evaporates from the leaf during the heat of the day. The presence of stomata (singular: **stoma**), pores that can open and close, is a remarkable adaptation that solves this problem. When the stomata are open, gases, including oxygen, carbon dioxide and water vapour, pass freely into and out of the leaf. When the stomata are closed, gases cannot enter or leave and water is conserved.

Stomata and guard cells

Stomata are pores or openings in the epidermis. They are flanked by **guard cells**, a pair of crescent-shaped cells that are shaped to form an opening (Figure 8.1.1). When the guard cells absorb water, they swell and become rigid, which opens the stoma. When they lose water, they become soft and fall closed. As a result, stomata tend to be open when a plant is experiencing moist conditions, and closed when a plant is experiencing dry conditions.

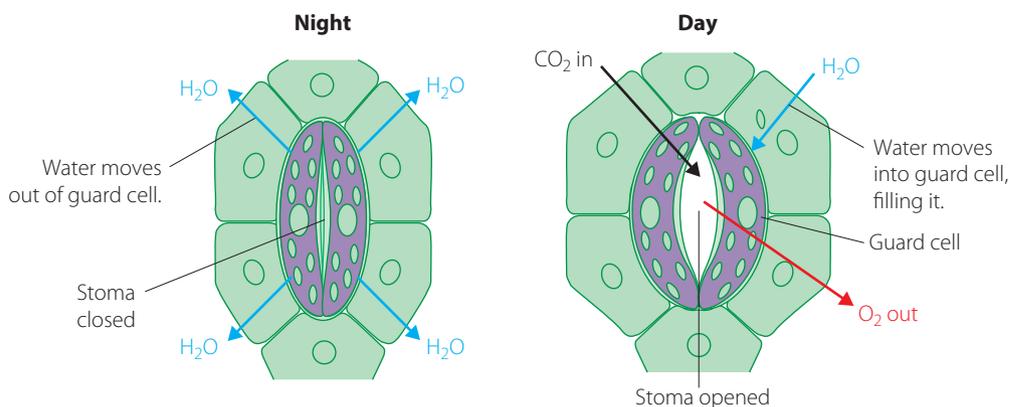


FIGURE 8.1.1
At night and at times of low humidity, water leaves the guard cells and the stoma closes, sealing the leaf off from the outside. During the day and at times of high humidity, water enters the guard cells and the stoma opens, allowing gases to enter and leave.

The timing of the opening and closing of stomata depends on a number of environmental factors. Under natural conditions, stomata open at daybreak and close at night because the leaves need CO_2 for photosynthesis during the day. However, other conditions can override the effects of light. For example, on a warm sunny day as the temperature increases, more and more water vapour is lost through the open stomata. If the water loss exceeds the uptake of water from the soil, the water content of the plant falls. Eventually, the guard cells will begin to lose their water and the stomata will close.

vascular
describes vessels that conduct fluid

epidermis
the surface layer of cells in an organism

stoma
a controlled opening found in leaves and young stems that controls the movement of gases into and out of a plant

guard cells
a pair of crescent-shaped cells that enable the opening and closing of a stoma

Under conditions of decreased water availability, photosynthesis may be reduced and the concentration of carbon dioxide inside the leaf will rise. This also causes the stomata to close and no further carbon dioxide will diffuse into the plant. Conversely, a fall in the internal concentration of carbon dioxide can cause the stomata to open, allowing carbon dioxide to diffuse into the plant.

High levels of humidity can also affect the stomata. If the air is saturated with water vapour, the rate of water loss from the leaf cells is reduced, enabling the stomata to remain open. However, when the stomata are open, water is also lost through them as water vapour. If excess water is lost, the plant wilts. Plants need to balance their gaseous requirements with their ability to withstand extreme water loss.

In situations of severe water stress, such as in a drought, the guard cells may lose water during the day and close the stomata. While this reduces the loss of water, it also cuts off the supply of CO_2 . This restricts the capacity of the leaf to carry out photosynthesis, thus restricting the overall growth of the plant under these environmental conditions.

A few plants have evolved mechanisms of storing carbon compounds for later use, allowing them greater control over when and under what conditions they open their stomata. These plants, such as pineapples and many cactuses and orchids, have evolved mechanisms whereby they can open their stomata during the evening, when it is cooler, and effectively store CO_2 for use in photosynthesis in the daytime. They are able to close their stomata during the hottest part of the day.



8.1.1 Stomate

SECTION REVIEW

8.1

REMEMBERING

- 1 Distinguish between stoma, stomata and guard cells.
- 2 Name three gases that move in and out of stomata.
- 3 List the factors that generally cause stomata to open and close.

UNDERSTANDING

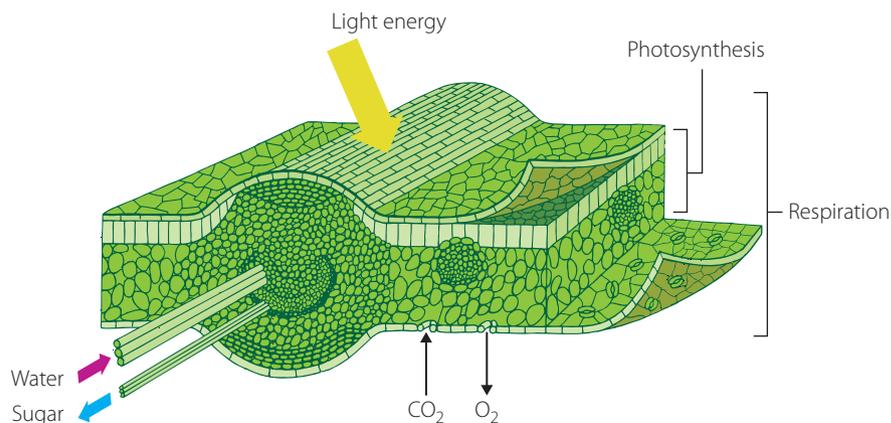
- 4 Explain how most plants respond to very high temperatures in order to limit the loss of water from leaves.
- 5 Draw a diagram demonstrating how guard cells operate during the day and night.

8.2 Leaf structure and photosynthesis

mesophyll
a chloroplast-containing cell in plant leaves that performs photosynthesis

The structure of the leaf is pivotal in enabling its photosynthetic cells, called the **mesophyll**, to function at maximum efficiency. The mesophyll cells form most of the living tissue of a leaf because photosynthesis is a key function of this part of the plant. Figure 8.2.1 shows the locations of each of the key processes in the leaf.

FIGURE 8.2.1 A leaf has various inputs, processes and outputs.



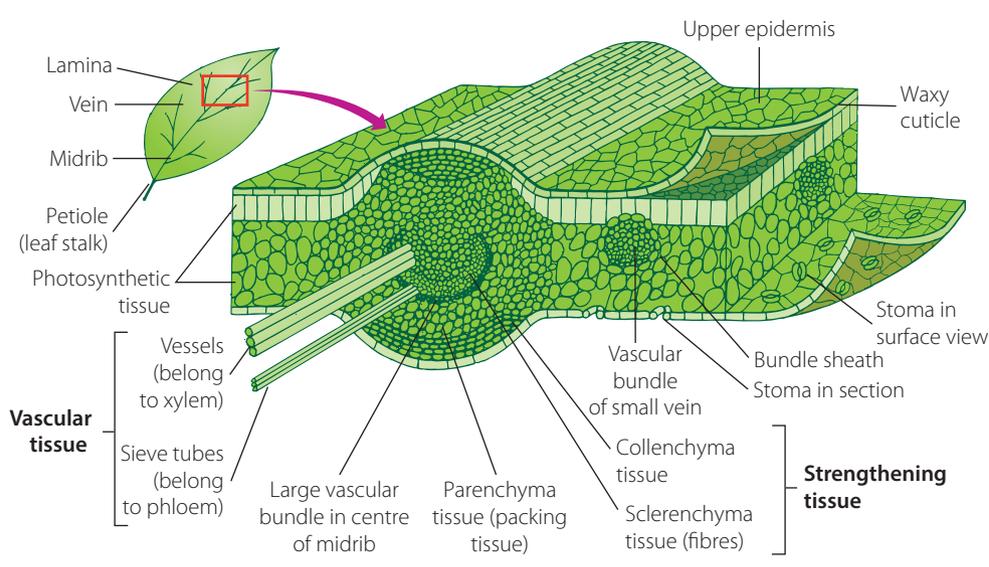
Leaves have the perfect structure to capture light energy (Figure 8.2.2). Their location and orientation ensures appropriate exposure to sunlight. They are generally thin and flat and collectively present a large surface area to the light, therefore maximising the photosynthetic rate. Being thin and flat makes the leaves liable to sag, but their shape is maintained by the **turgidity** of the cells inside them, and by the midrib and veins that are well supplied with strengthening tissue along with the vascular tissue (Figure 8.2.3). The large surface area of leaves, while allowing maximum photosynthesis, also increases evaporative water loss. This problem is overcome in most terrestrial plants by the presence of an impermeable waxy **cuticle** on the leaf surface.



FIGURE 8.2.2 The leaves of the giant water lily (*Victoria amazonica*) can grow to almost 3 m in diameter and can support up to 136 kg. They are still only millimetres thick though because of the limitations of passive transport of gases from the surrounding water and air.

turgidity
the state of being swollen with water, which usually causes the cell to become rigid

cuticle
a thin, transparent layer of wax on the outside of a leaf's epidermis to reduce water loss



M Roberts, M Reiss and G Monger: Advanced Biology (Nelson Thornes, 2000), copyright © Micheal Roberts, Michael Reiss and Grace Monger 2000.

FIGURE 8.2.3 The shape and structure of leaves play an important role in their efficiency.

Different leaves for different purposes

Leaves of rainforest plants show a great variation in size and shape. Plants at different levels within the rainforest receive different amounts of light. For example, plants that grow on the ground receive very little, if any, direct sunlight, and mainly collect filtered light. They still need to photosynthesise in order to provide both energy and nutrients. These plants often have very large, flat leaves, which increase the surface area available for the absorption of light.

Plants in the canopy have different problems to overcome. Their exposure to sunlight is unlimited, and the biggest threat to the wellbeing of the leaf is over-exposure. The leaves are very small, often hang vertically (limiting the amount of sunlight that strikes them directly), and point towards the trunk of the tree, so that any water is directed down the trunk to the roots of the plant.

Leaf tissues

palisade mesophyll

a densely packed layer of elongated cells that have many chloroplasts for photosynthesis

chloroplast

an organelle in mesophyll tissue that utilises light energy to make glucose through photosynthesis

Stomata provide openings through the epidermis and cuticle. Figure 8.2.4 shows that the location of stomata in the leaves allows for the diffusion of carbon dioxide into the mesophyll. These cells are also quite close to the vascular tissue, for access to water, sugars and other nutrients from the soil.

Palisade mesophyll

There are two types of mesophyll cells. Those immediately beneath the upper epidermis form the **palisade mesophyll**. Each palisade cell is elongated with its long axis perpendicular to the surface. They are separated from each other by narrow air spaces and are densely packed with **chloroplasts** to maximise light absorption beneath the transparent epidermis.

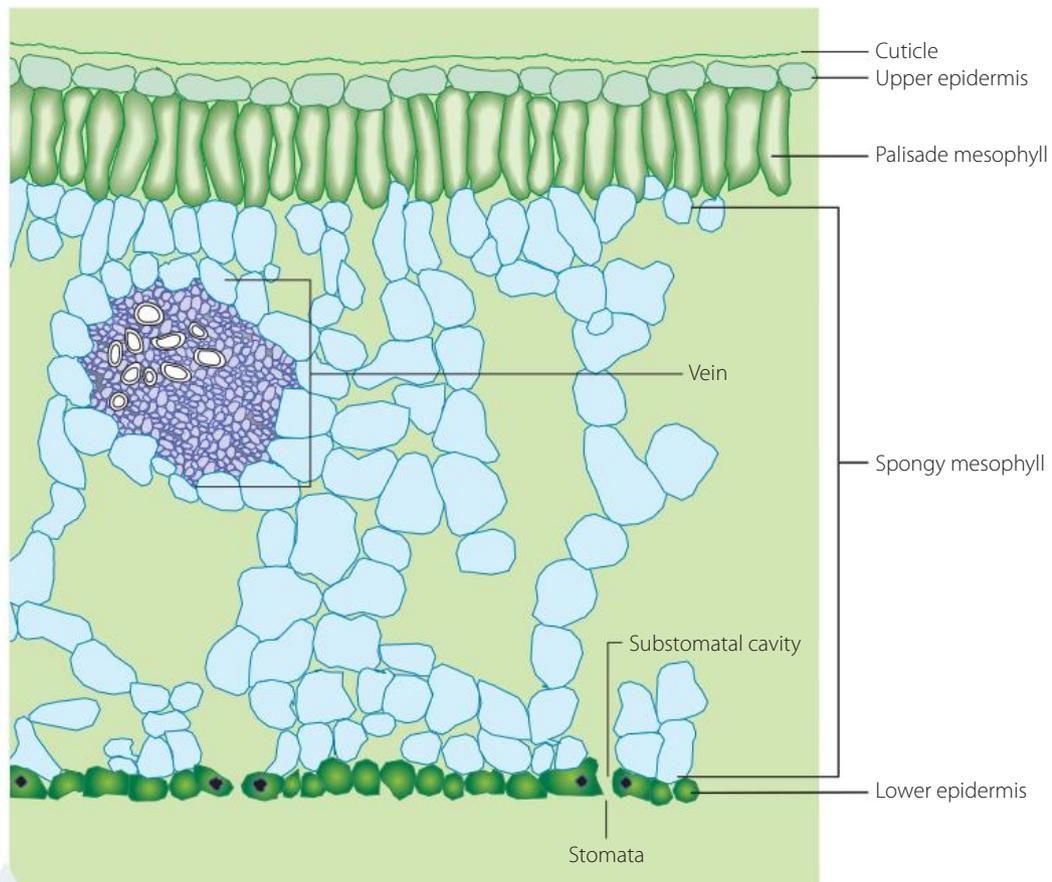


FIGURE 8.2.4 A general cross-section of a leaf

spongy mesophyll

a loosely arranged layer of irregularly shaped cells that have a few chloroplasts for photosynthesis and plenty of air spaces

Spongy mesophyll

Between the palisade mesophyll and the lower epidermis is the **spongy mesophyll**. These cells are irregular in shape and arrangement. They also contain chloroplasts, but fewer than the palisade cells, which is why the lower side of a leaf usually looks paler than the upper side. Their loose arrangement is a continuation of the interconnected air spaces that allow gases to diffuse throughout the leaf.

SECTION
REVIEW

8.2

REMEMBERING

- 1 Describe the main function of the leaf.
- 2 List the substances that enter leaves and are used for photosynthesis.
- 3 Distinguish between the spongy and palisade mesophyll.
- 4 Describe the role of chlorophyll in the plant.

UNDERSTANDING

- 5 Copy Figure 8.2.4 and show the pathways of CO₂, O₂ and light within the leaf.
- 6 Explain the function of the:
 - a epidermis
 - b palisade mesophyll
 - c stomata
 - d spongy mesophyll
 - e guard cells.

APPLYING

- 7 If the palisade mesophyll is so efficient at converting light, explain why the whole leaf isn't structured this way.

8.3 Plant transport systems

In a vascular plant, there are specialised cells and tissues that distribute organic compounds, water and minerals around the plant. Vascular tissue as a whole is composed of two different types of tissues: **xylem** and **phloem**.

Xylem

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 8.3.1). As xylem cells mature, they die, leaving behind hollow cells supported by the remaining cell walls, which are ideally suited to the mass movement 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.

Tracheids are present in all vascular plants and are made when mature cells die, leaving only an interconnected stack of empty cells. Water moves up these, but not particularly efficiently.

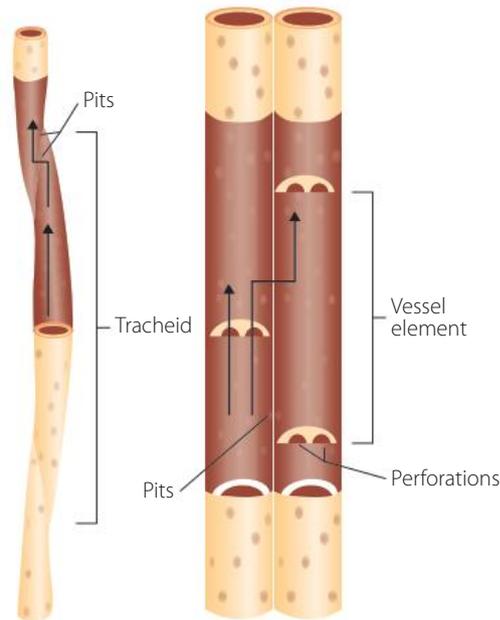


FIGURE 8.3.1 Vessel elements are a more advanced and efficient method of water transport than tracheids. In tracheids water moves only through the pits. In vessel elements water moves through perforations and pits.

xylem

the vascular tissue in plants, consisting of dead cells, responsible for the bulk transport of water and nutrients

phloem

the vascular tissue in plants, consisting of living cells, responsible for the transport of sugars from leaves to the rest of the plant

nutrient

a substance required by living organisms that are not directly involved in energy production, such as dissolved salts and vitamins

tracheid

a dead elongated cell that forms the unspecialised part of the xylem of plants

vessel element

a dead cell that is perforated at each end and stacked vertically, forming the specialised part of the xylem in flowering plants

angiosperm
a flowering plant, including many families of tree, shrub and grass

sieve tube cell
a long, tubular plant cell without a nucleus that forms sieve tubes, the main component of the phloem

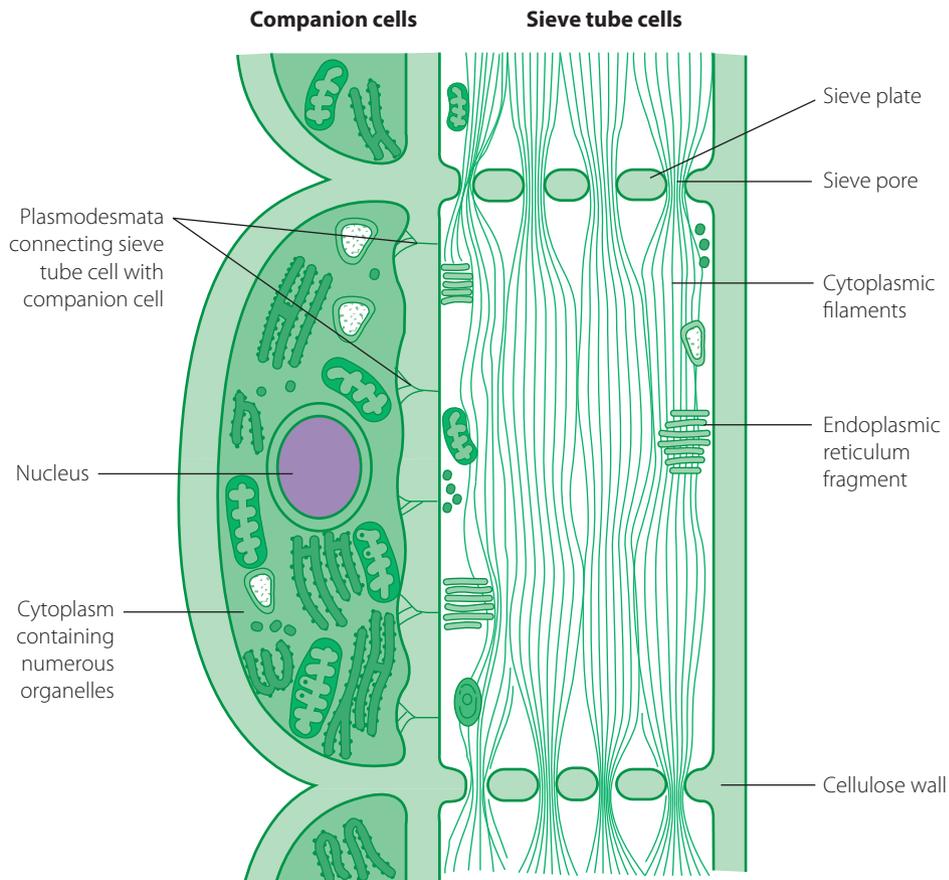
companion cell
a specialised plant cell situated beside the sieve tubes in the phloem, which provides most of the cell functions for the sieve tube cells

sieve plate
the tough cellulose walls between sieve tube cells that contain pores to allow the cytoplasm to flow between cells

Vessel elements have specialised tubular cells that butt up against each other before they die. Vessel elements form straight 'straws' that are extremely efficient at moving water. This evolutionary development only occurred in **angiosperms** (flowering plants), and have been a major reason for the success of flowering plants overall.

Phloem

Phloem is the other type of vascular tissue, composed of thin-walled, living cells that transport sugars and other plant products from one part of a plant to another. There are two types of phloem cells: **sieve tube cells** and **companion cells** (Figure 8.3.2). Sieve tube cells are long, thin cells that have large pores through the cell walls at either end (called **sieve plates**), similar to vessel elements in the xylem. Although these cells are living, they need the space to transport the sugar and nutrients and so, have no nuclei, mitochondria or vacuoles. Many cells arranged end-to-end form sieve tubes, which share cytoplasm through which the sugars and nutrients flow.



Adapted from Cowes, F. A. L. & Juniper, B. E. (1968) Plant Cells, Blackwell Scientific, Oxford.

FIGURE 8.3.2

Although living, sieve tube cells are missing key organelles such as a nucleus and vacuole. They would die and become useless without the companion cells acting as life support.

plasmodesma
a tiny channel through plant cell walls that allows communication between cells by sharing cytoplasm

Companion cells are specialised cells that are found alongside the sieve tubes. These cells have a nucleus and other organelles that are missing in the sieve tube cells. They control the activities of the sieve tube cells through plasmodesmata (singular: **plasmodesma**), tiny channels linking the companion cell to the sieve tube cell.

SECTION
REVIEW

8.3

REMEMBERING

- 1 Name and outline the functions of the two types of cells found in the xylem.
- 2 Name and outline the functions of the two types of cells found in the phloem.

UNDERSTANDING

- 3 Compare and contrast the structure and functions of the xylem and phloem vessels.
- 4 Explain how it is possible for dead cells to perform useful functions.

APPLYING

- 5 Figure 8.3.3 shows an example of ringbarking, a method of killing trees that removes a thin collar of bark from the trunk of a tree. Phloem tissue is located in the bark. Xylem tissue is located in the wood. Use your knowledge of xylem and phloem structure to explain how ringbarking could kill a tree.



FIGURE 8.3.3 Ringbarking is often espoused as a more environmentally friendly method of killing unwanted trees, as opposed to chopping them down or poisoning them.

Alamy Stock Photo / Adrian Davies

8.4 Transport of water

All plants need to be able to get water. Water is absorbed initially by the roots and moves against the pull of gravity through the stem to the leaves. Some of these leaves can be more than 100 m above the ground and they yet are still able to get fresh water.

Root 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 cases, they are the main energy storage area. Roots may take many forms, but the two most common are **taproots** and **fibrous roots** (Figure 8.4.1).

Taproots have one thick main root with slender, short side branches. These are able to push vertically through soil to reach the water table and provide a strong foundation for a tall tree. Fibrous root systems have many smaller roots of about equal size that grow out from the bottom of the plant stem. Although fibrous roots do not grow deeply, they grow quickly and can provide a wide base for energy storage.

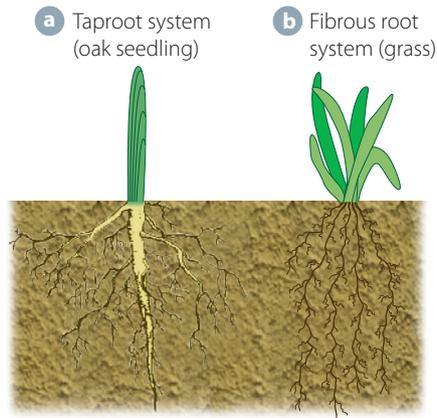


FIGURE 8.4.1 Large trees often have taproot systems while smaller shrubs and grasses generally have fibrous root systems.



8.4.1 Root system architecture

taproot
a large main root deep underground for stability and long-term water supply

fibrous root
a thin, branching root that spreads along the upper layers of soil for rapid colonisation and surface water uptake

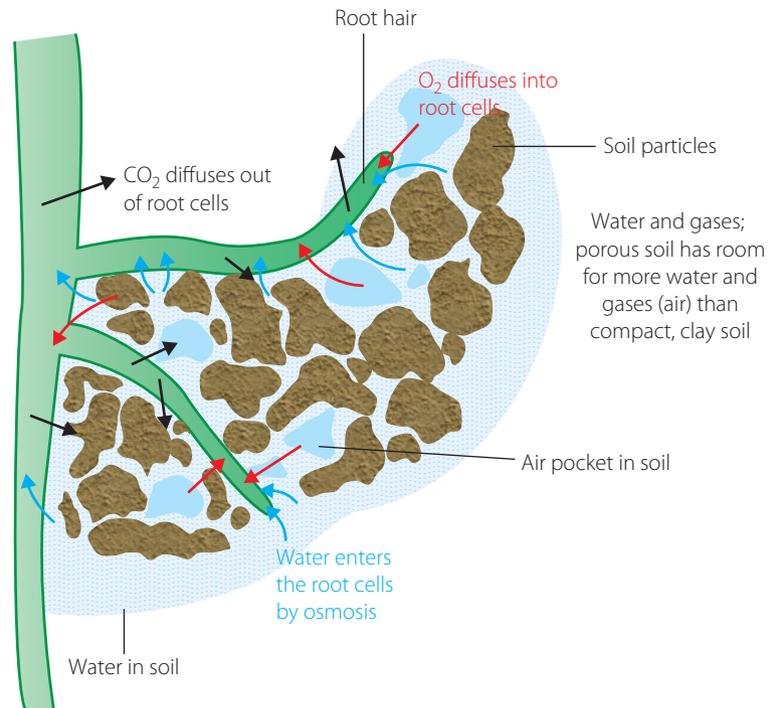
root hair

a thin extension of a root epidermal cell that greatly increases the cell's surface area

As well as anchoring the plant, the roots take up water through their epidermis. Their surface area is greatly increased by the presence of thousands of **root hairs** (Figure 8.4.2). These are slender extensions of each root epidermal cell and present an enormous surface area to absorb water.

FIGURE 8.4.2

Root hairs provide extra surface area for both gas exchange and water and mineral uptake.



osmosis

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

active transport

the process of using energy to move a substance across a membrane from a region of low concentration to a region of higher concentration

root pressure

the pressure, caused by the uptake of water in the roots, that forces water further up the stem

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 distinct groups of xylem and phloem cells. The vascular tissues are arranged in such a way that, as the root grows into the soil, it also extends down the centre of the root, enabling the continued transportation of materials.

Water and dissolved minerals enter the root 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 **root pressure**. In 1727, English scientist and clergyman Stephen Hales discovered 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.

Shoot system

Water and dissolved minerals continue their journey to the leaves through the stem of the plant. With so many roots and generally only one stem, the vascular tissue needs to be bundled and arranged differently in the stem to save space. A vascular bundle consists of several xylem and phloem tubes grouped together.

There are two general arrangements of the vascular bundles in the stem. In **monocotyledon** plants (monocots), such as wheat and sugarcane, the vascular bundles are scattered randomly throughout the stem (Figure 8.4.3a). In **dicotyledon** plants (dicots), such as apples and tomatoes, the vascular bundles are arranged in a single ring with the xylem towards the inside of the stem and the phloem towards the outside (Figure 8.4.3b).

Water is pulled up the plant

Since root pressure can only push water to a few metres above ground, the plant needs a second driving force to pull the water the rest of the way up to the leaves. To do this, plants take advantage of a unique property of water – it can pull itself.

Commonly referred to as capillary action, water in a thin enough tube will shoot skywards without any energy input. Two forces are occurring simultaneously to make this happen:

- ▶ **adhesion**, the force of attraction between water molecules and the molecules that make up the sides of the tube
- ▶ **cohesion**, the force of attraction between one water molecule and the next.

monocotyledon (monocot)

a flowering plant with a number of characteristics, including a scattered arrangement of vascular bundles in the stem

dicotyledon (dicot)

a flowering plant with a number of characteristics, including a ringed arrangement of vascular bundles in the stem

adhesion

the force of attraction between water molecules and the molecules that make up the sides of the tube

cohesion

the force of attraction between water molecules



FIGURE 8.4.3 (a) The random arrangement of vascular bundles in monocots allows the plant to be flexible and fast-growing. (b) The ring of vascular bundles in dicots enables the stem to grow very large, leaving the dead tissue behind to become structural wood as the bundles move ever outward.

transpiration
the loss of water from plants through evaporation

transpiration stream
a continuous column of water that moves up the stem of a plant

transpirational pull
the force arising from the evaporation of water from leaves that draws water up the xylem

Adhesion allows the water molecules that touch the sides of the tube to stick to it preferentially and cohesion allows these molecules to attract and pull up the other molecules around them. The thinner the tube and the more polar the sides are, the faster and further this capillary action will reach. Xylem vessels are extremely thin (around $15\ \mu\text{m}$ in diameter) and made of lignin, a highly polar substance.

However, once the water molecules reach the top of the xylem vessels in the leaves, they have nowhere to go and the flow of water would stop were it not for a third driving force. The evaporation of large quantities of water from leaves continually removes water from the tops of the xylem vessels, pulling the rest of the water up with it. This is called **transpiration**. The continuous upwards movement of water through the plant is known as the **transpiration stream** (Figure 8.4.4) and the combined forces that move it are called **transpirational pull**.

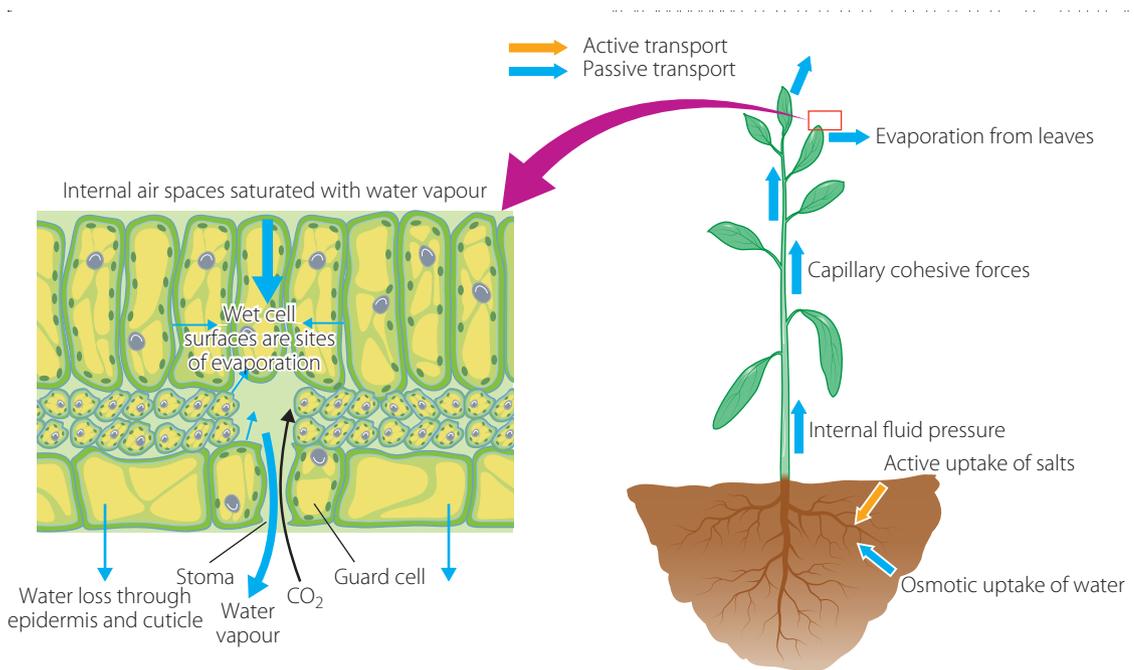


FIGURE 8.4.4 The process of transpiration in plants is driven by the Sun.

Factors affecting rate of transpiration

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. Conversely, if a plant cannot lose enough water through transpiration, the transpiration stream stops and water is not taken up from the soil, leading to waterlogging and suffocating the root system. Therefore, the rate of transpiration must be maintained at an optimal level to keep the transpiration stream flowing without resulting in water stress. Several factors affect the rate of transpiration.

Increasing rate of transpiration

Environmental factors that can increase the rate of transpiration include high air temperatures, low humidity, wind and long days with strong sunlight (as in summer). Plants that colonise hot, dry places tend to evolve extra protection against excessive water loss, such as thick waxy leaves and minimal stomata or the leaves having modified entirely to spines while the stem conducts photosynthesis.

Plant adaptations that increase the rate of transpiration include large, broad leaves, many leaves and dense stomata. Plants evolve these adaptations when the rate of transpiration in their natural environment is low, such as in the lower canopy of a rainforest.

Decreasing rate of transpiration

Environmental factors that can decrease the rate of transpiration include low air temperatures, high humidity, stifled airflow and short days with weak sunlight (as in winter). Plants that colonise cold places tend to evolve differently to produce tiny or highly modified leaves that reduce exposure to the cold rather than increase the transpiration stream.

SECTION REVIEW

8.4

REMEMBERING

- 1 Name the two types of vascular tissues in plants.
- 2 Describe how vascular tissue is arranged in most plants.
- 3 **a** List the main functions of both roots and stems.
b Identify the functions both perform.
c Determine which function roots perform almost exclusively.
- 4 Describe how root hairs increase the efficiency of water uptake.
- 5 List the features of xylem that make it effective in transporting water around the plant.
- 6 List three factors that increase the transpiration rate in plants.
- 7 List two factors that would decrease the rate of transpiration.

UNDERSTANDING

- 8 Explain the forces that enable water in a xylem vessel to reach the top of a tree.
- 9 Explain where the energy for transpiration originates.
- 10 Summarise the main characteristics and functions of the two types of vascular tissues in plants: xylem and phloem.

APPLYING

- 11 A student puts a stick of celery in a vase of coloured water. Over the next few hours, the leaves on top of the stick turn coloured. From this, can you deduce whether the celery was living or dead? Explain your answer.

8.5

Obtaining and distributing nutrients

All plants require a variety of mineral elements in addition to carbon dioxide, oxygen and water. These minerals are absorbed as ions dissolved in the surrounding water. Minerals are actively transported, or pumped into the root hairs and other epidermal cells in the root. The ions then move between cells through the plasmodesmata from the high concentrations in the epidermal cells to the low concentrations in the vascular bundles. Some nutrients (non-energy-producing molecules) move through the phloem and some through the xylem, depending on their size and structure. Inside the xylem, they are carried up the stem along with the water in the transpiration stream. Inside the phloem, they travel up the stem with the cytoplasm towards areas of high growth.

Once the mineral ions reach the leaf, they are used to produce chlorophyll, proteins, carbohydrates and other materials. Plants that do not receive sufficient amounts of mineral ions often suffer from deficiency diseases, which can be seen as yellowing of leaves, small leaves or stunted growth.

ALGAE
ARCHITECTURE

The first algae-powered building in the world opened in Hamburg, Germany, in 2013. A group of architecture and engineering firms collaborated to meet the challenge of designing more sustainable, low-energy-use buildings. Their solution, the Bio Intelligence Quotient House, took 3 years of research and development but resulted in a functioning 'green' building (Figure 8.5.1).

A 'bio-adaptive algae façade', made up of a double layer of 129 'SolarLeaf' vertical glass panels filled with 24 litres of algae and liquid, stretches along the front of two sides of the building. These shiny green living panels function in a number of ways. They form a layer of insulation against sound, heat and cold. As a functioning closed system, the algae behind the glass photosynthesise and convert solar energy into heat. The algae also take up carbon dioxide and produce oxygen, biomass and heat energy. Each algal cell can photosynthesise in this unicellular species, so algae can grow and produce biomass approximately 10 times faster than larger, multicellular plants. This biomass is harvested to produce biofuel to heat the building.

FIGURE 8.5.1 The algae in the Bio Intelligence Quotient House produce the energy required to insulate and heat the building.



Within the first year of operations, the algae façade has reached a conversion efficiency total of about 58% (converting sunlight captured into energy). This project marks the beginning of future designs for zero-energy and zero-carbon buildings.

- 1 Identify the ways in which the engineers and architects have 'copied' from plant structures and function.
- 2 The glass panels were described as a closed system. Assess whether or not this is possible and explain your answer. Create a diagram to illustrate your explanation.
- 3 Predict other ways in which the concept of modelling designs based on plant structure and function could be applied.
- 4 Evaluate whether or not you think algae-based architecture is a beneficial application of scientific knowledge.

Distributing the products of photosynthesis

Photosynthesis captures the energy the plant requires and packages it very neatly into glucose. Unfortunately, glucose is highly reactive and easily digested in the cytoplasm (called **sap**) that fills the phloem. The plant can't transport glucose directly because it would be used on route. Instead, the photosynthesising cells combine glucose and fructose, one of the pre-glucose **metabolites**, to form sucrose. This more stable molecule is then sent to the phloem for **translocation** around the plant.

Sucrose moves by active transport, which requires adenosine triphosphate (ATP), into the phloem (Figure 8.5.2). In the leaf, mesophyll cells produce sucrose and actively pump it against the concentration gradient into the sieve tube cells. As the concentration in the phloem increases, water moves by osmosis from the xylem to counteract the change. The influx of water increases the pressure in the phloem and forces the sap to stream away from the leaf, carrying the sucrose with it. Cells in need of energy will have used up most of the sucrose in the cell, making the inside of the cell less concentrated than the phloem. In such places, sucrose moves with the concentration gradient from the phloem into the cell. Areas of high growth, such as new leaves, shoots and fruits, draw the sap towards them as they remove more and more sucrose for respiration.

There are several variations on the movement of sap from leaves to cells in need of energy. Sometimes, more sucrose is produced than can be used by the plant; for example, during the long daylight hours of summer. In these cases, plants transport excess sugars to tubers, bulbs or corms, which store starch until it is needed. When the next growing season arrives, the stored starch is converted back into sucrose and flows to the new growing points of the plant.

sap
the thick, sugary cytoplasm that fills the phloem of plants

metabolite
a transitional molecule formed and modified during metabolic reactions

translocation
the bulk movement of substances around an organism

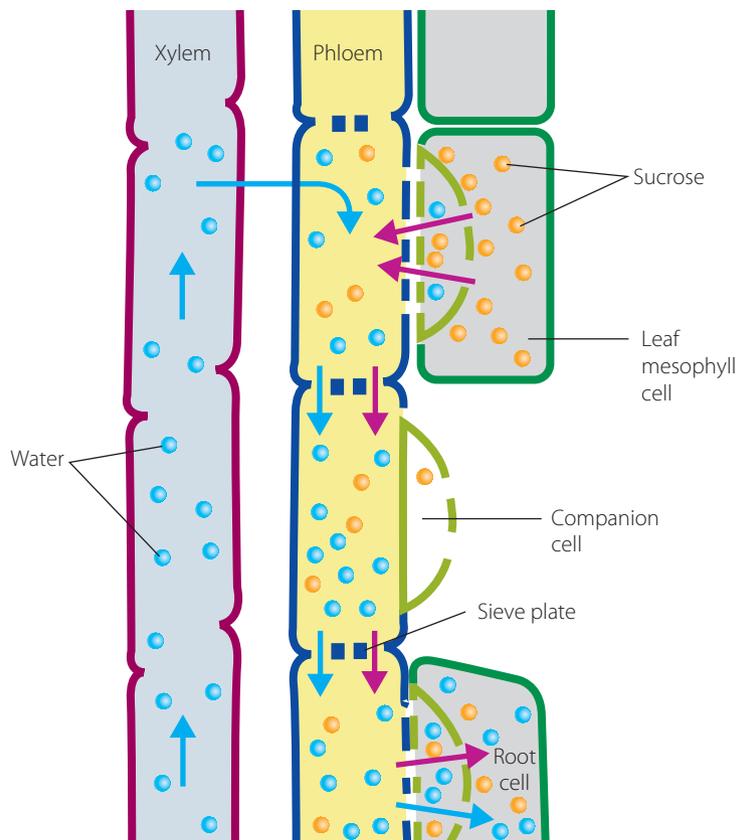


FIGURE 8.5.2 Sucrose is actively transported into the phloem in the leaves, but diffuses out when required. The blue arrows show the movement of water and the purple arrows show the movement of sugars.

PRACTICAL ACTIVITY 8.5.1

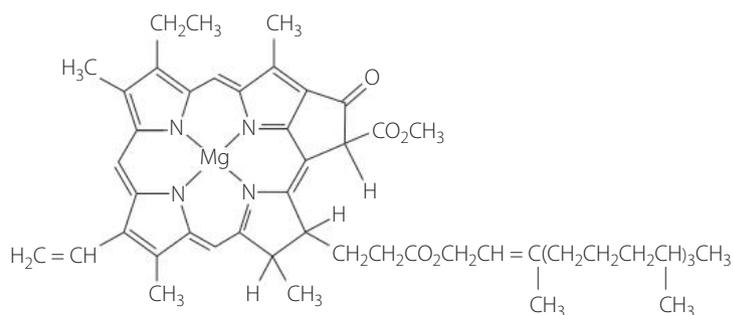
Extraction of chlorophyll from leaves

INTRODUCTION

Chlorophyll is the molecule responsible for capturing photons of light in plants (Figure 8.5.3). The energy from the photon is used by the chloroplasts to join CO_2 and H_2O molecules together to form glucose ($\text{C}_6\text{H}_{12}\text{O}_6$) and O_2 . However, chlorophyll molecules require a lot of energy for the plant to produce, so the optimal number is determined by how much light strikes the leaf surface (more light means less chlorophyll is required for the same amount of glucose).

FIGURE 8.5.3

Chlorophyll has many complicated ring structures, allowing it to absorb photons of light.



AIM

To compare the amount of chlorophyll extracted from different leaves

MATERIALS

- leaves of varying shapes and shades of green (for example, spinach, seaweed, silverbeet, grass, eucalypt)
- dehydrator or oven
- mortar and pestle
- ultraviolet (UV) lamp
- clean sand
- isopropanol
- small test tubes with stoppers or Eppendorf tubes
- marker pen



» PROCEDURE

Leaf preparation

- 1 Dry the leaves in the dehydrator (or oven at 40°C) until they are brittle and crumbly. This could take up to 2 hours and sclerophyllous (hard) leaves may take longer.

Chlorophyll extraction

- 2 Crumble the first type of leaf into the mortar with 10 mL of isopropanol and a pinch of sand.
- 3 Use the pestle in a downward, pressing motion (don't 'stir') to crush the leaves until the liquid is very green.
- 4 Transfer the liquid to a small test tube, stopper it and use firm downward flicks to separate the leaf material from the liquid. (This can also be done with a centrifuge and Eppendorf tube.)
- 5 Carefully pour the clear liquid into a new, labelled test tube.
- 6 Repeat steps 2–5 with each type of leaf.

RESULTS

- 1 Note the different densities of chlorophyll that was extracted.
- 2 Hold the tubes under a UV lamp and note the changes.
- 3 Draw up a table to compare the shapes, shades of green, chlorophyll density and UV fluorescence of each of the samples.

DISCUSSION

- 1 Plants have different amounts of chlorophyll depending on the amount of light they receive. Discuss whether the density of chlorophyll extracted matches what you would have expected from the leaves.
- 2 The UV fluorescence of chlorophyll is key to its function in the cell. Propose why the leaves don't fluoresce this way. Research your answer to discover what happens to the molecule in the chloroplasts.

SECTION REVIEW

8.5

REMEMBERING

- 1 Define:
 - a plasmodesmata
 - b concentration gradient
 - c sap.
- 2 List three mineral nutrients that plants take up with their roots.
- 3 Describe how sucrose enters and leaves the phloem.

UNDERSTANDING

- 4 Explain how sugars are moved through the phloem.
- 5 Explain why the function of the phloem depends on having xylem tissue nearby.
- 6 Explain why sucrose must be actively transported into the phloem.

APPLYING

- 7 In frozen climates, trees enter a sort of hibernation in winter. The phloem and xylem stop flowing and the dead parts of the tree (namely the woody interior and the xylem) freeze solid. However, the sieve tube cells and their companion cells are living and freezing solid would destroy them. Use your knowledge of sap and translocation to suggest how the sap doesn't freeze.

CHAPTER REVIEW QUESTIONS

DETAIL QUESTIONS

- 1 Construct a diagram of the whole plant, from roots to leaves, that includes as much information as possible about the intake, production and transport of water, carbon dioxide, oxygen, sucrose and nutrients.
- 2 Describe the functions of the different types of tissue in a leaf.
- 3 List the factors that affect the transpiration rate of plants.

CATEGORY QUESTIONS

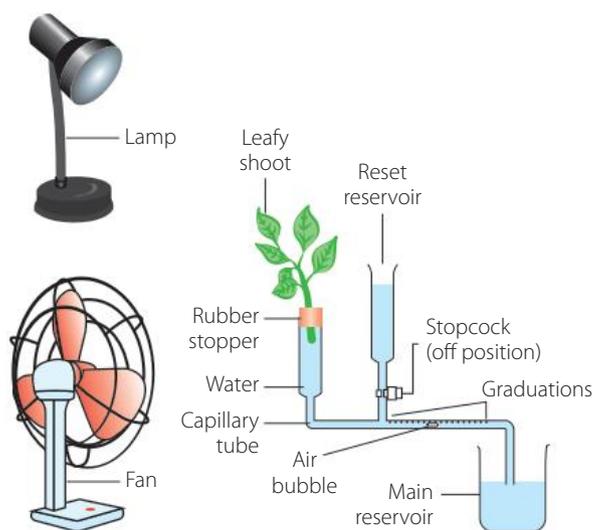
- 4 Explain the types of plants that would benefit more from taproots than fibrous roots.
- 5 Describe what you would look for in prepared longitudinal slides of plant stems to differentiate between the xylem and phloem.

ELABORATION QUESTIONS

- 6 Figure 8.6.1 shows the set up for a practical using a piece of equipment called a potometer. Determine the aim of the practical and explain what you think will happen.

FIGURE 8.6.1

A potometer is a specialised piece of glassware designed for a specific purpose, as in this practical set-up.



- 7 Deciduous trees drop their leaves in autumn. Most Australian native trees are evergreen and do not drop their leaves. Use your knowledge of the role of leaves in the plant to explain why native Australian trees are generally not deciduous.

EVIDENCE QUESTIONS

- 8 Suggest two limitations of the set-up in Question 6 and propose how you would minimise their effect on the results.
- 9 Summarise two scientific articles that support your response to Question 7.



- 1 The photosynthetic cells in a leaf are called the:
 - A parenchyma
 - B mesophyll
 - C epidermis
 - D phloem.
- 2 The phloem is composed of:
 - A companion cells and tracheids
 - B vessel elements and tracheids
 - C vessel elements and sieve tube cells
 - D sieve tube cells and companion cells.
- 3 Stomata are generally:
 - A open during the summer and closed during the winter
 - B open when it is cool and closed when it is hot
 - C open during the day and closed at night
 - D open when it is raining and closed when it is clear.
- 4 Compare and contrast xylem and phloem cells.
- 5 List three factors that influence the rate of transpiration.
- 6
 - a Describe the mechanism by which a plant opens and closes its stomata.
 - b Describe the conditions under which you would expect stomata to open and close.
- 7 Explain how root pressure, capillary action and the transpiration stream work together to move water through the xylem.
- 8 Outline the steps involved in moving a sucrose molecule from a photosynthetic cell in the leaf to a cell in the root.

» UNIT TWO

MAINTAINING THE INTERNAL ENVIRONMENT

- Topic 1: Homeostasis
- Topic 2: Infectious disease

Organisms live in a variety of environments that include many different factors that affect their survival. When there are changes to the internal environment of organisms, strategies are employed to stabilise internal conditions in order to maximise efficient functioning of their body. Plants and animals must balance their heat and water gains and losses and they need to fight off infection. The solutions to these challenges are achieved through adaptations. Like all organisms, humans are affected when internal conditions are not at their optimum. This unit examines the strategies humans employ to protect against changing conditions.

UNIT OBJECTIVES

By the end of this unit, students should be able to:

- 1 describe and explain homeostasis and infectious disease
- 2 apply understanding of homeostasis and infectious disease
- 3 analyse evidence about homeostasis and infectious disease
- 4 interpret evidence about homeostasis and infectious disease
- 5 investigate phenomena associated with homeostasis and infectious disease
- 6 evaluate processes, claims and conclusions about homeostasis and infectious disease
- 7 communicate understandings, findings, arguments and conclusions about homeostasis and infectious disease.

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MAINTAINING THE INTERNAL ENVIRONMENT



Topic 1: Homeostasis

Plants and animals have adaptations that enable them to detect and respond to changes in their internal and external environments. The stimulus–response model describes the process of detection of change and response. Responses are largely controlled by the nervous and hormonal systems in animals. They help organisms maintain a relatively constant internal state. Maintaining a constant body temperature is important because the bodies of plants and animals function best at specific temperature ranges. Animals have structural, behavioural, physiological and homeostatic adaptations that control heat exchange and metabolic activity. Water balance is also important for plants and animals to function efficiently. Plants and animals have adaptations to maintain water balance.

SCIENCE AS A HUMAN ENDEAVOUR

Students should be given opportunities to investigate models of human thermoregulation, the use of hormones in the dairy industry and the production of antivenom.

9 HOMEOSTASIS

Introduction

In 1988, Mark Dorrity went on an 8 km run in extreme heat in New South Wales. During the run, he neglected to drink water to stay hydrated and his muscles generated more heat than could be lost from his body. As a result, Mark's body overheated to 42.8°C and he suffered a rare condition known as rhabdomyolysis. His thigh muscles liquefied and released excess proteins into his blood. This caused Mark's kidneys and other organs to fail. Dehydration also caused Mark's blood to thicken to the point where it could not flow freely in some parts of his body, causing gangrene in his extremities. 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 had collapsed into a coma, was on dialysis and had one leg amputated.

Fortunately, few people engage in the kind of activity that Mark Dorrity did under such extreme conditions, though for many organisms these conditions are a feature of their daily lives. Mark pushed his body beyond tolerable limits and severely disrupted the biochemical processes that normally work to keep internal conditions relatively stable.

Stimulus questions

What assists organisms in maintaining a relatively constant internal state?

How does homeostasis enable organisms to survive in their environment?



Homeostasis is the term used to describe the maintenance of a relatively constant internal environment. Many processes going on within organisms require very specific conditions in order to operate effectively. Homeostasis works to maintain these conditions within very small **tolerance limits**. Although the term ‘homeostasis’ is often used to refer to balance across the entire organism, homeostasis involves managing a complex and diverse set of physiological conditions depending on the body system or organ studied. Figure 9.1.1 shows a small selection of the homeostatic processes in the human body.

homeostasis

the maintenance of a relatively constant internal environment within small tolerance limits, despite changes in the external environment

tolerance limits

the highest and lowest values of a particular factor (for example, temperature, blood glucose levels) that an organism can tolerate

Hormonal (endocrine) system

Hormones are released directly into the bloodstream and transported throughout the body. Target tissues involved in regulating cell activities respond.

Respiratory system

Oxygen from the air diffuses from the lungs into the capillaries and is carried to all cells. Carbon dioxide from the cells is carried to the lungs in the blood and diffuses into the alveoli from where it is exhaled. Removal of CO₂ helps regulate pH.

Circulatory system

Blood distributes warmth, hormones, O₂ and nutrients (including glucose, fatty acids and amino acids) to cells and removes wastes including CO₂.

Digestive system

The products of digestion (simple molecules) are absorbed into the blood and lymph vessels in the wall of the intestine, from where they are supplied to other parts of the body. Undigested material is eliminated.

Excretory system

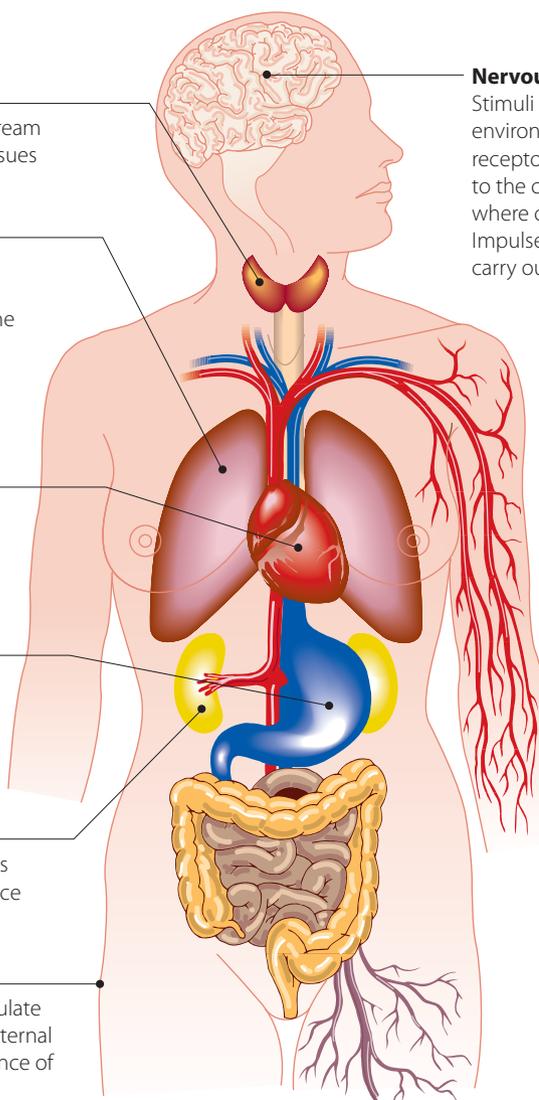
Nitrogenous wastes (urea), excess water and salts are excreted from the body in urine. Water balance (osmoregulation) is regulated in this way.

Integumentary system (skin)

Evaporation of sweat from the surface helps regulate temperature. The skin is a barrier between the internal and external environments and reduces the chance of entry of micro-organisms.

Nervous system

Stimuli in the external and internal environments are detected by receptors. Electrical impulses travel to the central nervous system (CNS) where coordination takes place. Impulses are sent to effectors that carry out a response.



9.1.1 Homeostasis and feedback

FIGURE 9.1.1 Homeostasis manages complex and diverse processes depending on the body system studied.

Feedback

Life would be much simpler if things always went according to plan and the perfect internal environment could be maintained indefinitely. Unfortunately, diseases, extremes in the external environment, trauma, inherited disorders and toxic substances can all interfere with homeostasis. Since organisms must keep internal conditions such as temperature and nutrient concentration stable, they must have a **feedback mechanism** to quickly identify and control all disturbances to homeostasis. This mechanism is called the **stimulus–response model** and it has three phases, shown in Figure 9.1.2.

A disturbance is referred to as a **stimulus** (plural: stimuli) and is detected by a **receptor**. The detected signal is then fed to a **processing centre**, which interprets and coordinates a specific **response** that either counteracts or reinforces the disturbance. This is conveyed to an **effector**, which carries out the response. The receptor then detects the new conditions, and the loop continues.

Responses that counteract the disturbance are defined as **negative feedback**, while responses that reinforce the disturbance are defined as **positive feedback**. Homeostasis, by its nature a stabilising process, employs only negative feedback. Positive feedback, while necessary for some life processes, such as childbirth, is not homeostatic.

Negative feedback

Mechanisms that counteract the stimulus are referred to as negative feedback. For example, when you eat a bar of chocolate, your blood glucose levels rise rapidly. Your 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 (Figure 9.1.3). On the other hand, exercising vigorously or fasting decreases blood glucose. The body responds by breaking down glycogen stores and returning blood glucose levels to normal.

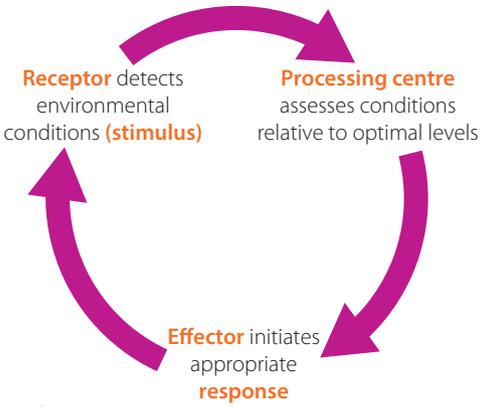


FIGURE 9.1.2 The stimulus–response model relies on the body detecting, assessing and responding to stimuli.

feedback mechanism

a process that monitors environmental conditions, usually, but not necessarily, in reference to biological systems

stimulus–response model

a model that shows how organisms respond to stimuli

stimulus

a signal that causes a response

receptor

a structure that detects or receives stimuli

processing centre

the organ or organ system, usually the central nervous system, that receives signals from receptors and sends appropriate responses to effectors

response

the action resulting from a stimulus

effector

an organ, cell or protein that acts in response to a stimulus

negative feedback

a cyclic process where responses counteract disturbances to keep concentrations of substances within narrow limits for optimal cellular function

positive feedback

a cyclic process where responses reinforce and strengthen disturbances to normal cellular function

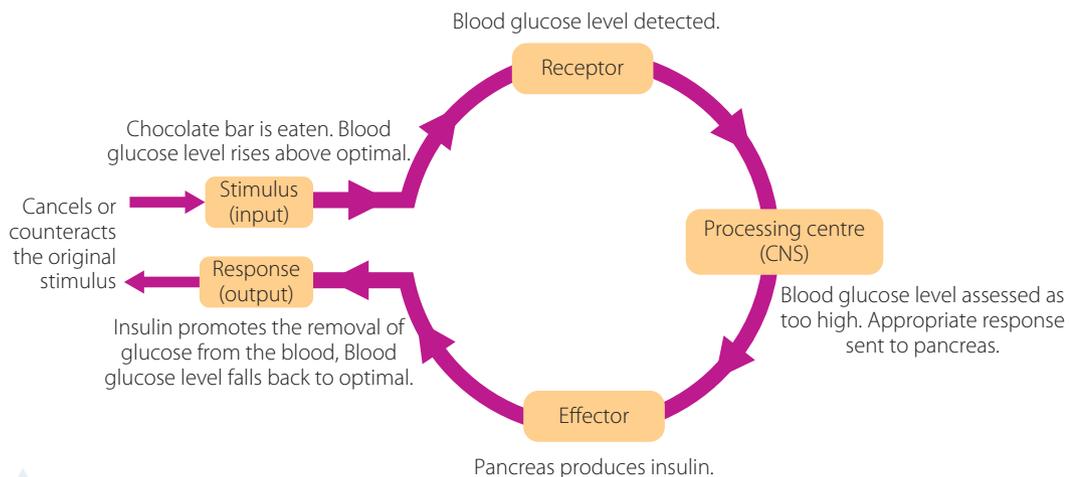


FIGURE 9.1.3 Negative feedback occurs when a response cancels or counteracts the original stimulus.

Continual maintenance

As conditions within the body are constantly fluctuating, negative feedback is constantly working to support homeostasis. The receptors continually scan the internal environment to ensure the narrow range of appropriate conditions is met. Figure 9.1.4 shows the process of homeostasis as a continual readjustment of the body conditions to maintain them within set tolerance limits.

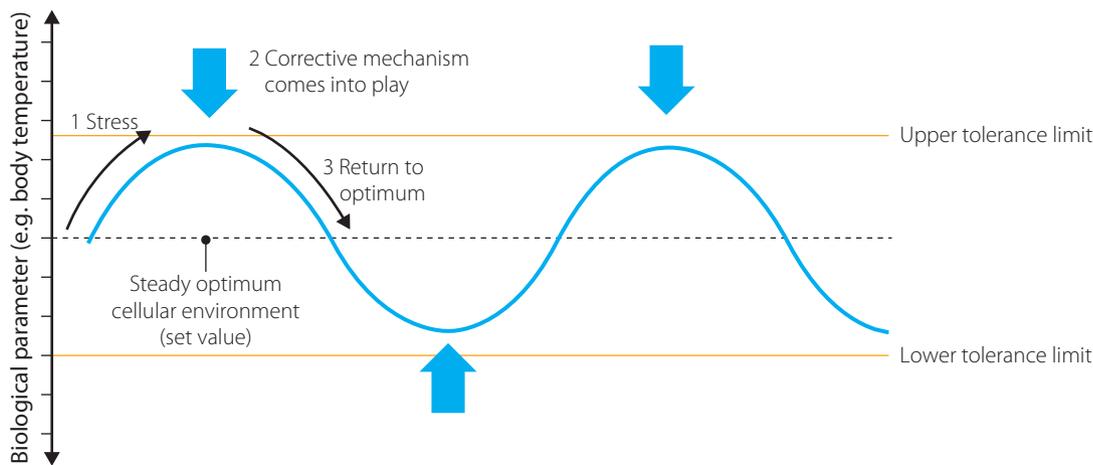


FIGURE 9.1.4
Optimum conditions within the tolerance limits are maintained through negative feedback.

SECTION REVIEW

9.1

REMEMBERING

- 1 Define:
 - a stimulus
 - b receptor
 - c effector
 - d response.
- 2 Draw a labelled diagram of the stimulus–response model.

UNDERSTANDING

- 3 With the use of an example, explain negative feedback.
- 4 Discuss how positive and negative feedback are different. Suggest why positive feedback is generally not associated with homeostasis.

9.2 Sensory receptors

Fundamental to homeostasis is the detection of stimuli by receptors. An organism and its cells receive many different types of information and this means receptors come in all shapes and sizes and are categorised by the type of stimulus they detect. Signals may come from the external environment, other parts of the organism or within the cell. Stimuli may be physical (light, heat, pressure) or chemical (hormones, neurotransmitters). There are millions of external and internal receptors that allow an organism to respond to stimuli. These receptors are grouped into five main categories: **chemoreceptors**, **mechanoreceptors**, **photoreceptors**, **thermoreceptors** and **nociceptors**.

Detection of external and internal signals

Homeostasis requires that organisms detect signals from their external and internal environments. **Exteroceptors** receive signals from the external environment. They can work as individual receptors or together as a group, and are either distributed evenly throughout the body (for example, pain receptors) or concentrated in organs (for example, the eye). Exteroceptors work by receiving outside information and converting it to a chemical or electrical signal that can then be relayed within the body.

chemoreceptor
a detector that detects a chemical stimulus such as oxygen concentration and pH

mechanoreceptor
a detector that detects a physical stimulus such as touch and sound

photoreceptor
a detector that detects light

thermoreceptor
a detector that detects changes in temperature

nociceptor
a detector that detects only intense (painful) chemical, mechanical or thermal stimulation

exteroceptor
a receptor that specifically receives signals from outside the body, such as air temperature, painful pressure or smells

interoceptor
a receptor that specifically receives signals from inside the body, such as body temperature, oxygen concentration or pH

interstitial fluid
extracellular tissue fluid; fluid in spaces surrounding cells

Interoceptors receive signals from within the body's internal environment, which is composed of the **interstitial fluid** that bathes the cells, and the blood plasma (Figure 9.2.1). Interoceptors help maintain the internal environment within narrow limits, allowing maximum cellular efficiency.

Table 9.2.1 lists some examples of exteroceptors and interoceptors in the body.

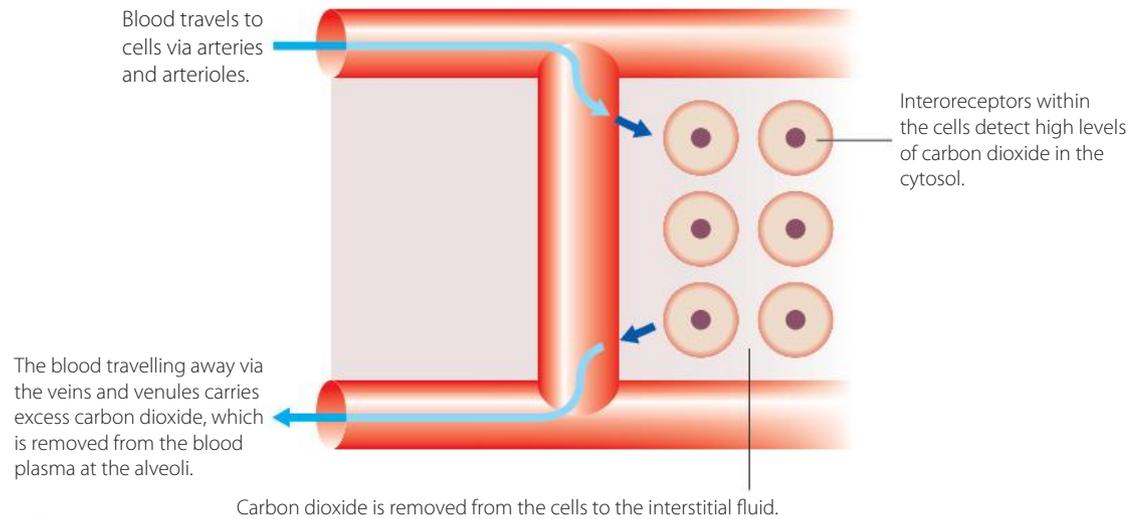


FIGURE 9.2.1 Interoceptors are vital to homeostasis because they monitor the internal environment. Carbon dioxide, oxygen, pH and ion levels are components homeostatically maintained by interoceptors.

TABLE 9.2.1 Some examples of exteroceptors and interoceptors

TYPE OF RECEPTOR	EXTEROCEPTOR STIMULI	INTEROCEPTOR STIMULI
Chemoreceptor	Smells and tastes in nose and mouth	Oxygen and ion levels in blood vessels
Mechanoreceptor	Pressure, touch, sound vibrations	Pressure, vibrations, balance
Photoreceptor	Light in the eyes and on the body surfaces of some invertebrates	None
Thermoreceptor	Air temperature on skin	Internal temperature in hypothalamus
Nociceptor	Painful heat, cold, pressure, light	Painful pressure, tension

INQUIRING FURTHER

The sensitivity of some receptors is amazing. The hair-like mechanoreceptors of certain insects can detect disturbances of 3.6 nm, making them extremely sensitive to airborne vibrations. Chemoreceptors on the antennae of some moths can detect a single molecule of female sex hormone released about 10km away.

Choose a receptor to research and write a five-paragraph summary of your findings.

SECTION REVIEW

9.2

REMEMBERING

- 1 Name the five main types of receptors and provide an example of each.
- 2 Describe what constitutes the internal environment.

UNDERSTANDING

- 3 Distinguish between exteroceptors and interoceptors.
- 4 List three signals that a cow might receive from its external environment and three signals that would need responding to in its internal environment.
- 5 Nociceptors are a special category of receptor. Explain why multicellular organisms might have needed to develop nociceptors in addition to the four other receptors.

9.3 Effectors

Homeostasis requires that, in addition to detecting stimuli, organisms respond to them. Only by counteracting disturbances can optimum conditions be maintained. These responses are carried out by effectors. Generally, effectors can be organised into two categories – muscles and **glands**.

Muscles

Muscles are organic tissues that can contract in response to neural (nerve) stimulation. As a tissue, they are constructed from bundles of muscle fibres, which are in turn constructed of repeatedly overlapping filaments of myosin and actin. These two molecules, shown in Figure 9.3.1, shuffle along each other when activated by a signal from a **motor neuron**.

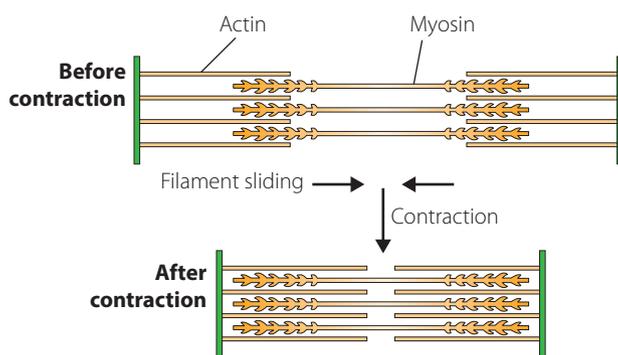


FIGURE 9.3.1 The filaments within a muscle pull against each other to contract in response to stimuli.

The contraction of muscles in response to stimuli leads to many of the movements we take for granted, such as walking, sitting and scratching our noses. Newborn babies need to learn how send appropriate signals to their muscles (Figure 9.3.2).



FIGURE 9.3.2 The jerky, uncoordinated movements of a newborn are the result of their brains learning how to send appropriate signals to their muscles.

Glands

Glands are organs that secrete chemicals or proteins either within the body, called **endocrine glands**, or externally, called **exocrine glands**. Endocrine glands secrete substances into the bloodstream, such as insulin and adrenaline. Unlike muscles, glands can respond to both neural and chemical stimulation.

gland

an organ that secretes chemicals or proteins within the body or externally

motor neuron

a cell that transmits nerve impulses from the central nervous system to an effector

endocrine gland

a gland that secretes substances directly into the bloodstream

exocrine gland

a gland that secretes substances onto an external surface or body tract

For example, insulin is released by pancreatic cells in response to direct contact with high blood glucose levels. Adrenaline is released by the adrenal glands in response to neural signals (Figure 9.3.3).

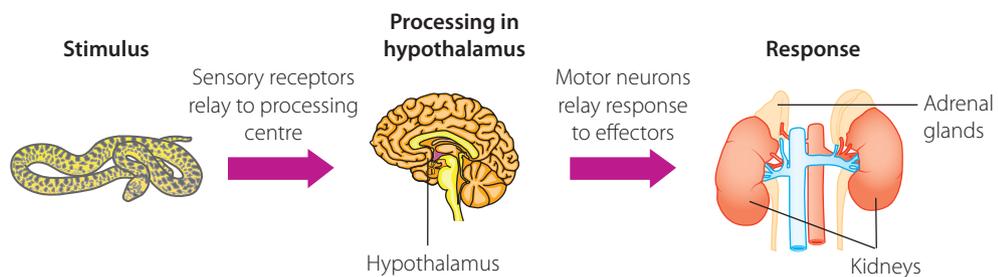


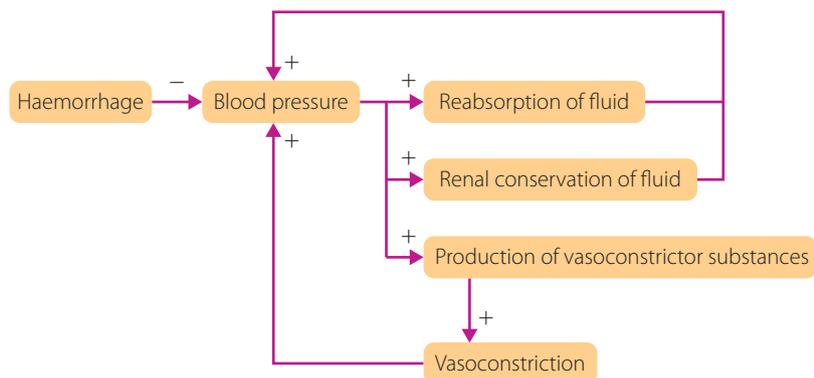
FIGURE 9.3.3 Adrenaline is secreted by the adrenal glands in response to fear, anger and stress.

Exocrine glands secrete substances onto an external surface, including surfaces within the body but open to the external environment such as the digestive and reproductive tracts. For example, saliva is produced in response to the thought of food (neural stimulation) as well as the taste of it (chemical stimulation).

Feedback control diagrams

Feedback control diagrams are specific versions of the general stimulus–response model and may contain multiple pathways, receptors and effectors. Interpreting these diagrams requires an understanding that they are loops, with the response circling back to the receptor. Figure 9.3.4 is a feedback control diagram showing what happens in the body following a haemorrhage.

FIGURE 9.3.4 Feedback control diagrams attempt to incorporate all of the physiological responses to a particular stimulus.



To correctly interpret this diagram, it is important to understand the code. The arrows indicate the progression of the system and the + and – signs indicate increases and decreases respectively. Knowing this, the left side of the diagram shows that haemorrhage decreases blood pressure. Decreased blood pressure then has three separate effects, shown by the three arrows leading out from blood pressure. All of these effects are increases, as shown by the + signs. Two of these effects have an arrow leading back to blood pressure, this time with a + sign. For example, increased reabsorption of fluid leads to increased blood pressure. However, production of vasoconstrictors doesn't have a direct effect on blood pressure. First, the substances lead to increased vasoconstriction, which then leads to increased blood pressure.



Chapter 11 discusses the role of hormones in homeostatic control pathways.

This is a negative feedback system because the responses counteract the original stimulus. When the haemorrhage is treated, this system will return blood pressure to normal, re-establishing homeostasis and allowing the body to function efficiently.

SECTION REVIEW

9.3

REMEMBERING

- 1 Define:
 - a effector
 - b muscle
 - c gland.
- 2 Describe the job of a motor neuron.
- 3 Outline the roles of arrows, + signs and – signs in feedback control diagrams.

UNDERSTANDING

- 4 Draw a simple diagram showing the steps of muscle contraction.
- 5 Use two examples each of endocrine and exocrine glands to compare the similarities and differences between them.
- 6 Compare the types of stimuli to which muscles and glands respond.

APPLYING

- 7 Draw a feedback control diagram to show the effects of exercise. Include both temperature and glucose level maintenance.

9.4 Metabolism

Metabolism is the sum of all the chemical reactions that occur within an organism to maintain life. The main metabolic pathways that transfer energy through living systems are photosynthesis and cellular respiration. These reactions transform energy in order to keep an organism alive.

Reactions in which a complex molecule, such as starch, break down into simpler ones, such as glucose, are called **catabolic reactions**. When amino acids are joined together to form proteins, small molecules build up into larger molecules. These are **anabolic reactions**. You may have heard the term ‘anabolic’ before with reference to anabolic steroids and body building. Both anabolic and catabolic reactions apply to building up and breaking down of structures or molecules.

Now consider the energy changes of chemical reactions. **Exergonic reactions** (‘exo’ = out) are those that release energy. They are sometimes referred to as ‘downhill’ reactions. When molecular bonds are broken, energy is released. It makes sense that when a large molecule is broken down to smaller molecules, a large amount of energy is released. The opposite type of reaction, when molecular bonds are formed, is called an **endergonic reaction** (‘endo’ = in). This is sometimes referred to as an ‘uphill’ reaction and requires an input of energy.

When starch breaks down to sugar, energy is released. Catabolic reactions always release energy so they are always exergonic. When proteins are built up from amino acids, energy is used. These types of anabolic reactions are always endergonic. Cells use the available energy released from catabolic reactions to fuel anabolic reactions (Figure 9.4.1, page 152).

The energy held within chemical bonds is released when they are broken. In the body, this energy is captured in the molecule ATP (adenosine triphosphate), which can then be stored or transported around the cell to be used in anabolic reactions.

metabolism

the sum of chemical reactions that maintain life within an organism

catabolic reaction

a reaction that involves the breakdown of complex molecules to simpler products, e.g. cellular respiration

anabolic reaction

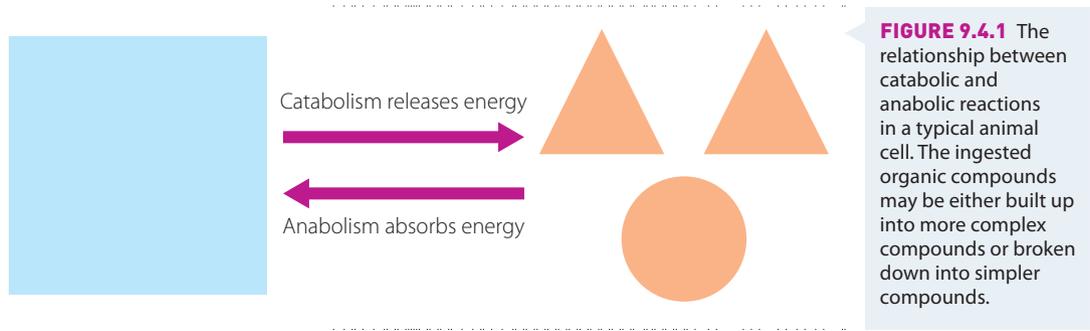
a reaction that builds up complex molecules from simple molecules

exergonic reaction

a chemical reaction that releases energy

endergonic reaction

a chemical reaction that requires energy



A biochemical process or reaction occurs when the chemical bonds of inputs or reactants are broken and the atoms recombine to form a new substance or substances: the output or products. In endergonic reactions, a total net amount of energy is absorbed and locked up in the bonds of the products, which have more stored energy than the reactants. In exergonic reactions, a total net amount of energy is released from the bonds of the reactants, and the products have less energy than the reactants (Figure 9.4.2).

Anabolic reactions use energy to build up molecules in an endergonic reaction. Catabolic reactions release energy when molecules are broken down in an exergonic reaction.

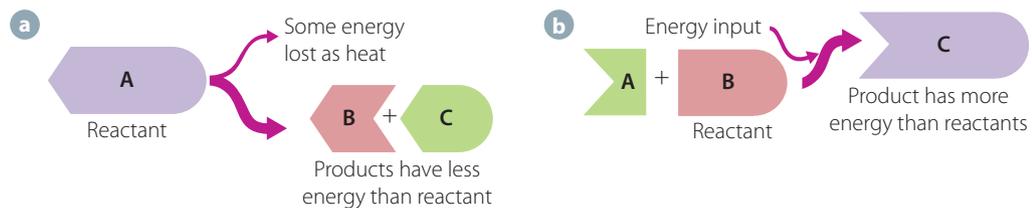


FIGURE 9.4.2 (a) The reactants of exergonic reactions have more energy than the products. (b) The reactants of endergonic reactions have less energy than the products.

tolerance range
the range within which an organism can function

enzyme
a protein that catalyses biochemical reactions

Metabolic activity affects conditions

Each organism has a set range in which they tolerate different levels of conditions such as pH and temperature. This is known as the **tolerance range**. Homeostasis maintains the levels within the optimum range. If homeostasis fails and tolerance limits are reached (for example, the level of pH becomes too high), the organism can fall into a state of physiological stress, affecting its function.

Most biochemical reactions in the body require the catalytic help of **enzymes**. Each enzyme functions best within specific pH and temperature tolerance limits. Even small changes in pH and temperature within the body can significantly affect the function of enzymes, which drastically affects the efficiency of life-sustaining reactions. Without homeostasis, metabolism and its life-sustaining reactions cannot be maintained.

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 as a result of the energy released in the reactions, which affects how quickly the reactions proceed. However, there are



Chapter 3 discusses enzymes and the conditions under which they operate.

other factors that affect temperature and pH levels. For example, carbon dioxide concentration can alter pH levels. If carbon dioxide concentrations increase as a result of exercise, pH levels decrease. Decreasing the pH causes lower enzyme functionality, which reduces metabolic activity, resulting in less heat energy. The body must maintain pH levels to ensure the supply of nutrients to cells is met and internal temperature remains constant.



9.4.1
Metabolism and
thermoregulation

SECTION REVIEW

9.4

REMEMBERING

- 1 Define:
 - a metabolism
 - b anabolic reaction
 - c catabolic reaction.
- 2 List two factors that homeostasis maintains.
- 3 Describe a consequence of an organism going beyond its tolerance limit.

UNDERSTANDING

- 4 Compare anabolic and catabolic reactions and give an example of each.
- 5 Describe the relationship between:
 - a anabolic and endergonic reactions
 - b catabolic and exergonic reactions.
- 6 Identify each of the following as either an anabolic or a catabolic process, and justify your choice in each case.
 - a Protein synthesis
 - b Digestion
 - c DNA synthesis
 - d Photosynthesis
 - e Cellular respiration
- 7 Explain how changes in metabolic activity alter optimum conditions for enzymes.

CHAPTER REVIEW QUESTIONS

DETAIL QUESTIONS

- 1 Define:
 - a stimulus
 - b receptor
 - c processing centre
 - d effector
 - e response
 - f metabolism.
- 2 Outline the stimulus–response model.
- 3 Explain how negative feedback works.

CATEGORY QUESTIONS

- 4 Compare and contrast positive and negative feedback.
- 5 Describe the common characteristics of catabolic reactions.

ELABORATION QUESTIONS

- 6 Suggest why enzymes require specific pH and temperature levels to function correctly.
- 7 Using your knowledge of homeostasis, explain the biological cause(s) of Mark Dorrity's injuries (page 144).

EVIDENCE QUESTIONS

- 8 Find two reliable sources that support your response to Question 6.
- 9 Explain two limitations of the stimulus–response model as a way of understanding homeostasis, and describe how feedback control diagrams address at least one of them.

END-OF-CHAPTER EXAM



End-of-chapter test

- 1 Homeostasis is best described as the:
 - A maintenance of a fixed and unaltered internal state
 - B maintenance of a relatively constant internal state
 - C ability of the body to manipulate the external environment
 - D process that describes all of the body's functions.
- 2 The three phases of the stimulus–response model are:
 - A assessment by an effector, response by a processing centre and detection by a receptor
 - B assessment by a processing centre, detection by a receptor and response by an effector
 - C detection by a processing centre, assessment by an effector and response by a receptor
 - D detection by a receptor, assessment by a processing centre and response by an effector.
- 3 Which of the following receptors would you expect to find in the skin?
 - A Chemoreceptors and thermoreceptors
 - B Mechanoreceptors and thermoreceptors
 - C Chemoreceptors and nociceptors
 - D Mechanoreceptors and photoreceptors
- 4 Two types of chemical reactions in metabolism are:
 - A catabolic (breaking down) and anabolic (building up)
 - B anabolic (breaking down) and catabolic (building up)
 - C metabolism (breaking down) and anabolic (building up)
 - D anabolic (breaking down) and metabolism (building up).
- 5 Outline the stimulus–response model.
- 6 List the five categories of receptors and the stimuli they detect.
- 7 Use at least two examples to describe what effectors are.
- 8 Explain the consequences of exteroceptor and interoceptor failure.

- 9 Adam and Robert were given a meal and their blood glucose levels were recorded over a 5-hour period. From the graph in Figure 9.5.1, identify which man's blood glucose was under homeostatic control. Justify your response.

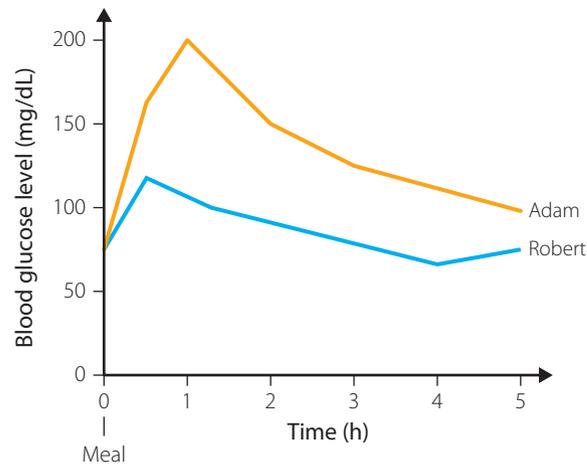


FIGURE 9.5.1 Blood glucose levels over a 5-hour period

- 10 Explain how changes in metabolic activity can alter the catalytic activity of enzymes.

10

NEURAL HOMEOSTATIC CONTROL PATHWAYS

Introduction

Homeostasis in higher-order animals is supported by the nervous system. Peripheral nerves pick up messages and transmit them to the central nervous system (CNS) for processing. They also deliver messages to muscles lining glands, skeletal muscles, hairs and ducts in a response coordinated by the CNS. The brain alone contains one trillion neurons that are connected to each other and to the peripheral nerves to form circuits. To function within this circuit, a neuron must receive, process and relay signals to the correct neurons, while blocking transmission along incorrect pathways.

Stimulus question

How does the structure and function of neurons support homeostasis?



10.1

Cells that transport nerve impulses

The nervous system comprises the central nervous system (CNS) and peripheral nervous system (PNS). The brain and the spinal cord form the CNS, which is responsible for processing, storing and coordinating information. All the other **neurons** in the nervous system form the PNS, which is responsible for transmitting information to and from the CNS.

Nerve impulses travel along defined pathways. From the source of stimulation, nerve impulses travel along the **sensory neurons** to the CNS. From the sensory neurons, the electrical impulses are relayed to **interconnecting neurons (interneurons)** located in the CNS to the appropriate **motor neurons**. From the CNS, motor neurons relay the signal to the effectors (muscles or glands) (Figure 10.1.1).

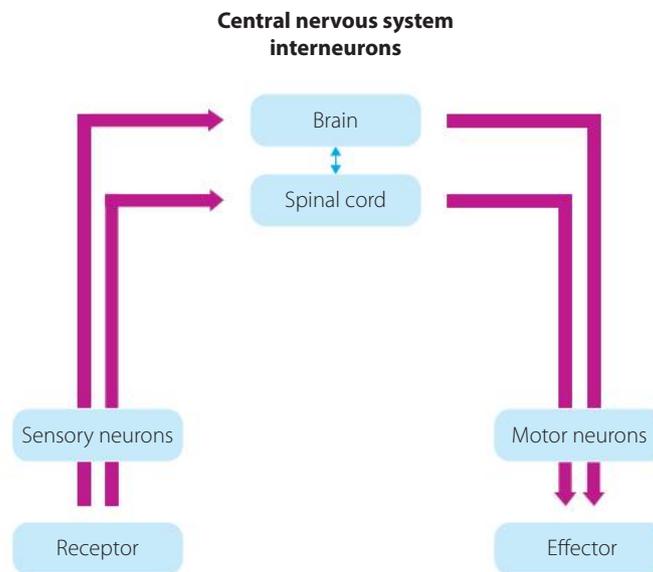
neuron
a nerve cell that transmits electrical impulses in the body

sensory neuron
a cell that transmits nerve impulses from the receptor to the central nervous system

interconnecting neuron (interneuron)
a cell that transmits nerve impulses within the central nervous system, between sensory and motor neurons

motor neuron
a cell that transmits nerve impulses from the central nervous system to the effector

FIGURE 10.1.1 Nerve impulses travel from receptor to effector through three types of neurons: sensory neurons, interneurons and motor neurons.



Nerve structure

Neurons are the basic cellular units of the nervous system. Their structure is directly related to their function, so three different functions means there are three different structures. However, there are general features common to all neurons. These include the **soma**, the main cell body, and the **axon**, the long, thin extension of the soma which gives neurons their characteristic elongated shape. Many axons together make a nerve fibre. A bundle of nerve fibres comprises a nerve and each nerve is wrapped in a tube of connective tissue (Figure 10.1.2). The soma of the neurons are often bundled together in a big lump called a ganglion (plural: ganglia).

10.1.1 Structure and function: nerves

soma
the main cell body of a neuron

axon
the tubular extension of a neuron cell body that conducts the nerve impulse

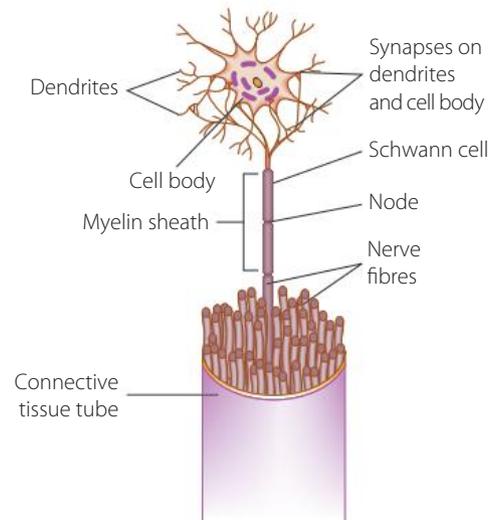


FIGURE 10.1.2 Generally, nerves are bundles of nerve fibres, each of which is the myelin-wrapped axon of a neuron.

Individual nerve fibres consist of two parts: the axon and the **myelin sheath**. The myelin sheath is made of thin **Schwann cells** that wrap tightly around the axon (Figure 10.1.3), leaving small sections of bare axon in between the cells of myelin sheath. These bare sections are known as **nodes of Ranvier**, after the French physician who discovered them. The Schwann cells act as a fatty layer of insulation around the axon, allowing an electrical impulse to jump from node to node. This arrangement allows the electrical impulse to travel faster along the length of the nerve. The myelin also keeps the message from accidentally crossing over to adjacent neurons. Damage to the myelin sheath hinders the transmission of the nerve impulse and is the cause of multiple sclerosis and other debilitating neurodegenerative conditions.

myelin sheath
the fatty layers of insulation surrounding the axon of a neuron; made of Schwann cells

Schwann cell
a cell that wraps tightly around the axon of a neuron to form the myelin sheath

node of Ranvier
a small space between the Schwann cells along the axon of a neuron

INQUIRING FURTHER

Prior to writing *Frankenstein*, Mary Shelley had been listening to scientific discussions about the work of Galvani, who used electricity to stimulate movement of a dissected frog's leg. This spurred philosophical discussions with her husband, the poet Percy Shelley, and their friend Lord Byron on using electricity to revive the dead. Today, there is a blurring of the lines between science fact and science fiction.

Reflect on the question: In what way does electricity help us to revive the dead?



FIGURE 10.1.3 The thick insulation around a neuron is made with a single Schwann cell, wrapped thousands of times around the axon so tightly you can barely see the layers.

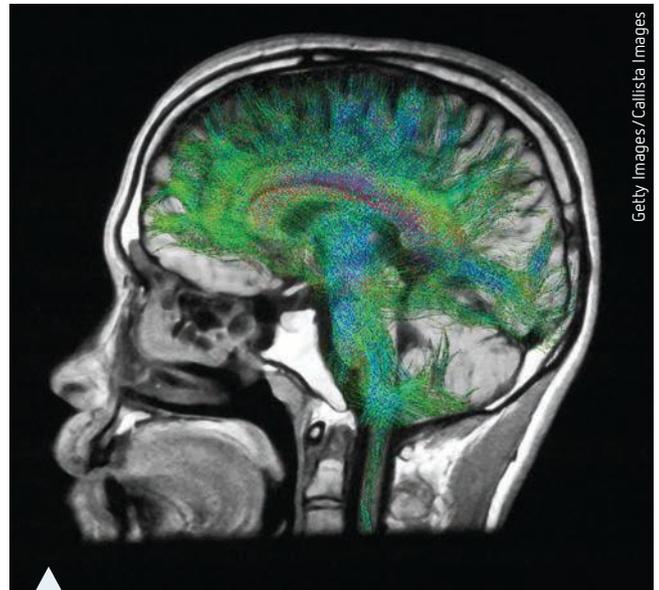


FIGURE 10.1.4 Scientists can now remove the fats from brains to make them transparent. This allows them to use molecular markers to distinguish between particular neurons, or to compare cells of diseased and healthy brains. Design and complete a research task that investigates why removing the fats from brains could lead to new scientific discoveries.

SECTION REVIEW

10.1

REMEMBERING

- 1 Define:
 - a soma
 - b axon
 - c myelin sheath
 - d Schwann cells
 - e nodes of Ranvier.
- 2 List the three categories of neurons.
- 3 Describe the differences between nerve, neuron and nerve fibre.



UNDERSTANDING

- 4 Explain how the myelin sheath is formed and outline its function.
- 5 Predict one consequence of a lack of myelin in the nervous system.
- 6 Describe some of the key features that differentiate neurons from other cells in the body.
- 7 Draw a labelled diagram of a general neuron structure.

10.2 Different types of neurons

Neurons are the basic units of the nervous system. Their structure is directly related to their function (Figure 10.2.1). There are three kinds of neurons: sensory, motor and interconnecting.

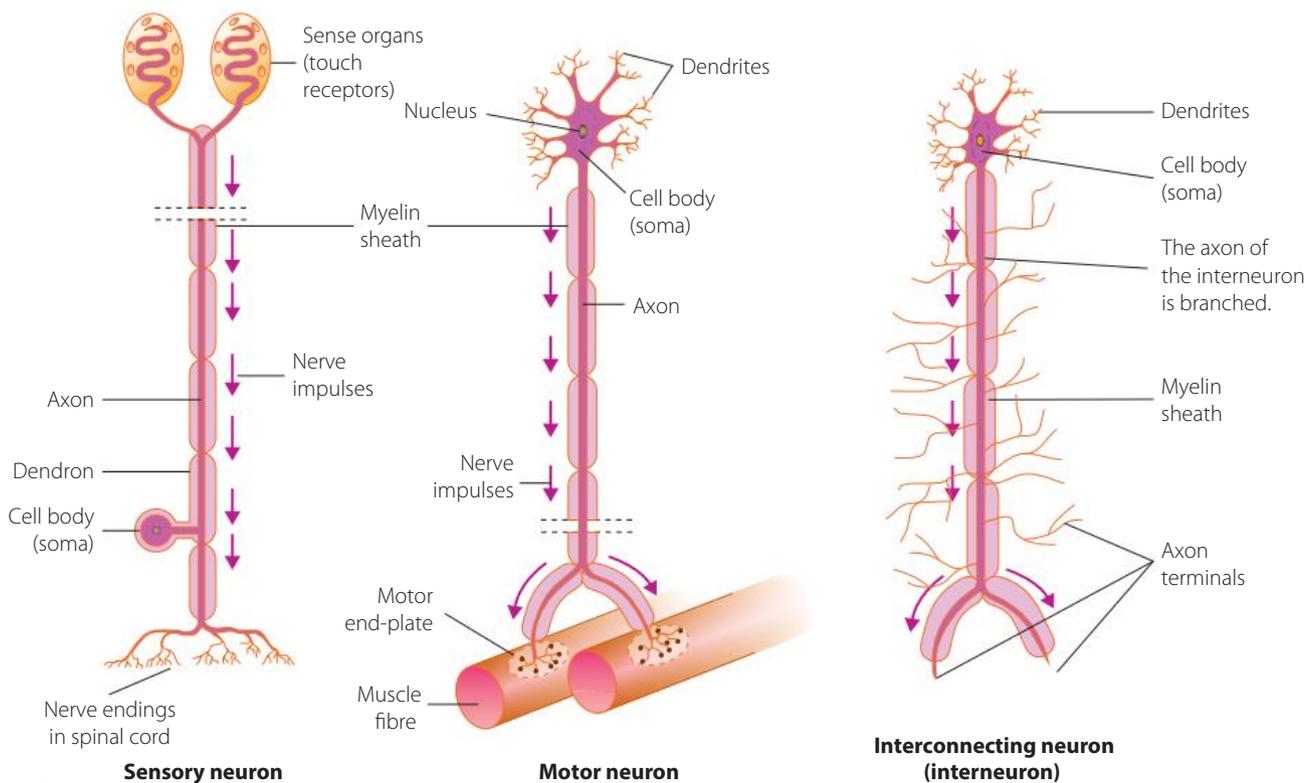


FIGURE 10.2.1 The structures of sensory, motor and interneurons are directly related to their functions.

Sensory neurons

dendrite
a fine, thread-like extension of the neuron that converts external signals to nerve impulses within the neuron

Sensory neurons are the nerve cells that detect stimuli and transmit impulses towards the CNS. At the dendritic end, **dendrites** house the sensory receptors that detect stimuli, while at the terminal end, dozens of nerve endings link with interneurons in the spinal cord or brain.

The soma is usually located as a side bulge somewhere along the length of the axon. Although the soma of the sensory neuron is only 0.1 mm in diameter, the axon can be as long as 1.5 m in adults, reaching from the receptors in the soles of the feet to the terminals in the lower spinal cord.

Sensory neurons often have multiple receptors on the dendritic end that can send signals individually for finely tuned detection (such as when reading braille) or send signals as a group for large-scale sensation (such as feeling that you're wearing clothes). These neurons are responsible for feeding every piece of information about both the internal and external environments to the brain and spinal cord, making them vital to successful homeostasis.

Motor neurons

Motor neurons are the nerve cells that transmit impulses away from the CNS to trigger responses. The dendrites receive signals from the interneurons of the CNS and pass them through the cell body and down the axon. However, the axon terminals of motor neurons are slightly different depending on the effector that they are linked to. When linked to muscles, the axon terminates in a structure called an end plate – a multi-pronged series of terminals directly on the muscle fibre (Figure 10.2.2). When linked to glands, the axon terminates within the gland structure.

Interneurons

Interneurons, or interconnecting neurons, are the nerve cells that combine into neural circuits to make decisions and conduct what we know as 'thinking'. They are primarily located in the brain and spinal cord and make up the vast majority of neurons in the CNS. Their ability to connect with many other neurons sets them apart from the sensory and motor neuron categories. Of the three categories, only interneurons can form the complex webs required for memory, thought and emotion.

Interneurons perform two functions in the nervous system.

- ▶ They receive sensory information from the sensory neurons and send response information to the motor neurons. By connecting to the other two types of neurons, interneurons can detect the environment and control the body.
- ▶ They process the information received by sending the impulse through a convoluted series of interneurons that result in the appropriate response signal. Neuroscientists are still trying to understand how different pathways produce different outcomes.

In order for interneurons to connect with many other neurons, they need to have many terminals off their axon and many dendrites off their soma. As shown in Figure 10.2.3, the soma is located in the middle of this sea of fine threads, all of which connect to a new neuron.

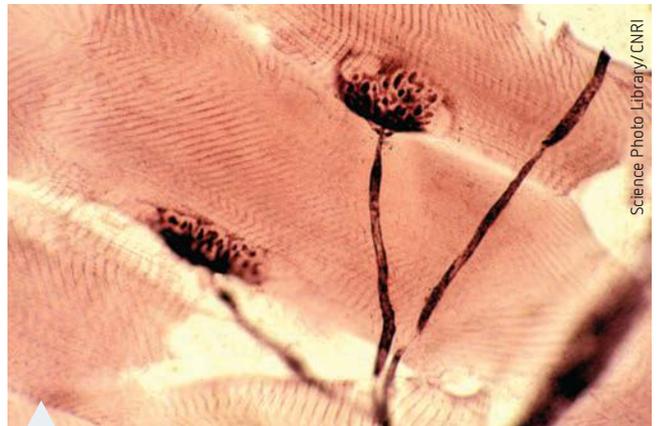


FIGURE 10.2.2 When motor neurons are linked to muscles, they terminate at end plates lodged deep in the muscle fibre.



FIGURE 10.2.3 Interneurons in the brain connect with each other in vast and complex webs.

Discriminating between sensory and motor neurons

Although very similar, sensory and motor neurons have four key differences in their structure and function: the soma, dendritic terminals, axon terminals and direction of the impulse.

Soma

The soma, or cell body, of a neuron contains the nucleus and other vital organelles. In sensory neurons, the soma is located as a side bulge somewhere along the length of the axon. It is still unclear why the soma is not in line with the axon as in other neuron types, but it may be related to the speed of the signal. In motor neurons, the soma is located at the dendritic end of the neuron and the axon and dendrites branch directly off it.

Dendritic terminals

At the dendritic end of the motor neuron, the soma branches out into fine, thread-like extensions. These dendrites terminate in synapses, which link to and receive signals from interneurons. However, in sensory neurons the dendrites branch off one end of the axon instead of the soma. These sensory dendrites do not terminate in synapses. Instead, their ends contain sensory receptors that detect stimuli from the internal or external environment.

Axon terminals

At the opposite end to the dendrites are the axon terminals. In sensory neurons, the axon terminates in many synapses that link and send signals to interneurons in the CNS, while in motor neurons, the axon terminates in structures called end plates that interface with the muscle or gland directly.

Direction of impulse

While the impulses in sensory and motor neurons both travel from dendrites to axon terminals, the direction of the impulse in relation to the body is different. Sensory neurons send nerve impulses towards the CNS, while motor neurons carry the impulses away from the CNS.

SECTION REVIEW

10.2

REMEMBERING

- 1 Draw a labelled diagram of a sensory neuron, connected to an interneuron, connected to a motor neuron.

UNDERSTANDING

- 2 Describe the four main differences between a sensory neuron and a motor neuron.
- 3 Explain why interneurons are important to multicellular organisms.

10.3 Passage of a nerve impulse

Many stimuli can initiate a nerve impulse. Stimulation can come from an external receptor organ, certain chemicals or even physical stimulation, such as a pinch. In all cases, the message is initiated by opening up ion channels in the cell membrane of the dendrites, thus allowing the movement of sodium (Na^+) and potassium (K^+) ions across the membrane. This influx of positive ions changes the net charge inside the neuron, starting a cascade of electrical activity down the axon.

Transmission within the neuron

Initially, the cell membrane of an axon is polarised (i.e. there is a potential difference in charge between the inside and the outside of the cell). This does not mean that one side is positive and the other is negative, although there are many diagrams that depict it as such. Instead, both sides are positive, but one is more positive than the other.

Resting potential

An axon that is at rest (not transmitting an impulse) is slightly positive on the inside and very positive on the outside. This is called the **resting potential**, when the outside is more positive. In this state, **sodium-potassium pumps** in the cell membrane actively pump three sodium ions out of the cell for every two potassium ions they pump into the cell. Consequently, there is an accumulation of sodium ions outside the cell and potassium ions inside. Although both sodium and potassium ions are equally positive, the 'three out vs two in' mechanism results in more positive ions outside than inside.

Action potential

When an impulse is triggered, the influx of positive ions causes the membrane to become permeable to sodium ions. As sodium ions have been actively pumped outside the cell, they are about 10 times more concentrated on the outside than the inside and so they diffuse in rapidly. Since the membrane is not permeable to potassium ions, most of them are trapped inside while the sodium continues to flood in. This leads to a large positive charge inside the cell and only a small positive charge outside. As this is the reverse of the resting potential polarity, the process is called **depolarisation** of the membrane and results in an **action potential**. The whole process takes place in a millisecond (Figure 10.3.1).

resting potential
the state of a neural cell membrane at rest, when outside the cell is more positive than inside

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

depolarisation
a change in a cell's membrane potential so that the inside of the membrane is less negative than the outside

action potential
the state of a neural cell membrane in active transmission, when inside the cell is more positive than outside

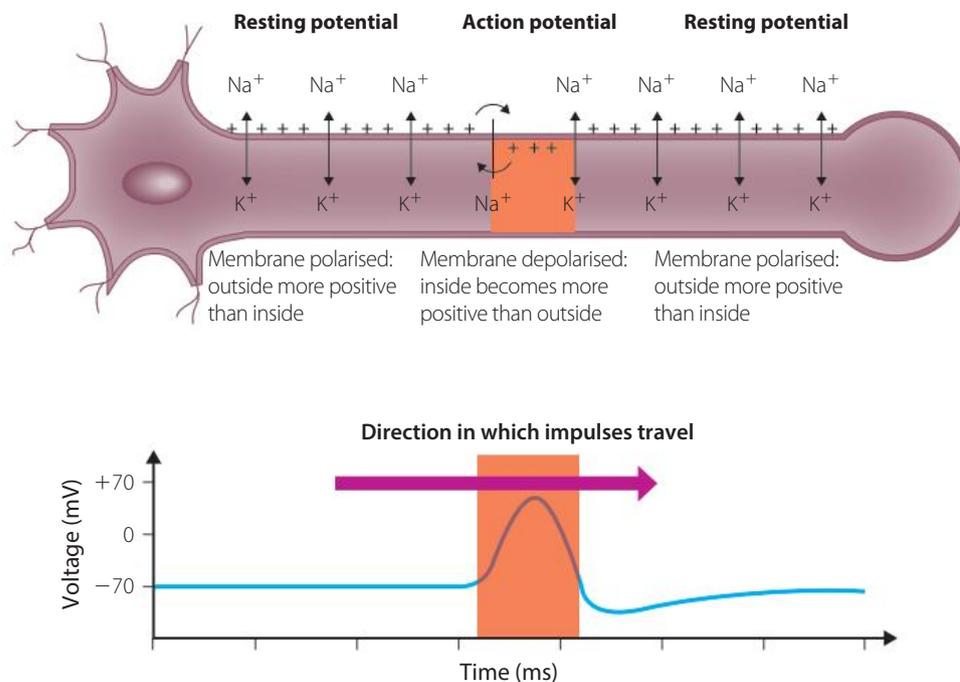


FIGURE 10.3.1 The transmission of an impulse along the axon requires most of the axon membrane to be at rest while the small action potential travels like a ripple along it.



10.3.1 Myelin

synapse (synaptic cleft)

the tiny space between an axon terminal and its target (neuron, muscle or gland)

presynaptic neuron

the neuron sending the signal across the synapse

postsynaptic neuron

the neuron receiving the signal from the synapse

signal transduction

the process of converting a signal from one type to another (for example, chemical to electrical)

Restoration of resting potential

While the sodium ions diffuse into the axon, the potassium ions slowly begin to leave: this is the start of the recovery process. The membrane becomes impermeable to sodium once more and the sodium–potassium pumps restore polarisation by pumping out sodium ions. As a result, the axon returns to its resting potential.

Role of myelin

In order to switch between resting and action potentials, the axon membrane must be exposed to the extracellular environment from which it can access sodium and potassium ions. The myelin sheath insulates the axon and prevents this exposure, which serves two very important purposes.

First, the proximity of other neurons means that when the sodium ions flow into the axon to trigger the action potential, it would also trigger the action potential in neighbouring exposed axons. Myelin ensures that only one axon is exposed in any particular area, insulating the rest.

Second, the ripple of action potential is quite slow, particularly when the axon is metres long. By insulating most of the axon, the action potential must jump from one exposed node to the next, accelerating the transmission speed. This results in faster reaction times – a distinct advantage for a multicellular organism.

Transmission between neurons

Once the action potential has reached the axon terminal, it is necessary to use a different method to transfer the signal across the terminal membrane to the next cell. The tiny space (around 20 nm) between the axon terminal and its target is called the **synapse** or **synaptic cleft** (Figure 10.3.2). The terms **presynaptic neuron** and **postsynaptic neuron** differentiate between the neuron sending the signal and the one receiving it, respectively.

Signal transduction is the process by which a cell converts one type of signal to another. In this case, from electrical to chemical and then back to electrical.

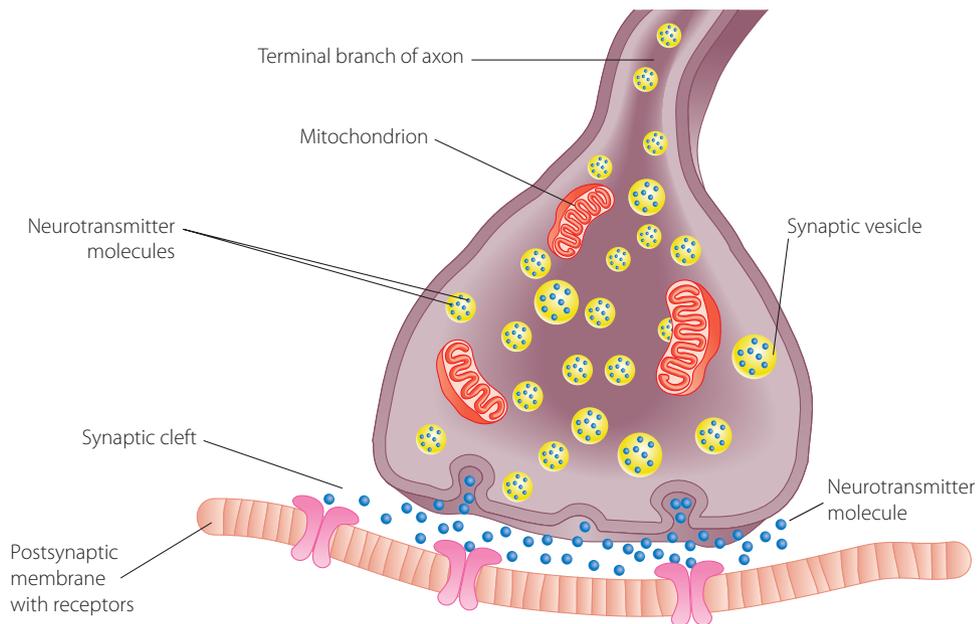


FIGURE 10.3.2 Neurons use neurotransmitters to cross the synapse, rather than touch each other directly.

Neurotransmitters

Neurotransmitters are chemical messengers, molecules that cross the synapse. They are stored in vesicles within the presynaptic neuron, ready for transmission of an impulse.

When the impulse arrives, it causes calcium ion channels in the cell membrane to open, resulting in an influx of calcium ions. These stimulate **exocytosis**, in which the **vesicles** fuse to the presynaptic membrane and release their neurotransmitters into the synapse. The neurotransmitters then diffuse across the synapse to bind with specific receptors in the postsynaptic membrane. This causes ion channels to open there, allowing sodium ions to move from the synapse into the postsynaptic neuron. If sufficient channels are opened to cause depolarisation, an action potential will be triggered.

Once the neurotransmitters have activated the channels, it is important that they do not continue their stimulation. Thus, excess neurotransmitters in the synaptic cleft are deactivated by enzymes and recycled back into the presynaptic neuron (Figure 10.3.3).

neurotransmitter
a hormone that is used by neurons to carry a signal across the synapse

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

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



10.3.2 What are neurotransmitters?

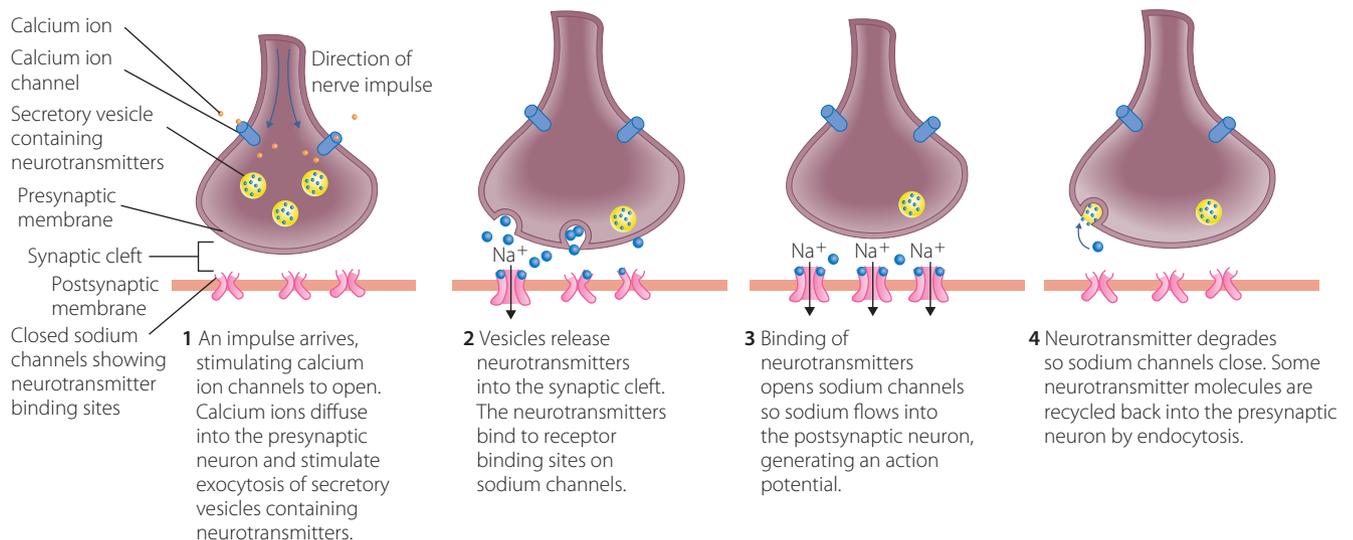


FIGURE 10.3.3 Signal transduction across the synapse

PRACTICAL ACTIVITY 10.3.1

Chicken nerve dissection

INTRODUCTION

Axons are extremely thin and can only be seen through an electron microscope. However, larger nerve fibres are often visible inside the main nerves of the body. Chickens share similar nerve patterning to humans, including ganglia and nerve fibres.

AIM

- To use dissecting equipment safely
- To visualise nerves and neurons

MATERIALS

- chicken leg (including thigh)
- light microscope
- microscope slides
- coverslips
- tweezers
- water dropper
- dissecting needle
- dissecting board or tray
- dissecting pins
- scalpel
- gloves
- lab coat



WHAT ARE THE RISKS IN DOING THIS EXPERIMENT?	HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?
Coverslips can break easily and can cut.	Take care with coverslips and do not push hard when placing them.
Scalpel and dissecting needle are sharp and can cut easily and deeply.	Take care with sharp objects and always use tweezers to hold the chicken while dissecting.
Raw chicken meat may contain pathogens.	Always wear gloves and a lab coat when handling the chicken.

PROCEDURE

Part A: Dissection

- 1 Put on your gloves and lab coat.
- 2 Rinse and pat the chicken leg dry and arrange it and your dissecting tools on the board or tray.
- 3 Using the scalpel and tweezers, cut the skin and peel it away from the muscle. You may need to cut the connective tissue in some places (Figure 10.3.4).
- 4 Insert your finger into an indentation between the muscle bundles in the lower leg (you may need to be quite firm to break the fascia (slimy clear lining)) and pull gently to separate them from each other but don't tear them from the bone (Figure 10.3.5).
- 5 Observe the muscle bundles and the strong white tendons holding each end of the muscle to the bone. Carefully cut the tendons of one muscle bundle and lift it away from the bone.
- 6 Between the bone and muscle, you should find a thinner, white nerve. If you cannot find it, choose a different muscle and try again. The nerves in the thigh should be thicker and easier to find.





FIGURE 10.3.4 Removing the skin from the chicken



FIGURE 10.3.5 Separating the muscle bundles

- 7 Draw a labelled diagram of your dissection.

Part B: Wet mount

- 8 Using the scalpel and tweezers, carefully remove a nerve from the chicken leg. Slice a small cross-section from one end.
- 9 Put the section of tissue onto a microscope slide. Try to avoid getting folds in it. Add one or two drops of water and using the dissecting needle, carefully lower the coverslip.
- 10 Examine the slide under low power, moving to higher magnifications. Draw what you see.
- 11 Repeat steps 9 and 10 with a longitudinal section of the nerve.

DISCUSSION

- 1 Explain why the nerves in the thigh are thicker and easier to see.
- 2 Compare and contrast the cross-section and longitudinal section of the nerve.
- 3 Discuss why the nerves are generally located between the muscle and bone.

CONCLUSION

Using your knowledge of nerves, relate the location and appearance of the nerve tissue to its function in the body.

SECTION REVIEW

10.3

REMEMBERING

- 1 Describe the structure of an axon terminal in a presynaptic neuron.
- 2 Describe the function of a myelin sheath.

UNDERSTANDING

- 3 Summarise what happens to sodium and potassium ions during the rising and falling phases of an action potential.
- 4 Compare and contrast signal transmission with signal transduction.
- 5 Create a flowchart of the steps required for:
 - a signal transmission along the axon
 - b signal transduction across the synapse.

APPLYING

- 6 Explain how sodium deficiency could be life-threatening.

CHAPTER REVIEW QUESTIONS

DETAIL QUESTIONS

- 1 List the sequence of neurons required to go from stimulus to response.
- 2 Make a simple annotated diagram to show how nerve impulses are transmitted:
 - a along the axon
 - b from presynaptic to postsynaptic neurons.

CATEGORY QUESTIONS

- 3 Describe the key features of neurons that distinguish them from other cells in the body.
- 4 Outline the features that you would look for to differentiate between sensory, interconnecting and motor neurons.
- 5 Compare and contrast the neural pathways of a conscious and a non-conscious action.

ELABORATION QUESTIONS

- 6 Ritalin is a common drug for the treatment of childhood ADHD (attention deficit hyperactivity disorder). Ritalin blocks dopamine channels in the presynaptic neuron, preventing the neurotransmitter from leaving the synapse. Use this and your knowledge of signal transduction to propose possible malfunctions in the nervous system that may cause ADHD symptoms.
- 7 Defibrillators administer strong electrical shocks to the chest. Suggest what these shocks do in the body in order to restore normal heart function.

EVIDENCE QUESTION

- 8 Give an example of a situation where a person with ADHD would be at a distinct advantage. Explain why you think so.
- 9 Find two reliable sources that support your response to Question 7.

END-OF-CHAPTER EXAM



End-of-chapter test

- 1 Which of the following statements applies to the transmission of nervous impulses in vertebrates?
 - A Myelinated nerve fibres usually transmit an impulse more slowly because the myelin interferes with the movement of ions across the membrane.
 - B Neurons make direct contact with other neurons, creating a pathway for electrical signals.
 - C Schwann cells create myelin and are found around the dendrites of a neuron.
 - D Interneurons relay the electrical impulses from sensory neurons to motor neurons.
- 2 Which of the following statements about the nervous system is correct?
 - A The central nervous system consists of the brain and its neurons.
 - B Interconnecting neurons are found in the CNS and connect sensory and motor neurons.
 - C The peripheral nervous system contains the spinal cord.
 - D A sensory neuron takes impulses from sensory receptors to motor neurons.
- 3 Which of the following is a type of neuron?
 - A Interconnecting
 - B Linking
 - C Slow-twitch
 - D Light
- 4 In sensory neurons, the soma is:
 - A the branching appendages on the cell body
 - B a cell body at the end of the axon
 - C a side bulge along the length of the axon
 - D the tightly wrapped cells shielding the axon.
- 5 The two phases of a nerve impulse are:
 - A resting potential and signal transmission
 - B action potential and signal transmission
 - C resting potential and signal transduction
 - D action potential and signal transduction.

- 6 Describe how the sodium–potassium pump works.
- 7 Explain two purposes of myelin, including the significance of conditions that degrade it.
- 8 Copy the graph from Figure 10.3.1 (page 163) and label it with the following terms: depolarisation, repolarisation, resting potential, action potential, recovery period and impulse arrival.
- 9 Botox is a toxin produced by the bacteria *Clostridium botulinum*. It acts as a neurotransmitter inhibitor. Eating food contaminated with botox causes death. Yet many people have botox injections to make them look younger. Draw an annotated diagram to demonstrate how botox disrupts nerve signalling pathways to relax facial muscles.
- 10 Use Figure 10.3.1 (page 163) and your knowledge of impulse transmission to outline two ways that the rhythm of a heartbeat could be disrupted.
- 11 Smooth muscles lining arteries control blood flow by responding to signals from two types of nerves. Stimulatory nerves cause them to contract, resulting in vasoconstriction, and inhibitory nerves cause them to relax, resulting in vasodilation. Decide which nerves would be more active in the brain and fingers of a person in a cold environment. Explain your choices.

11

HORMONAL HOMEOSTATIC CONTROL PATHWAYS

Introduction

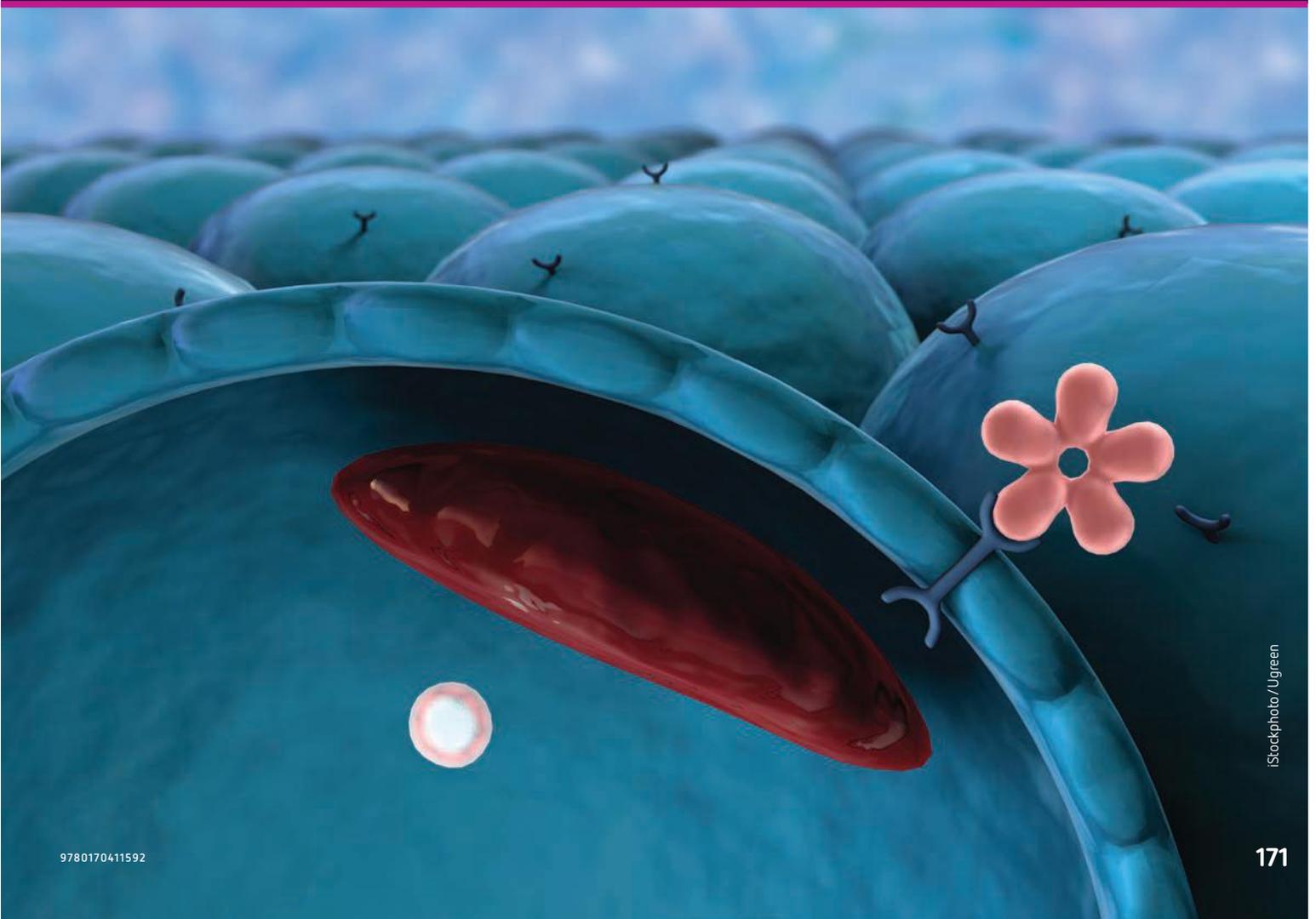
Not all changes in an organism's internal and external environment require an immediate response. Some responses take time or need to affect almost all of the body. Nerve impulses are both too fast and too local to be effective. In these cases, the body uses a second, slower pathway to produce a response – the endocrine system. Endocrine glands receive the response signal from the central nervous system (CNS) and release hormones directly into the bloodstream.

Stimulus questions

How do hormones cause their effects?

Why don't all cells respond the same way to a particular hormone?

How do hormones work?



11.1

Hormones as chemical messengers

hormone
a chemical produced by the body to prompt a response from specific cells

Hormones are chemicals produced by the body to prompt a response from specific cells. The human body produces more than 50 different hormones. Each hormone targets and activates a particular cell and causes a particular response. Some hormones and the responses they produce are shown in Table 11.1.1.

TABLE 11.1.1 Examples of human endocrine glands, hormones they secrete, and the responses they produce

ENDOCRINE GLAND	HORMONE SECRETED	TARGET TISSUE/ ORGAN	HOMEOSTATIC RESPONSE
Posterior pituitary	Antidiuretic hormone	Kidney	Stimulates reabsorption of water
Adrenal	Adrenaline	Kidneys, liver, blood vessels	Constricts blood vessels in kidney and liver; stimulates liver to release more glucose; prepares for 'fight or flight'
	Cortisol	Many tissues	Prevents excessive immune response
Thyroid	Thyroxine	Nearly all tissues	Increases metabolic rate; therefore, increases oxygen consumption and heat release
Pancreatic beta cells	Insulin	Most body cells	Lowers blood sugar level, increases glycogen storage by liver, stimulates protein synthesis
Pancreatic alpha cells	Glucagon	Liver	Stimulates conversion of glycogen to glucose and the release of glucose

endocrine system
the glands of the body that produce hormones

gland
an organ that secretes chemicals or proteins within the body or externally

Although only minute quantities of a hormone are produced, hormones have considerable impact. Some effects are temporary, such as when adrenaline signals the release of glucose and increased heartbeat in the fight or flight response. Regulatory mechanisms, such as those in foetal development, can have a longer effect.

Coordination of activities associated with the **endocrine system** (Figure 11.1.1) is often connected to the pituitary **gland**. The pituitary gland is known as the master gland because it produces many hormones that affect hormone production by other endocrine glands.

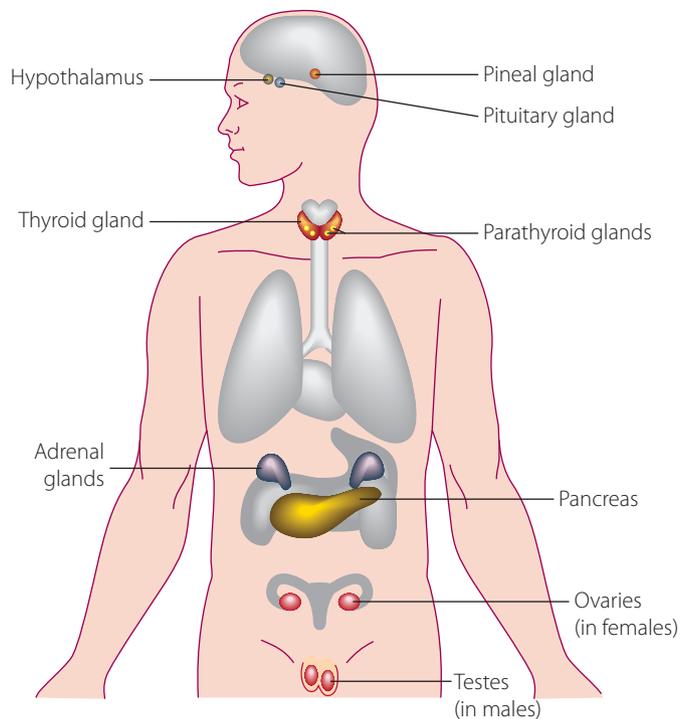


FIGURE 11.1.1 Humans have eight main endocrine glands.

Hormones and hormone-like substances occur in other organisms, including plants, and are essential to the regulation of a variety of activities. Female ring doves coo during courtship to stimulate the release of hormones that result in egg development. In plants, a light-sensitive hormone called auxin is responsible for plant growth towards light (phototropism) to maximise photosynthesis.

Types of hormones

Hormones are generally divided into two categories, water-soluble and fat-soluble (Figure 11.1.2). Water-soluble hormones (called **hydrophilic hormones**) are polar molecules derived from amino acids. They cannot pass through the cell membrane without assistance and usually bind to **receptors** on the outside of the cell. Fat-soluble hormones (called **hydrophobic hormones** or **steroids**) are non-polar molecules derived from cholesterol (with the exception of thyroxines, which are amine-based). These need a companion molecule to travel through the blood but can detach and pass through the cell membrane by themselves. They usually bind to receptors once inside the cell (Figure 11.1.2).

hydrophilic hormone

a hormone that is soluble in water and binds to extracellular receptors to initiate a response in that cell; for example, peptide and some amine hormones

receptor

a structure that detects or receives stimuli

hydrophobic hormone

a hormone that is insoluble in water and binds to intracellular receptors; for example, steroid and thyroid hormones

steroid a hydrophobic signal molecule produced from cholesterol

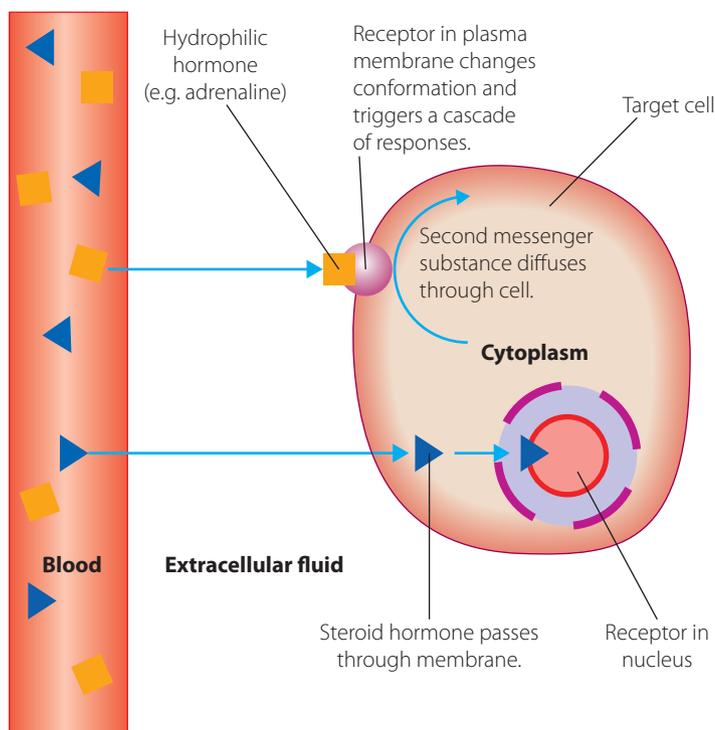


FIGURE 11.1.2 Water-soluble hydrophilic hormones bind to extracellular receptors to trigger a cascade of events inside the cell, resulting in a cellular response. Fat-soluble steroid hormones pass through the cell membranes to bind to intracellular receptors, leading to a change in gene expression.

Targeting specific cells

Only the cells in the body that express receptors for a particular hormone will respond to it (Figure 11.1.3). Without a receptor to bind to, the hormone will drift by the cells without any effect. In this way, a hormone such as ADH (antidiuretic hormone) can be secreted from the pituitary gland in the brain and travel the entire body without triggering its water-reabsorption effect until it reaches the kidney cells, where it can finally find its receptor.

INQUIRING FURTHER

The average adult's heart rate can range from 60 to 200 beats per minute, depending on fitness and activity. This means the hormones in your blood can do a full circuit of your body in as little as 25 seconds or as long as 90 seconds.

Arrange for someone to scare you at some point during the day. Count how long it takes for your heart to start racing from the effects of adrenaline released by your adrenal glands.

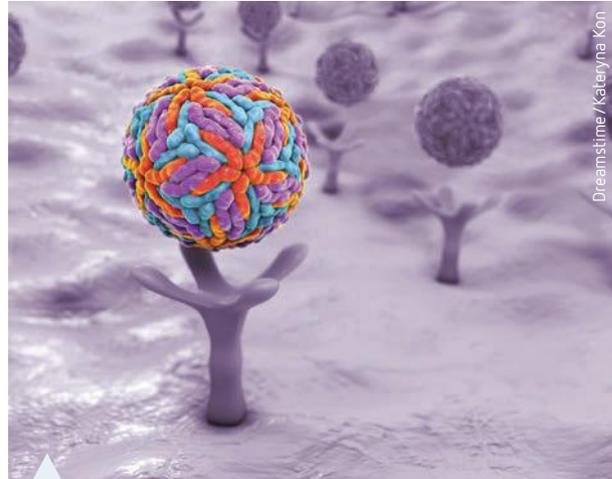


FIGURE 11.1.3 Hormones only bind to their specific receptor and thus, only affect cells that express their specific receptor.

SECTION REVIEW

11.1

REMEMBER

- 1 Define:
 - a hormones
 - b glands
 - c receptors.
- 2 Give two examples of a hormone, the gland that produces it and the target cells that it affects.

UNDERSTAND

- 3 Outline three key differences between water-soluble and fat-soluble hormones.
- 4 Explain why signalling molecules only have an effect on their target cells.

APPLY

- 5 When taking hormones for medical reasons, fat-soluble hormones are more dangerous in high doses than water-soluble hormones. Suggest why water-soluble hormones are less likely to cause overdose.

11.2

Upregulation and downregulation of cellular processes

Throughout its life, each cell sends and receives signals that regulate and coordinate many cellular processes for the benefit of the whole organism. These processes control whether a cell should move or stay in **stasis**, what molecules and structures to build and which ones to digest, whether to grow, what to engulf, and what to secrete.

Hormone sensitivity

A cell's ability to carry out cellular processes depends on how well it responds to signals. For example, a cell in a high-turnover tissue such as the lining of the mouth will need to be very sensitive to the hormones responsible for cell division and cell death. A cell in a low-turnover tissue such as skeletal muscle will need to be less sensitive to these and more sensitive to hormones responsible for metabolism.

A cell's sensitivity to any particular hormone is determined by the number of receptors that it expresses for that hormone. More receptors make a cell more sensitive and responsive than fewer receptors. However, there are many hormones for which a cell needs to produce receptors. Most cells only permanently express a small number of each type of receptor and when the hormone is detected, the cell quickly produces many more receptors to become more sensitive. This type of response is called **upregulation** (Figure 11.2.1), while a response that dampens a cellular process is called **downregulation**.

Therefore, a hormone actually activates two pathways when it binds to its receptor – the pathway that triggers production of its own receptor, and the pathway it is signalling for.

stasis
showing little or no change over time

upregulation
when a cell is prompted to produce more of a particular cellular component, such as enzymes or receptors

downregulation
when a cell is prompted to produce less of a particular cellular component, such as enzymes or receptors

INQUIRING FURTHER

Upregulation of serotonin receptors occurs in Parkinson's disease. Downregulation of insulin receptors is a contributor to insulin resistance, often resulting in type 2 diabetes.

Research other examples of upregulation and downregulation of hormone receptors in humans.



11.2.1 Parkinson's disease

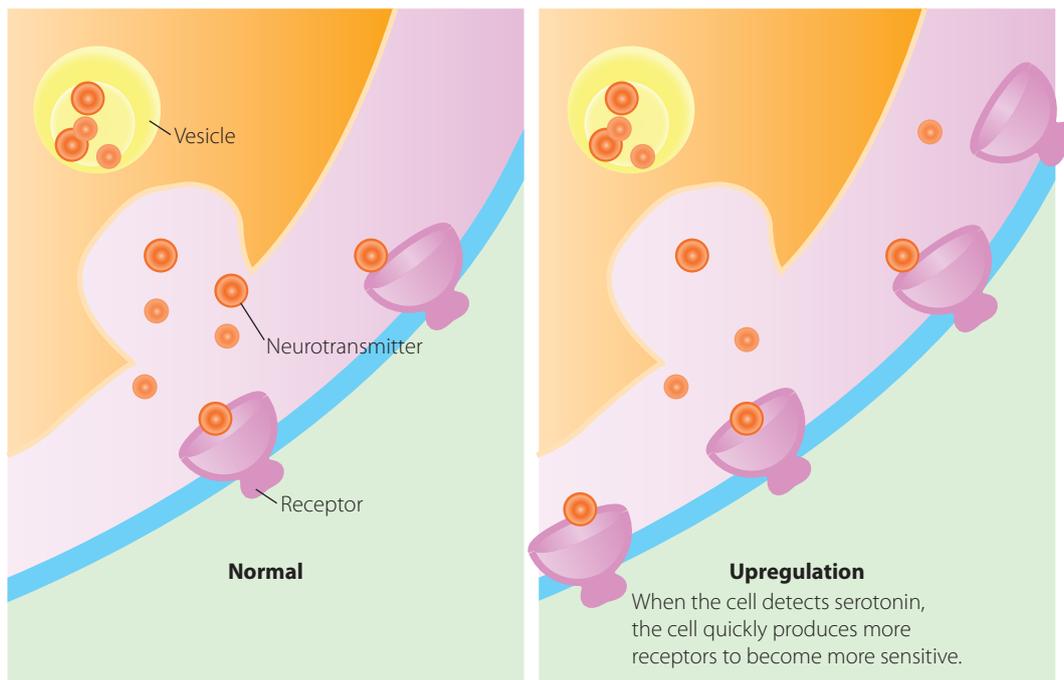


FIGURE 11.2.1 Upregulation of serotonin receptors occurs in Huntington's disease, which is an inherited disease that causes the progressive breakdown of nerve cells in the brain. It is possible that, in order to compensate for decreased levels of serotonin, the brain increases the number of receptors for that specific neurotransmitter.

REMEMBER

- 1 Describe the two pathways that a hormone triggers in its target cell.
- 2 Explain what is meant by cell sensitivity.

UNDERSTAND

- 3 Explain the difference between upregulation and downregulation.
- 4 Give one example of each of a body tissue that would require mitosis to be upregulated and one that would require mitosis to be downregulated.

11.3 Receptor binding

When a signal molecule binds to its receptor protein, the receptor changes shape and becomes activated. The activated receptor alters the activity of intracellular proteins, setting off an intracellular signalling cascade that transmits the message through the cell to effector proteins, which are stimulated to elicit a response. This process is called signal transduction (Figure 11.3.1).

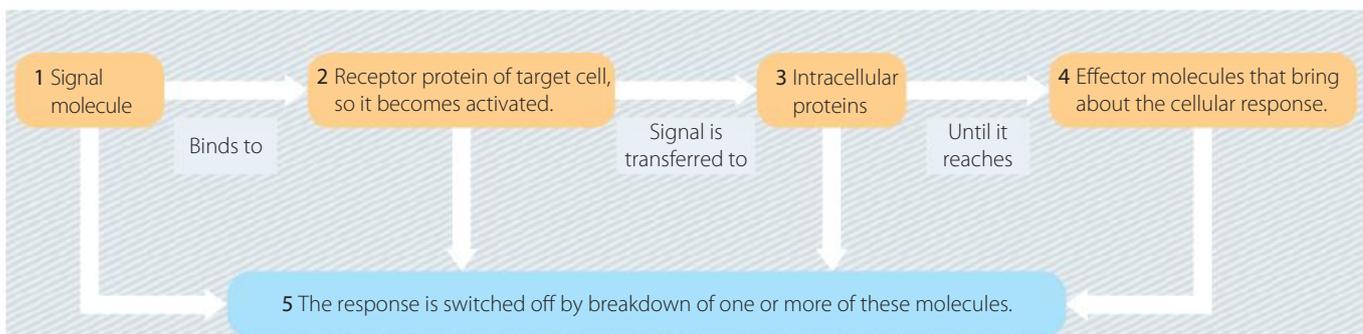


FIGURE 11.3.1 The principles of signal transduction allow cells to respond to hormones.

transcription factor

a regulatory protein whose function is to activate or inhibit transcription of DNA by binding to specific DNA sequences

Hydrophobic hormones bind to intracellular receptors

Hydrophobic, fat-soluble hormones, such as steroids and thyroxines, pass through cell membranes and bind to intracellular receptors in the cytoplasm or nucleus (Figure 11.3.2). These receptors are often **transcription factors**, which become active only when the hormone is bound, and can then bind to DNA and regulate gene expression.

One hormone, many effects

Cortisol, a steroid hormone, is produced by the adrenal glands. It is often referred to as the ‘stress hormone’ because it is produced in response to stressful situations, such as during starvation. Although its primary role appears to be in protein and fat metabolism, it has a wide range of effects in a wide range of target cells, including maintenance of blood pressure and coordination of immune responses. A single hormone is able to have such a diverse range of effects because of the variety of receptors it can bind to in the cell.

In liver cells, cortisol binds to a transcription factor that regulates the expression of genes coding for enzymes that control biochemical pathways for building glucose from amino acids and glycerol. Binding changes the **conformation** of the transcription factor, so that it can bind to its specific DNA region and switch on gene expression. The appropriate enzymes are then produced and the pathway is upregulated.

conformation

the shape of a molecule that is determined by the three-dimensional arrangement of its atoms and bonds; important for molecular functioning

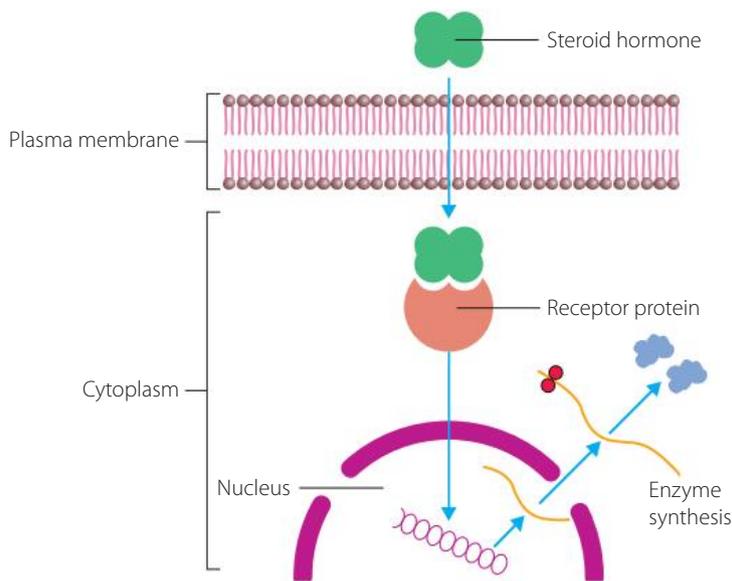


FIGURE 11.3.2

The steroid hormone cortisol binds to a transcription factor in liver cells, activating gene expression. The result is the production of a set of proteins needed to make glucose from amino acids and glycerol.

While cortisol switches on one particular set of genes in the liver, it binds to different transcription factors in adipose (fat) tissue. Therefore, a different set of genes is switched on, a different set of enzymes is made and a different biochemical pathway is upregulated. As a result, the response of adipose cells is different from the response of liver cells, even though the two types of cell accept the same hormone.

Hydrophilic hormones bind to extracellular receptors

Water-soluble hormones are signals that cannot pass across the cell membrane owing to their charge and size. Instead, they bind to extracellular receptors that are embedded in the cell membrane.

Extracellular receptors

Extracellular receptors are generally grouped into three categories on the basis of how they transfer a message into a cell.

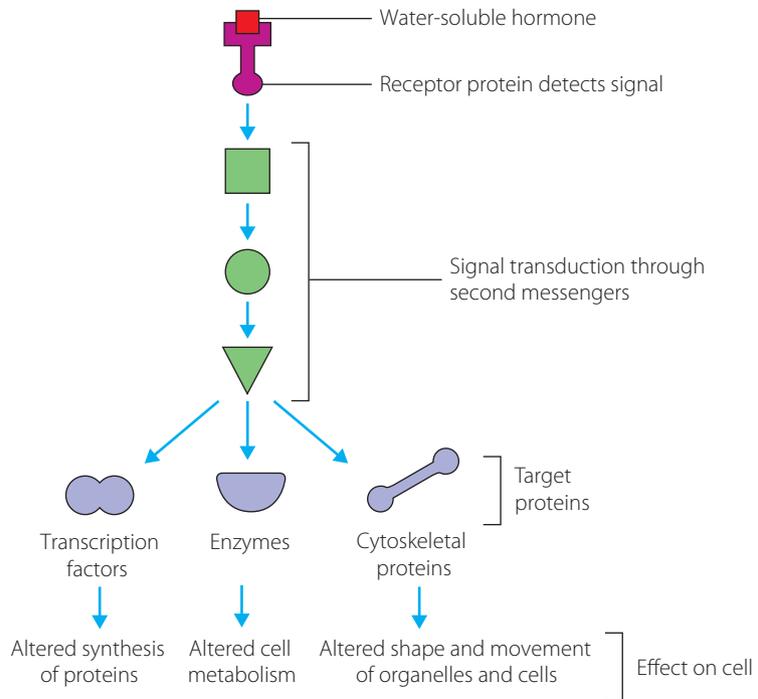
- 1 Ion channel receptors: When a hormone binds to an ion channel protein, the channel opens so that ions can be transported across the cell membrane. This response is fast because the cell responds quickly to changes in ion concentrations.
- 2 G protein-coupled receptors: These receptors have a protein called a **G protein** attached to them on the inside of the cell membrane. When a hormone binds, the receptor changes conformation and the G protein is released to activate other proteins in the signal transduction pathway.
- 3 Tyrosine kinase receptors: These receptors are inactivated enzymes embedded in the cell membrane. Binding of a signal activates these enzymes by changing their conformation, usually by removing a phosphate group from an adenosine triphosphate (ATP) molecule and adding it onto a protein in a process called **phosphorylation**. Protein phosphorylation switches on signal transduction pathways that ultimately lead to changes in gene expression inside the cell.

G protein
a protein that relays signals from a cell membrane G protein-coupled receptor to other signal transduction proteins inside the cell

phosphorylation
the addition of a phosphate group to a protein or other organic molecule

Activating these receptors triggers a cascade of modifications to molecules and proteins, activating or inactivating them (Figure 11.3.3).

FIGURE 11.3.3
Water-soluble hormones cannot pass freely through the cell membrane and so must activate signal transduction from outside the cell.



second messenger
a small molecule that relays a signal from receptors on the cell surface to target molecules inside a cell

Second messengers

Signal transduction in cells occurs through the use of **second messengers**, which are activated when the initial hormone binds to its receptor. Second messengers often amplify the signal by activating many molecules inside the cell, rather than just one each (Figure 11.3.4). This means that a single hormone molecule can have a large effect on a cell through its second messengers.

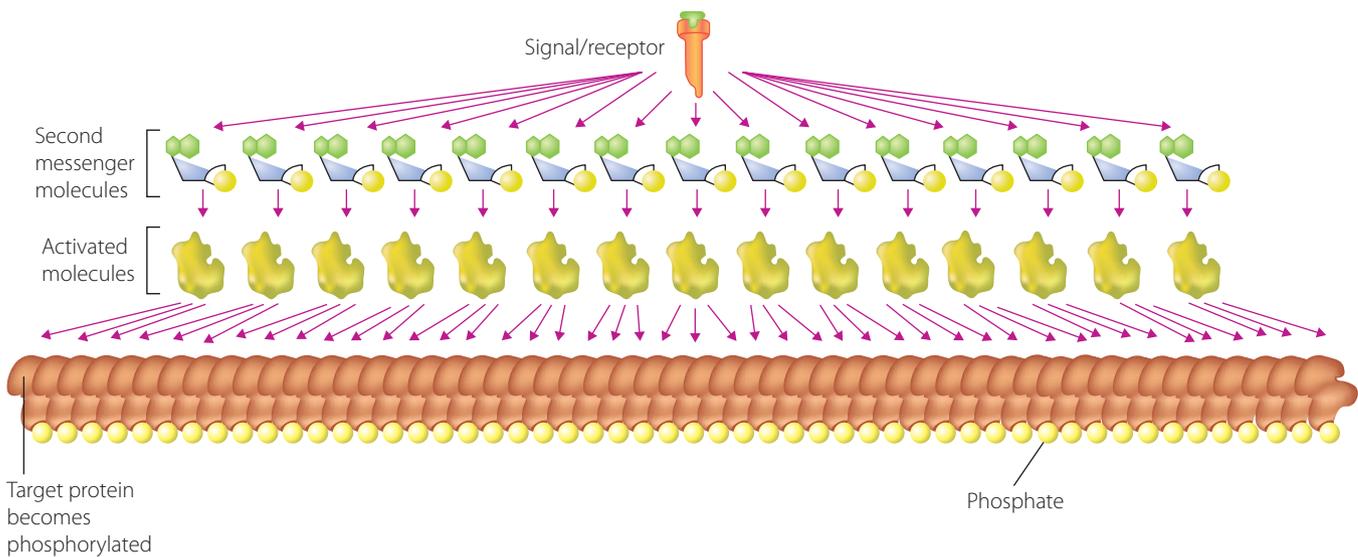


FIGURE 11.3.4 A tiny amount of hormone can have a massive effect in the body through signal amplification.

Effector proteins

After the signal has been transduced and amplified, it will finally reach the target effector proteins. These will be either enzymes that will stimulate cell processes when activated, or transcription factors that will upregulate or downregulate gene expression in the cell.

INQUIRING FURTHER

INCREASING MILK YIELD IN DAIRY CATTLE

Somatotropin (ST) is a growth hormone secreted by the pituitary gland of all mammals. It stimulates liver cells to produce and secrete a hormone called insulin-like growth factor (IGF-1). Circulating IGF-1 binds to receptors in target cells, activating signalling pathways that promote cell growth and proliferation, and inhibit cell death. In the late 1980s, a synthetic version of bovine somatotropin (BST) was produced. This growth hormone, named rBST, is identical to the natural growth hormone found in cows. Injecting dairy cattle with rBST inhibits natural cell death of milk-producing cells and thus more milk is produced over an extended time.

Amid much controversy, the drug was approved by the US Food and Drug Administration (FDA) for use by dairy farmers in 1993. rBST is not approved for use in Australia, the United Kingdom, Canada and the European Union as there are some health and animal welfare concerns.

First, it is not known if rBST affects the health of consumers of milk. The main health concern is that cows treated with rBST have elevated levels of IGF-1 in their milk. IGF-1 survives pasteurisation and digestion, so it can enter the human circulatory system. There were concerns that elevated IGF-1 concentrations in milk could promote cancer in humans. To date, scientific studies have not found a correlation between drinking the milk of rBST-treated cows and the incidence of cancer.

Second, there were concerns about animal welfare. Increasing milk yield in dairy cattle can lead to increased incidence of mastitis, a bacterial infection of the udder requiring treatment with antibiotics. Cattle treated with rBST can also suffer injection-site reactions, and are more likely to experience lameness and have reproductive problems. The results of scientific studies into these concerns are conflicting.

Many argue that rBST would allow farmers to produce more milk or produce the same amount of milk from fewer cows. This would lower production costs and increase profit. This could also have a positive effect on the environment because fewer cows means less methane gas enters the atmosphere. Recent studies claim that rBST-treated cattle also produce less gas.

- 1 Discuss concerns about producing milk with elevated levels of IGF-1 even though scientific studies have not revealed a correlation between drinking this milk and adverse health effects.
- 2 Some companies in the US started to label their milk as BST-free. Discuss why this labelling is misleading and why it was banned by the FDA.
- 3 Would you approve the use of rBST in Australia? Construct a table to evaluate the risks and benefits from the perspective of dairy cattle, consumers, economics and the environment, and then make your decision.



FIGURE 11.3.5 International debate has raged for more than a decade as we try to decide whether synthetic growth hormone should be used to increase milk yield in dairy cattle. Its use is currently banned in Australia.

- 11.3.1 Australian Government review of Elanco Posilac
- 11.3.2 FDA
- 11.3.3 Bovine somatotropin (BST)

SECTION REVIEW

11.3

REMEMBER

- 1 List the steps of signal transduction for water-soluble hormones.
- 2 Briefly describe the three types of extracellular receptor.

UNDERSTAND

- 3 Explain why fat-soluble hormones don't require signal transduction.
- 4 Outline signal amplification.
- 5 Explain how hormones can have different effects in different cells.

APPLY

- 6 High levels of cortisol are produced in response to stress. Given what cortisol does in the body, describe the effects that continued exposure to stressful situations would have on a person's health.

CHAPTER REVIEW QUESTIONS

DETAIL QUESTIONS

- 1 List the eight endocrine glands of the human body.
- 2 Outline the relationships between glands, hormones, receptors and target cells.
- 3 Define:
 - a upregulation
 - b downregulation
 - c signal transduction.

CATEGORY QUESTIONS

- 4 Compare and contrast water-soluble and fat-soluble hormones in terms of structure, properties and signal mechanisms.
- 5 Give two examples of hormones that have different effects in different body tissues.

ELABORATION QUESTIONS

- 6 Explain how only a tiny amount of a single hormone can have wide-ranging effects on the body.
- 7 Anabolic steroids are a serious problem in competitive sports. The most commonly abused hormones are structurally similar to testosterone. Construct an argument against the use of anabolic steroids, based on your knowledge of testosterone's effects.

EVIDENCE QUESTIONS

- 8 Summarise the findings of two scientific studies that support your argument in Question 7.
- 9 Explain why someone might consider it worthwhile to use steroids in sport. How would you respond to them?

- Upregulation of a receptor is:
 - starting to degrade it
 - a tightening of control over it
 - it binding to a hormone
 - an increase in its production.
- In general, fat-soluble hormones are:
 - external binders
 - made from amines
 - heavily ring-structured
 - hydrophilic.
- Which of the following is not a phase of hormonal signal transduction?
 - Hormone binds to receptor.
 - Neurotransmitters cross the synapse.
 - Second messengers amplify signal.
 - Receptor activates second messengers.
- Outline why signalling molecules can only exert an effect on target cells.
- Describe three major differences between water-soluble and fat-soluble hormones.
- How does a hormone binding externally effect change in the cell?
- Explain the significance of signal amplification.
- Outline the arguments for and against a cell permanently expressing a large number of receptors for each hormone.
- Explain why an organism might need an endocrine system as well as a nervous system.
- Use Figure 11.4.1 to construct a stimulus–response model to represent the chain of events that occur at the cellular level when ADH binds to receptors in a kidney cell.

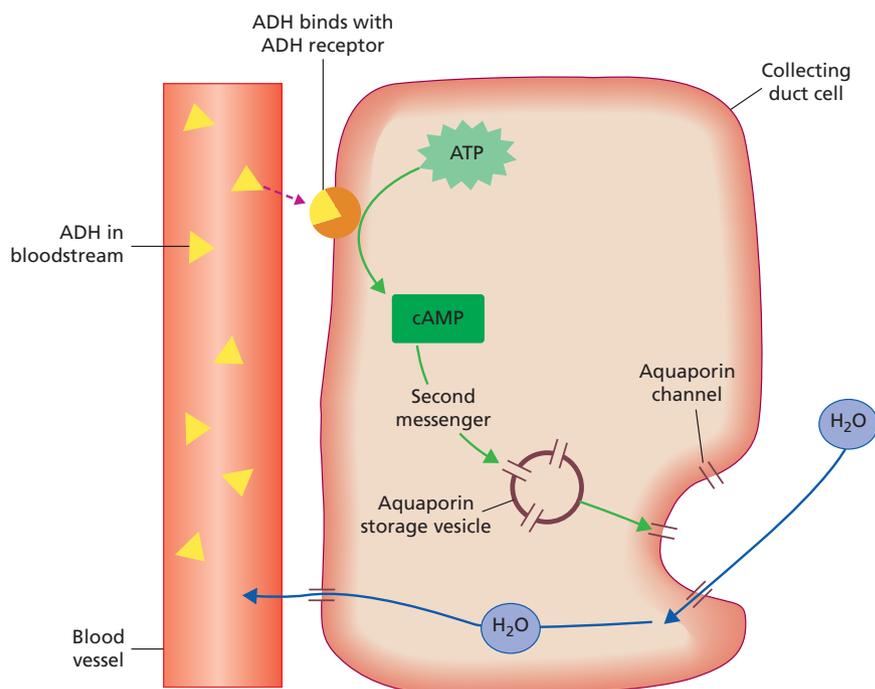


FIGURE 11.4.1 Antidiuretic hormone (ADH) stimulates a kidney cell to reabsorb water.

12

THERMOREGULATION

Introduction

The temperature on race day is important to a marathon runner because their muscles generate heat. On a hot day, the athlete's body needs to lose heat at a greater rate than when they are running on a cool day or at rest. Under normal conditions, such as at rest or doing routine tasks, the body's systems work together to maintain heat balance. Under extreme conditions, such as running on a very hot day, the body's temperature control mechanisms may be unable to cope. If the body's core temperature rises above a critical point, the conditions in the body's internal environment become intolerable. This could potentially have fatal consequences. This chapter explores the structural features, behavioural responses and physiological and homeostatic mechanisms that aid organisms to maintain a relatively constant internal temperature.

Stimulus questions

How do structural features contribute to control heat exchange and metabolic activity in endotherms?

How do behavioural responses contribute to control heat exchange and metabolic activity in endotherms?

How do physiological mechanisms contribute to control heat exchange and metabolic activity in endotherms?

How do homeostatic mechanisms contribute to control heat exchange and metabolic activity in endotherms?



12.1 Balancing heat loss and gain

Different animals have slightly different internal core temperatures. At these temperatures, their enzymes work efficiently. If internal temperatures rise above the set point, enzymes become less efficient. Enzymes will denature if the temperature rises too much. Metabolic processes fail and the individual suffers from **hyperthermia**. Conversely, if body temperatures fall, enzyme function slows significantly and the individual suffers from **hypothermia**.

Endotherms are animals that generate most of their heat by internal metabolism. Endotherms do not rely solely on external sources of heat to maintain their body temperature. Endotherms living in hot environments need to reduce heat gain and increase heat loss. In cool environments, the problem is how to increase heat gain and reduce heat loss. Apart from homeostatic mechanisms that involve the physiology of the animal, behaviours and structures can also contribute to maintaining a relatively stable body temperature. Thermoregulation is the process by which animals maintain their body temperature within a normal range. The principle of thermoregulation is maintaining a rate of heat gain that equals the rate of heat loss.

Table 12.1.1 shows various mechanisms a mammal uses to maintain its heat balance. A number of thermoregulatory adaptations will be explored in the next section.

hyperthermia
a state in which the internal temperature rises above the set point

hypothermia
a state in which the internal temperature drops below the set point

endotherm
an animal that retains heat generated by metabolic activity

TABLE 12.1.1 Mechanisms of controlling body temperature in a mammal

STRUCTURAL FEATURES	BEHAVIOURAL RESPONSES	PHYSIOLOGICAL MECHANISMS	HOMEOSTATIC MECHANISMS
Insulation Brown adipose tissue Shape and size	Changing locations Huddling Torpor	Vasomotor control Evaporative heat loss Counter-current heat exchange Thermogenesis	Hormone negative feedback

12.1.1 Hyperthermia
12.1.2 Hypothermia

SECTION REVIEW

12.1

REMEMBERING

- Define:
 - thermoregulation
 - endotherm
 - hypothermia
 - hyperthermia.
- Describe the problems faced by endotherms living at low temperatures in order to maintain body temperature. Compare these with endotherms living at high temperatures.

UNDERSTANDING

- Identify if the following statements are correct or incorrect and explain why.
 - If internal temperatures rise above the set point, enzyme efficiency increases.
 - When the temperature becomes too high, enzymes denature.
 - Hypothermia occurs when the body's enzymes significantly slow down.

12.2 Structural features of endotherms

Insulation

The feathers of mutton birds and the fur of polar bears (*Ursus maritimus*) aid thermoregulation by trapping an insulating layer of air close to the skin. A polar bear is so well insulated that virtually no heat escapes to the environment. The emperor penguin is also well insulated by several layers of scale-like feathers, and it takes a strong wind to ruffle them. Although they don't have feathers under their feet, emperor penguins are able to stand on ice for long periods (Figure 12.2.1). In hot climates, fur can insulate animals from radiant heat or hot air around them. For example, the hair on the top of the camel's hump reflects heat.

Variation in fur thickness and periods of moulting are other structural adaptations that assist thermoregulation in challenging environmental conditions.

FIGURE 12.2.1
Emperor penguins (*Aptenodytes forsteri*) have physiological and behavioural adaptations to survive in the freezing Antarctic temperatures.



Brown adipose tissue

Unlike other bears, which hibernate, the polar bear actively moves about throughout the Arctic winter. The outermost layer of its coat consists of coarse, hollow guard hairs that shed water when the bear shakes itself after swimming. This behaviour helps keep the body from becoming chilled. The thick, soft underhair is a heat-trapping layer. Beneath the skin is a layer of brown adipose tissue (brown fat), often about 11.5 cm thick, that insulates and helps generate metabolic heat.

Brown adipose tissue is richly endowed with blood vessels and mitochondria (Figure 12.2.2). The high number of mitochondria per cell is what gives brown fat its characteristic colour and increased heat output. The controlled flow of hydrogen ions in the mitochondria is used to generate heat, instead of adenosine triphosphate (ATP).

Hibernating mammals have high levels of brown fat and some mammals also have brown adipose tissue in their neck and between their shoulders. This tissue is specialised for rapid heat production. In human infants, brown adipose tissue makes up about 5% of total body weight. Newborns do not shiver in the cold and are poorly insulated. Brown adipose tissue is a valuable adaptation that generates heat when babies are cold. The brown adipose tissue gradually reduces with age.

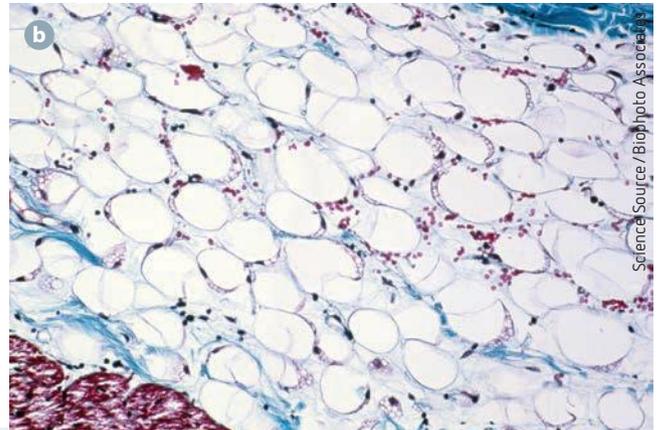
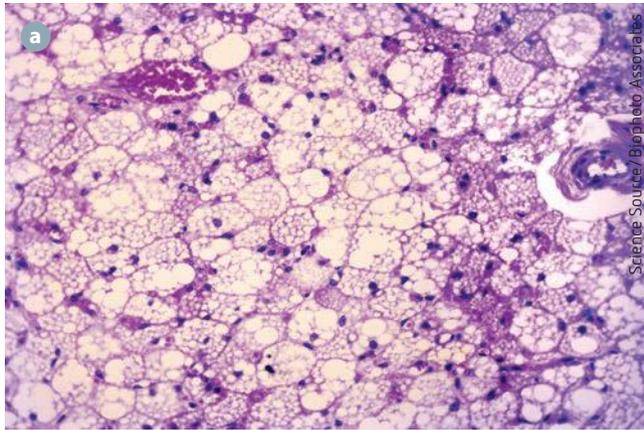


FIGURE 12.2.2
(a) Brown adipose tissue has more mitochondria per cell than **(b)** white adipose tissue.

Shape and size

The shape of an organism helps to maintain homeostasis and internal temperature. Adaptations that reduce the surface-area-to-volume ratio reduce heat loss. For example, some bird species living in the cooler environment of Tasmania need to retain heat. They tend to be larger than birds on the warmer mainland where heat gain is more of a problem. The ears and limbs of Arctic foxes are more rounded than those of their relatives elsewhere (Figure 12.2.3).



FIGURE 12.2.3 Ear shape and size differ between **(a)** the Arctic fox and its relatives **(b)** the red fox and **(c)** the fennec fox.

SECTION REVIEW

12.2

REMEMBERING

- 1 Describe three structural features an endotherm has to regulate temperature.

UNDERSTANDING

- 2 Explain how the shape of an organism aids thermoregulation.
- 3 Compare the composition of brown adipose tissue with the composition of white adipose tissue. Explain why brown adipose tissue generates more heat than white adipose tissue.

APPLYING

- 4 Referring to Figure 12.2.3, account for the differences shown in the size and shape of the ears of different species of fox.

12.3 Behavioural responses

As well as physical adaptations to heat and water loss, animals and birds also have behavioural responses. To reduce heat gain, dingoes, birds and rock wallabies normally shelter from high temperatures, only emerging to feed in the relative cool of dusk and dawn. Various wallabies and kangaroos lick their wrists, where the blood vessels form a dense network close to the surface. The saliva has a cooling effect, even though licking means the loss of precious water.

Huddling

To reduce heat loss, emperor penguins survive in the freezing Antarctic temperatures by huddling together (Figure 12.2.1, page 184). This type of behaviour reduces the group's overall surface-area-to-volume ratio. The penguins move around within the huddle to prevent any individual from being exposed to the harsh environment for an extended period of time.

In 2009, François Brischoux and colleagues from Australia proposed a new form of thermoregulation. **Kleptothermy** is the term they proposed to describe a form of thermoregulation in which an animal shares the warmth of another animal. Its most common form is huddling. In endotherms, the body heat of one animal in a cool environment is used to maintain body temperature in another animal at a higher and more stable level than would be possible in the environment of an individual.

Huddling reduces energy expenditure. The amount of energy saved depends on a number of factors such as the number and density of individuals in the huddle and the temperature of the surroundings.

Shutting down in extreme conditions

Some animals respond to environmental conditions by slowing their metabolic processes and reducing their body temperature, entering what is known as **torpor**. Torpor is a state of decreased activity and metabolism that allows animals to survive unfavourable conditions and/or conserve energy. Torpor results in reduction of body temperature and inactivity typically lasting a few hours. Many Australian carnivorous marsupials undergo daily torpor. The Kowari or brushy-tailed marsupial rat (*Dasyuroides byrnei*) is a carnivorous marsupial that lives in Queensland. Kowari shelter in burrows during the day

and are capable of entering torpor when required. This species is listed as vulnerable by Queensland's Department of Environment and Heritage Protection.

Sometimes behaviours and physical features are inadequate to stabilise temperature. At particular external temperatures, the metabolic rate of an animal begins to rise, increasing heat output. The external temperature at which the metabolic rate begins to rise is the **lower critical temperature**, which varies according to species (Figure 12.3.1). The increase in metabolic activity requires a supply of energy that for some animals proves difficult if food is scarce.

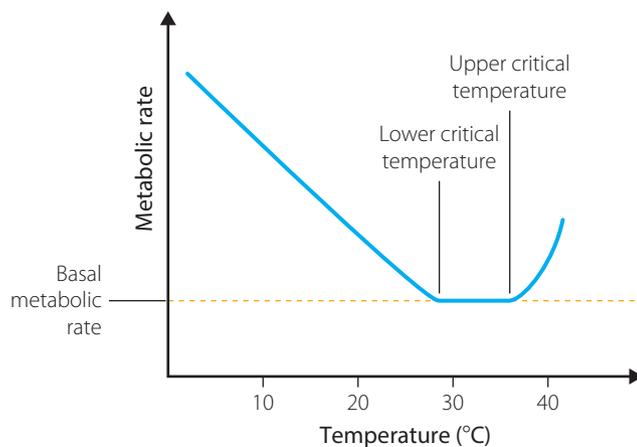


FIGURE 12.3.1 The effect of environmental temperature on the metabolic rate of a generalised mammal

12.3.1 Kleptothermy

kleptothermy

a form of thermoregulation in which an animal shares in the metabolic thermogenesis of another animal; its most common form is huddling

torpor

a state of decreased physiological activity, usually by a reduced body temperature and metabolic rate

lower critical temperature

the external temperature at which metabolic activity begins to rise, thereby increasing the output of heat

Under very cold conditions, the increase in metabolic rate may be insufficient to maintain body temperature within tolerance limits. Many animals in these situations hibernate, a long-term version of torpor. During **hibernation**, the metabolic rate falls to a level that just sustains life; the set point is lowered considerably – an excellent mechanism for conserving energy (Figure 12.3.2).

hibernation
a period of dormancy over long periods of cold conditions

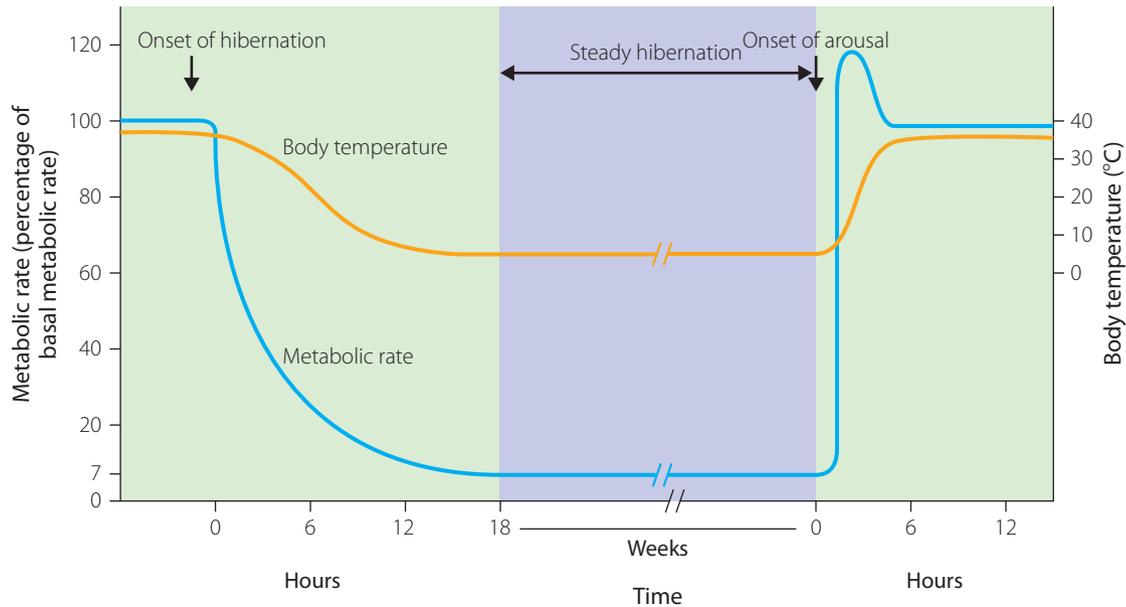


FIGURE 12.3.2 Metabolic rate and body temperature of a ground squirrel before, during and after hibernation

The **upper critical temperature** is the external temperature at which the body's cooling mechanisms fail and the metabolic rate increases with the rise in external temperature.

upper critical temperature
the temperature at which the body's cooling mechanisms fail to keep the body temperature stable and the metabolic rate increases with rise in external temperature

At high temperatures and very dry conditions, some animals survive by reducing their body temperature, energy expenditure and water loss. This kind of seasonal dormancy is known as **aestivation**. It is similar to hibernation because it involves long-term (weeks or months) inactivity and reduced metabolic rate. In general, aestivation appears to be a fairly 'light' dormancy involving no physiological changes that cannot be very rapidly reversed. The garden snail retreats into its shell and seals itself off; some earthworms coil into balls wrapped in mucus that dries out. Lungfish burrow in mud that hardens, and they remain there until the next rainy season some months later.

aestivation
dormancy in some animals during periods of drought

Torpor, hibernation and aestivation are common features of desert life.

SECTION REVIEW

12.3

REMEMBERING

- 1 Explain the difference between lower and upper critical temperature.

UNDERSTANDING

- 2 Explain how huddling reduces heat loss.
- 3 Identify the difference between torpor, hibernation and aestivation.
- 4 Identify if the following statements are correct or incorrect and explain why.
 - a Kleptothermy is an example of torpor.
 - b Some animals hibernate when conditions are very cold.

12.4 Physiological mechanisms

Generally, on a hot day a person's skin will look redder and feel warm and the person may feel thirsty. On a cold day, the person's skin may look pale and feel cold and they may start shivering. These are all physiological responses.

Vasomotor control

vasodilation
dilation (widening) of blood vessels, particularly arterioles

vasoconstriction
the constriction of blood vessels by the surrounding smooth muscle cells, which increases blood pressure and redirects blood flow away from the constricted vessel

counter-current
a current that flows in the opposite direction to another current

thermogenesis
the process of heat production in organisms

The amount of blood flow near the surface of the body alters heat flow between the external environment and the body's interior. In response to hot conditions, nerve impulses stimulate the arterioles in skin to dilate (**vasodilation**), which allows a lot of blood to flow close to the skin's surface, warming it and letting heat escape through the skin. Exposing a large surface area to the environment allows heat to escape the body. As a consequence of increased blood flow near the body surface, the skin looks redder and feels warm.

The reverse response happens under cold conditions. Nerve impulses cause skin arterioles to constrict. This process of **vasoconstriction** decreases the diameter of the blood vessels. Blood flow and heat transfer is decreased. The skin looks paler and feels cooler.

Evaporative heat loss

On hot days, sweat glands open to release water and salt onto the skin. Water absorbs considerable heat when it evaporates. 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. Under 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.

Panting and licking the skin or fur are other adaptations animals use to increase heat loss through evaporation. Panting is shallow, rapid breathing that increases evaporative water loss from the respiratory tract. The body cools when water evaporates from the nasal cavity, mouth and tongue.

Counter-current heat exchange

Aquatic birds and mammals have a very effective system of keeping their extremities warm – the **counter-current** heat exchange. Arteries and veins are located close to each other in the heat exchanger. Blood travelling in the arteries to the foot or fin warms the blood returning to the body in the adjacent veins. The outgoing blood to the extremity is cooled in the process but not enough to affect cell activities. As the temperature gradient between the extremity and the surroundings is reduced, heat loss is minimised (Figure 12.4.1). Heat in arteries coming from the body core is transferred directly to the returning blood in the veins rather than being lost to the environment.

Thermogenesis

While many responses to low temperatures conserve heat, some types of responses generate heat (**thermogenesis**). All metabolic processes produce heat. Endotherms have the ability to vary heat production. One way to increase thermogenesis is through shivering.

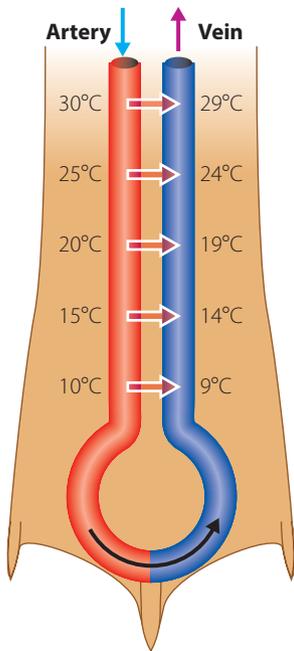


FIGURE 12.4.1 A model of counter-current heat exchange in the foot of an emperor penguin

This response may occur when an endotherm is exposed to the cold. Rhythmic tremors begin as skeletal muscles contract, 10–20 times a second. Shivering increases heat production by several times. However, it has a high energy cost and is a short-term adaptation.

Some mammals increase thermogenesis by causing mitochondria to increase their metabolic activity. This process, called **non-shivering thermogenesis**, takes place in skeletal muscle and other tissues throughout the body but particularly in brown adipose tissue.

non-shivering thermogenesis

an increase in the cellular metabolic rate in skeletal muscle and other tissues to increase heat production

SECTION REVIEW

12.4

REMEMBERING

- 1 Describe three physiological responses to a drop in body temperature.
- 2 Describe two physiological responses to an increase in body temperature.

UNDERSTANDING

- 3 Explain how vasodilation helps to maintain internal temperature.
- 4 Explain how counter-current heat exchange helps to maintain internal temperature.

APPLYING

- 5 Suggest why an individual feels cooler on a hot windy day than on a hot humid day.
- 6 Penguins in the Antarctic endure winter temperatures as low as -70°C . The bottoms of their webbed feet are in constant contact with snow and ice but remain free from frostbite. Use a diagram to illustrate how they achieve this.

12.5 Homeostatic mechanisms

Thermoregulation is an example of a homeostatic system involving negative feedback.

The **hypothalamus** is 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. Conversely, if the temperature of the blood is below normal, the centre initiates the processes that warm the body.

Thyroid hormones

One response by the hypothalamus at low temperatures is to release a hormone, **thyrotropin-releasing hormone (TRH)**, which activates the anterior pituitary gland to release **thyroid-stimulating hormone (TSH)**. TSH stimulates the **thyroid gland** to secrete the hormone **thyroxine** into the blood. Thyroxine increases the metabolic rate, which increases heat production, especially in the liver.

When temperatures start to increase again, the hypothalamus responds by reducing the release of TSH by the anterior pituitary gland so less thyroxine is released from the thyroid gland. Thyroxine itself has an inhibitory effect on the anterior pituitary gland, which responds by secreting less TSH when thyroxine levels are high (Figure 12.5.1).

hypothalamus

a region of the forebrain that coordinates the endocrine and nervous systems; it secretes hormones and releasing factors that regulate the anterior pituitary gland, controlling body temperature, thirst, hunger and other homeostatic systems

thyrotropin-releasing hormone (TRH)

a hormone produced by the hypothalamus that activates the anterior pituitary gland to release TSH

thyroid-stimulating hormone (TSH)

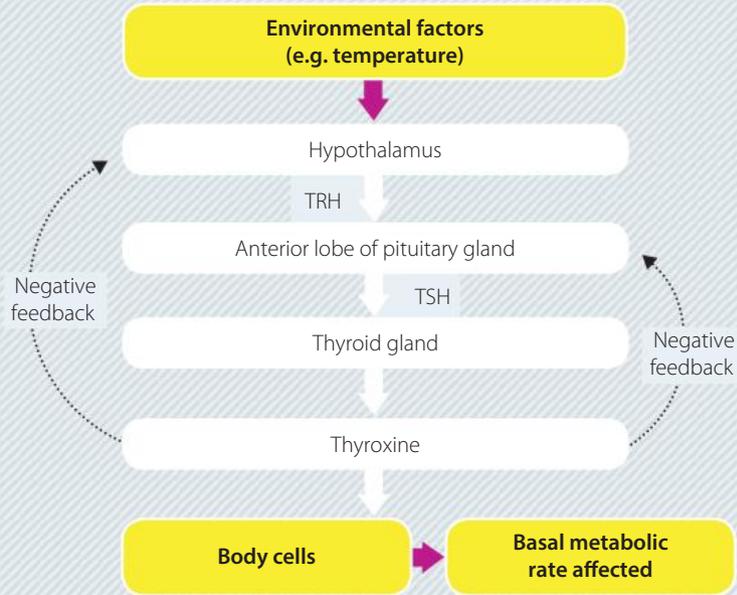
a hormone produced by the pituitary gland in response to signals from TRH; stimulates the thyroid gland to produce thyroxine; also called thyrotropin

thyroid gland

a gland in the neck that secretes iodine-containing hormones, including thyroxine

thyroxine
a hormone produced by the thyroid gland that acts to increase metabolic rate and regulate growth

FIGURE 12.5.1
When temperature drops, thyroxine production increases.



Insulin

Glucose is the main source of energy for cellular metabolism. It is vital that a constant supply of glucose is available. One response of the body to a drop in temperature is to increase the metabolic rate. This requires more glucose to supply the increased rate of cellular respiration. Uptake of glucose from the blood increases to supply the demand.

insulin
a hormone produced by the pancreas that regulates the amount of glucose in the blood

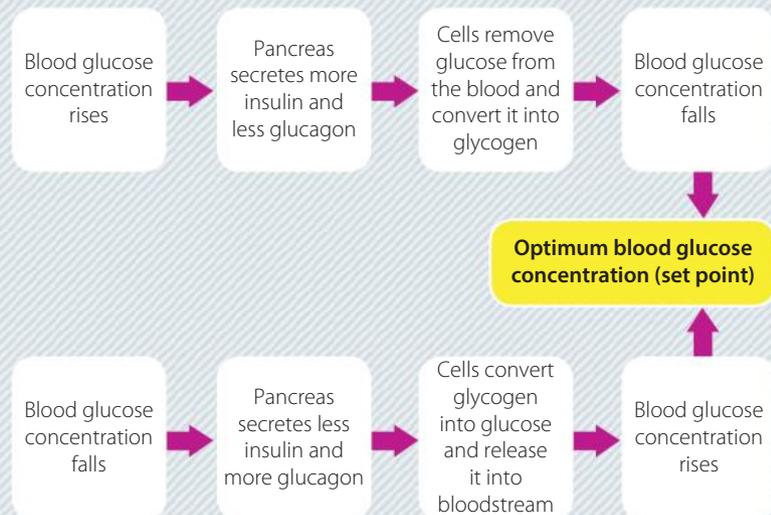
The concentration of glucose in the blood and tissue fluids at any time is determined by the action of two opposing hormones, **insulin** and **glucagon**. When blood glucose levels rise, insulin is secreted by cells in the pancreas. The response of cells is to increase the uptake of glucose from the blood and to convert the excess glucose to fat and **glycogen**, an energy-storing compound.

glucagon
a hormone produced in the pancreas that promotes the breakdown of glycogen to glucose in the liver

If blood glucose levels drop, other cells in the pancreas secrete glucagon. This hormone causes cells in the liver to convert glycogen to glucose and to inhibit the production of insulin.

glycogen
an important energy-storing polysaccharide in animals

FIGURE 12.5.2
Insulin and glucagon work together to maintain glucose balance.



PRACTICAL ACTIVITY 12.5.1

The skin and temperature control

INTRODUCTION

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?

Hot water can burn.

HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?

Use a funnel and fill test tubes carefully.



PROCEDURE

Part A: Effect of insulation on heat loss

- 1 Label three test tubes A, B and C, and place each test tube into a separate beaker.
- 2 Surround test tube A with cotton wool or another insulating material.
- 3 Place test tube B in a cardboard cylinder. 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 Leave test tube C with no insulating material around it.
- 6 Fill each of the three test tubes with 20 mL water at 80°C.
- 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.

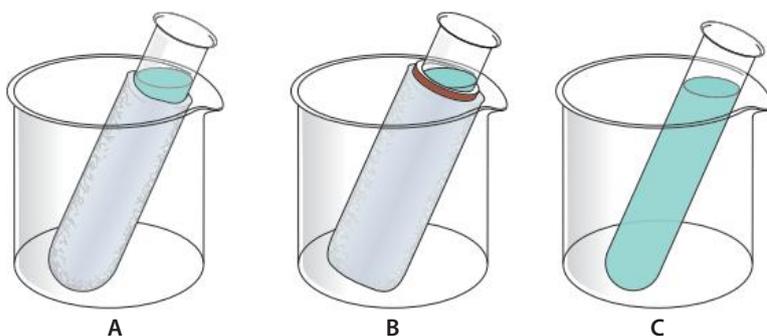


FIGURE 12.5.3 Experimental set-up to investigate the effect of insulation on heat loss





Part B: Effect of moisture on heat loss

- 1 Place four test tubes that have been wrapped in cotton wool in separate beakers. 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.

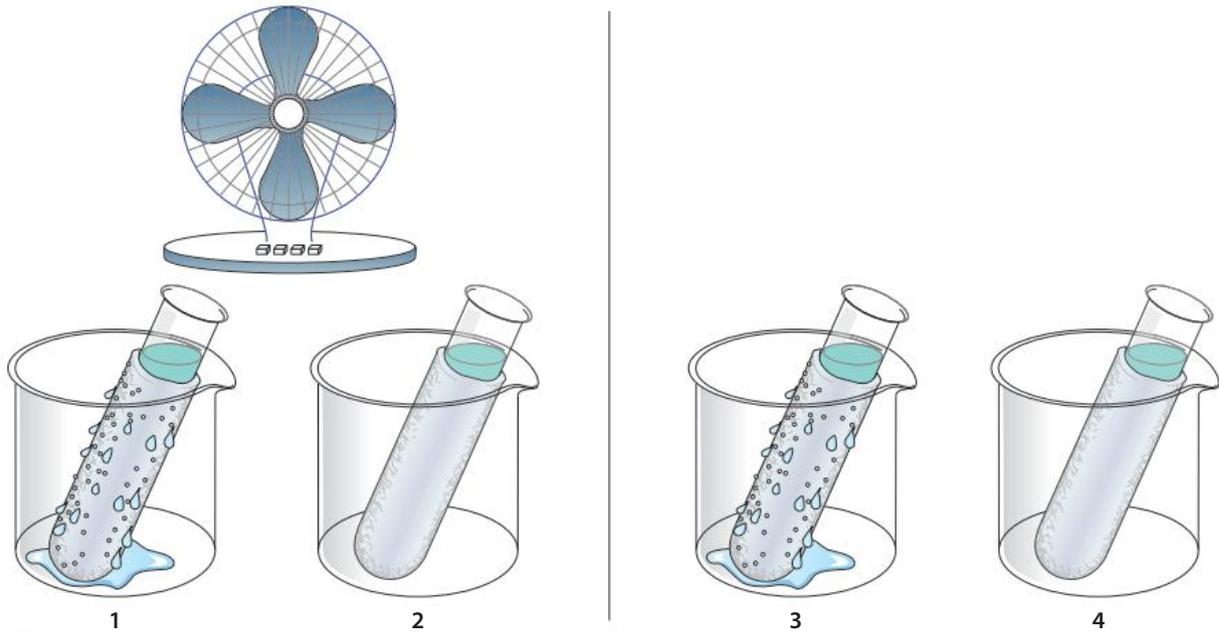


FIGURE 12.5.4 Effect of moisture on heat loss

RESULTS

Record your observations in tables and then graph them.

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 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 your answer.
- 5 When 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 your answer.

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 would on a cold day?
- 4 A small mammal ate more than its body weight in food in a 24-hour period; a larger mammal ate less than its body weight in food in the same time period. Explain why.

SECTION REVIEW

12.5

REMEMBERING

- 1 Describe the role of the hypothalamus in temperature control.

UNDERSTANDING

- 2 Detail the response of the hypothalamus, the anterior pituitary gland and the thyroid gland to low temperature.
- 3 Describe how insulin levels change in response to body temperature changes.

APPLYING

- 4 Using an example, explain why thermoregulation is said to be a homeostatic system involving negative feedback.

CHAPTER REVIEW QUESTIONS

DETAIL QUESTIONS

- 1 Why does heat exchange and metabolic activity need to be controlled in endotherms?
- 2 What types of thermoregulatory mechanisms contribute to maintaining constant body temperature?

CATEGORY QUESTIONS

- 3 What structural features are associated with thermoregulation in endotherms?
- 4 What behavioural responses are associated with thermoregulation in endotherms?
- 5 What physiological mechanisms are associated with thermoregulation in endotherms?
- 6 What homeostatic mechanisms are associated with thermoregulation in endotherms?

ELABORATION QUESTIONS

- 7 How do thermoregulatory mechanisms control heat exchange and metabolic activity?
- 8 What changes would you expect if an endotherm's environmental temperature increased?
- 9 What changes would you expect if an endotherm's environmental temperature decreased?

EVIDENCE QUESTIONS

- 10 What, if any, external sources did you use to support your answers to Questions 7–9?
- 11 Explain the reasoning behind your answers to Questions 7–9.
- 12 What factors other than environmental temperature could affect thermoregulation mechanisms?
- 13 How could your answers to Questions 7–9 be improved?
- 14 What further evidence could be used to support your answers to Questions 7–9?



- 1 Structural adaptations assist an organism to cope with changes in environmental temperature. Mammals such as polar bears reduce heat loss by:
 - A finding shelter and curling up into a ball during a storm
 - B decreasing activity so they do not have to consume as much food
 - C maintaining a distance from other polar bears
 - D being well insulated by thick fur.
- 2 The following is an example of torpor.
 - A A cat going to sleep
 - B A ground squirrel hibernating
 - C A dog shivering
 - D The feet of penguins
- 3 Thermoregulation is an issue for any organism living in a cold environment. Important mechanisms to conserve heat are:
 - A high metabolic rate
 - B panting and sweating
 - C layers of feathers and down
 - D vasodilation.
- 4 Secretion of TSH is increased by:
 - A negative feedback effect of thyroid hormones on the hypothalamus
 - B direct action of thyroid hormones on the anterior pituitary gland
 - C release of TRH by the hypothalamus
 - D high temperature of the external environment.
- 5 Physiological responses to an increase in body temperature include:
 - A a person's skin looking redder and feeling warm on a hot day
 - B a desert mammal undergoing aestivation
 - C penguins huddling together
 - D an animal developing deposits of brown adipose tissue.
- 6 Body temperature of an endotherm decreases as a result of:
 - A shivering
 - B sweating
 - C vasoconstriction of blood vessels in the skin
 - D an increase in metabolic rate.

- 7 The temperature control centre in mammals is located in the:
- skin
 - thyroid gland
 - pituitary gland
 - hypothalamus.
- 8 Name two structural features, two behavioural responses, two physiological mechanisms and two homeostatic mechanisms that control heat exchange in endotherms.
- 9 Explain why a small mammal would shiver more than a large mammal on a cold day.
- 10 Emperor penguins live in the Antarctic. They often huddle together. The arteries going to the feet of the penguins are close to veins returning blood to the body.
- Explain how huddling together helps penguins to survive the extreme cold.
 - Name the type of system that is used to describe the arrangement of blood vessels found in the feet of emperor penguins.
 - Explain how this system reduces the loss of heat from the feet.
- 11 Figure 12.7.1 shows the relationship between environmental temperature and metabolic rate of different animals. The basal metabolic rate for each animal is given a value of 100%. Any increase in metabolic rate is in relation to this value.
- Explain what is meant by set point.
 - Determine at what external temperature the metabolic rate of the Eskimo dog pup begins to increase.
 - Determine at what external temperature the metabolic rate of the sloth begins to increase.
 - Determine which animal represented in the graph has a critical temperature of about 40°C.
 - The gradients of the lines of the graph indicate the rate of increase in metabolic rate. Determine which animal, the ground squirrel or the polar bear cub, shows the greater rate of increase in metabolic rate.
 - Analyse the information in the graph and compare species living in Arctic conditions with species living in tropical conditions.
 - Suggest what strategies animals employ if they are unable to meet their energy needs.

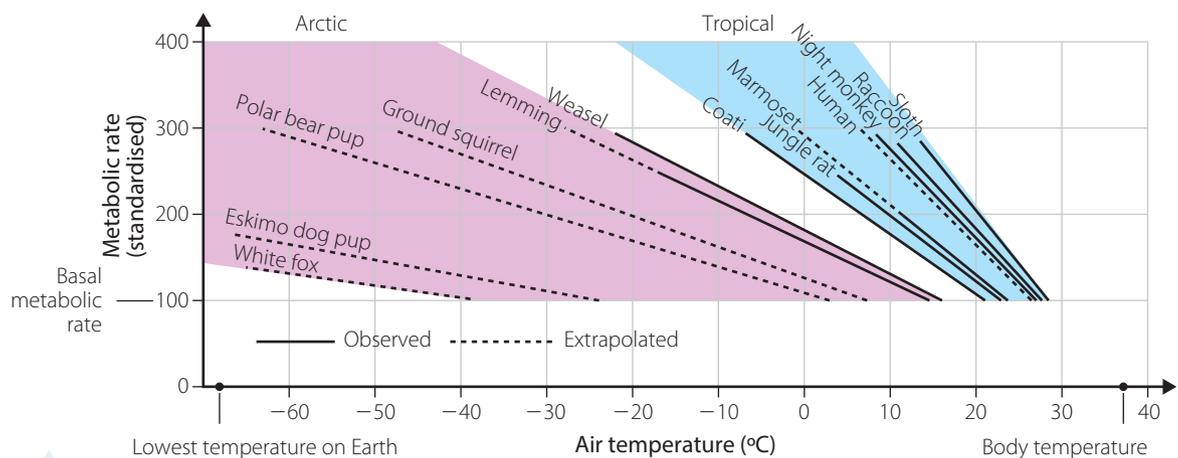


FIGURE 12.7.1 The relationship between environmental temperature and metabolic rate

13

OSMOREGULATION

Introduction

Water is the universal solvent and essential to life. Metabolic reactions occur in a solution composed mainly of water. Water dissolves most salts and minerals in organisms by dissociating the ions.

Water balance requires continual homeostatic control, or osmoregulation. If the supply of water does not meet what is lost, the relative concentrations of solute and solvent in tissue fluids become difficult to regulate. Therefore, physiological functions are affected. In animals, a loss in blood volume results in a drop in blood pressure; toxic wastes cannot be excreted effectively and enzyme function is affected. Severe dehydration can lead to death. In plants, loss of water can mean collapse of shoot systems and reduced cellular functioning.

Stimulus questions

How is water balance maintained in animals and plants?

How do animals and plants living in different environments respond to variability in water supply?





Chapter 1 discusses osmosis and the effect of differing amounts of solute concentration.

13.1 Water balance in animals

Animals are continually gaining and losing water and solutes. They continually produce metabolic wastes. Even with all of the inputs and outputs, the overall composition and volume of the body's **extracellular fluid** are kept within ranges that its cells can tolerate.

Extracellular fluid is made up of the **interstitial fluid** between cells, tissues and blood. The blood plasma that transports substances is approximately 90% water. Blood not only supplies nutrients to cells, it also transports waste products for removal. The main wastes that require removal are nitrogenous compounds.

The function of **osmoregulation** is to control solute concentration in cells. To do this, the body makes compensatory adjustments to the extracellular fluid to maintain its volume and composition. In vertebrates, an excretory system is important to balancing the intakes and output of water and solutes.

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

interstitial fluid
extracellular fluid; fluid in spaces surrounding cells

osmoregulation
the processes by which internal water and solute concentration are maintained despite fluctuations in the external environment

osmotic concentration
the measure of solute concentration

osmoregulator
an organism that has specialised mechanisms for regulating internal water and solute concentrations, despite concentration changes in the external environment

osmoconformer
an organism in which the internal solute concentration changes with the concentration of solutes in the external environment

isotonic
fluid with an equal solute concentration to another fluid

urea
a nitrogenous waste that is a less toxic breakdown product of ammonia in mammals; it is excreted in urine

euryhaline
an organism that can tolerate a wide change in salinity

Osmoregulators and osmoconformers

Organisms have various mechanisms for maintaining water balance. Some organisms regulate their **osmotic concentration** to be either higher or lower than their external environment; these organisms are called **osmoregulators**. Others allow their osmotic concentration to be equal to the concentration of the external environment; these organisms are called **osmoconformers**.

Most marine invertebrates are osmoconformers. Their interstitial fluid concentration fluctuates to match the external environment. The body fluids of an organism that are of the same concentration as the surrounding water are referred to as **isotonic**. Cartilaginous fish such as sharks and rays are also osmoconformers. They are able to concentrate **urea** in their bodies to maintain a high osmotic concentration, thus matching the ocean's high concentration of solutes. Some fish, such as sturgeon, sawfish and bull sharks, are capable of living in the brackish water found in estuaries and rivers. Organisms such as these that can tolerate the fluctuation in salinity within this mix of salt and freshwater are known as **euryhaline** species.

Because osmoconformers live in water that has a stable composition and their internal osmotic concentration is the same or similar to their surroundings, they don't lose or gain much water.

Osmoregulators can live in environments that osmoconformers cannot. Osmoregulation allows animals to move between different environments. Structural features, as well as behavioural responses and physiological and homeostatic mechanisms, aid water balance in osmoregulators.

Structural features

Dehydration is a major problem for land animals, so adaptations that reduce water loss are important for survival. For example, a waterproof or impermeable outer layer can reduce water loss. This is evident in the scales of reptiles, the hair of mammals and the feathers of birds where the upper part of the epidermis contains keratin, a protein that hardens and waterproofs the body surface (Figure 13.1.1, page 199).

INQUIRING FURTHER

Keratin is used in some hair treatments. Find out more about the claims made by the beauty industry regarding its effects.



13.1.1 Osmoregulation



FIGURE 13.1.1 The scales of reptiles and feathers of birds contain keratin, which prevents water loss.

The kidneys

The kidneys are essential organs, involved in maintaining a constant internal environment. Specifically, they play an important role in osmoregulation (Figure 13.1.2). Their osmoregulatory function includes:

- ▶ removal of nitrogenous wastes
- ▶ regulation of water concentration in blood
- ▶ maintaining ion levels in the blood.

The elimination of nitrogenous wastes formed from the synthesis of protein molecules is essential. Nitrogenous wastes, such as **ammonia**, are toxic. A build-up of ammonia can affect a cell's pH severely. In humans, ammonia is quickly converted to the less toxic substance, urea, so that waste nitrogen can be safely transported to the kidneys and excreted.



13.1.2 How do kidneys work?

ammonia
a product of amino acid breakdown that is extremely toxic in humans (NH_3)

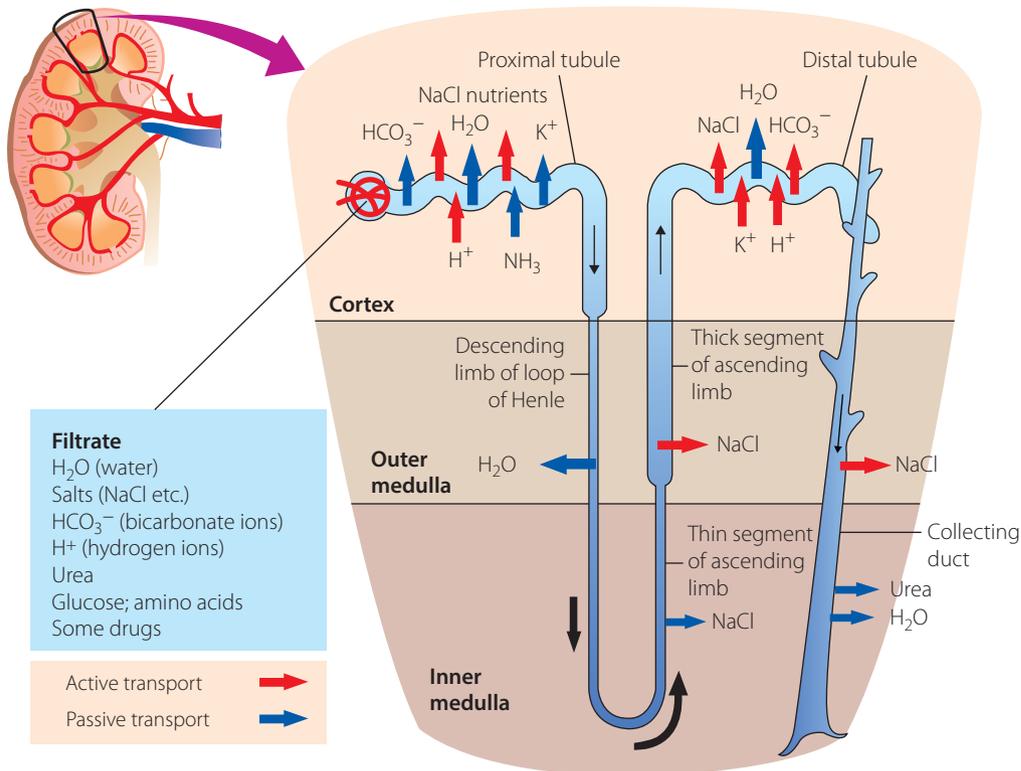


FIGURE 13.1.2 A mammalian kidney. Water is conserved when it is removed in the descending portion of the loop of Henle. The longer the loop of Henle, the more concentrated the urine and the more water saved.



Chapter 7 explains the function of each of the sections of the kidney nephron and outlines the different types of nitrogenous wastes.

Urea and excess salts leave the body in the watery fluid urine. By controlling how much water is in the urine, the body can maintain a fluid balance. Hormonal feedback control regulates water balance.

Different organisms have different ways of coping with the waste product ammonia. Freshwater fish produce abundant amounts of dilute urine containing ammonia. It is excreted quickly and continuously. On the other hand, marine fish and terrestrial mammals must quickly convert the ammonia to urea. The urea is then released as concentrated urine containing less water. Other organisms, such as reptiles and birds, produce **uric acid**, which is the least toxic form of nitrogenous waste and contains very little water.

uric acid

a nitrogenous waste produced by desert animals, birds, reptiles and insects

Behavioural responses

Desert frogs have adaptations ranging from producing highly concentrated urine to burrowing in the desert sands for several months at a time. For example, the water-holding frog, *Cyclorana platycephala*, found in southern Queensland, tucks itself in a water-conserving cocoon formed from layers of skin. The frog's metabolic rate slows as it enters aestivation under the ground. It can survive in this way for many months.

Other desert animals spend a large proportion of time in burrows. Burrows have lower temperatures and higher humidity than the open air, so water loss is reduced. The spinifex hopping mouse, *Notomys alexis*, found throughout Queensland, has a bushy end to its tail, which it wraps around its face. This interesting strategy reduces water loss by saturating the air between the hairs at its body surface and the air in the burrow with water vapour.

Physiological mechanisms

Many reptiles and birds reabsorb water from their cloaca, the cavity into which their rectum and ureter opens. This means they excrete nitrogenous waste as uric acid and save water. Many terrestrial vertebrates, such as the Australian desert frog *Chiroleptes*, slow the production of urine by reducing the rate of glomerular filtration. The frog, swelling up like a ball, retains urine in its bladder for use in the dry season. The spinifex hopping mouse can concentrate its urine more than any other known rodent. Water is conserved when it is removed in the descending portion of the loop of Henle. The longer the loop of Henle, the more concentrated the urine and the more water saved. The desert hopping mouse has a very long loop of Henle to maximise water conservation (Figure 13.1.3, page 201).

Camels are renowned for their ability to go for several weeks without drinking water. Camels can produce water by metabolising the fat in their hump; however, it is not enough to compensate for the water lost by evaporation. As water is lost, the camel's body fluids become more concentrated. The camel's tissues have adapted to be extremely tolerant of this condition.

The body fluids of marine vertebrates tend to be **hypotonic** with their surroundings; that is, their body fluids are of a lower concentration than the medium in which they live. Water is lost via osmosis from the gill surfaces. Marine fish drink copious amounts of sea water, which creates a problem due to the additional salt intake. Marine vertebrates solve this problem by actively removing salts by special chloride secretory cells in the gills. In addition, a slow filtration rate and the excretion of concentrated nitrogenous waste help them reduce water loss. Some marine animals, such as sharks and rays, tolerate high levels of urea in their body tissues, thereby reducing water loss. In this way, the internal solute concentration of their tissues becomes slightly higher than, or **hypertonic** with, the surrounding water. The water that consequently moves in by osmosis is easily removed by the kidneys.

hypotonic

a solution with a lower solute concentration than another solution

hypertonic

a solution with a higher solute concentration than another solution

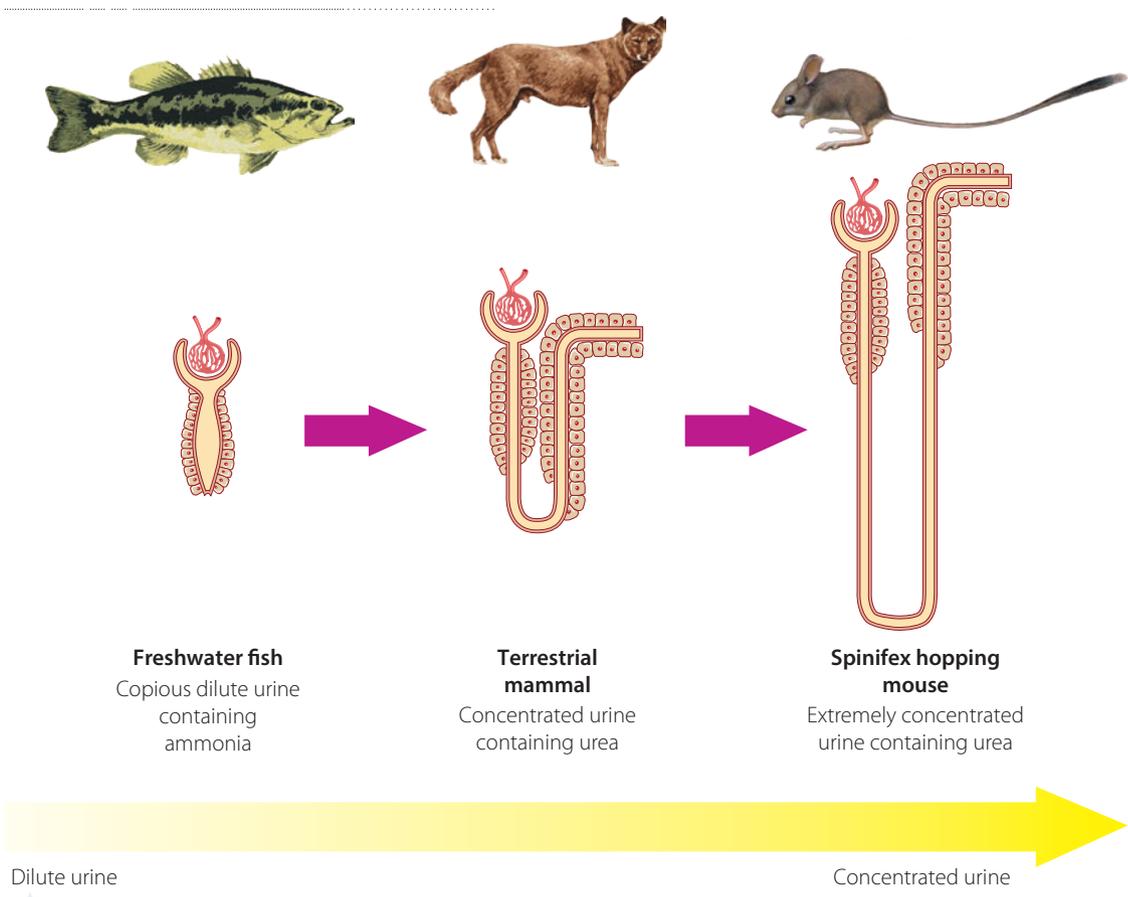


FIGURE 13.1.3 A comparison of the size of the loop of Henle and urine concentration in animals

In freshwater vertebrates, the concentration of ions in the tissues is higher than in the surrounding water. Freshwater vertebrates have a high kidney filtration and produce copious amounts of dilute urine. Freshwater fish must actively absorb salts from their external environment in order to maintain their high ion concentration levels.

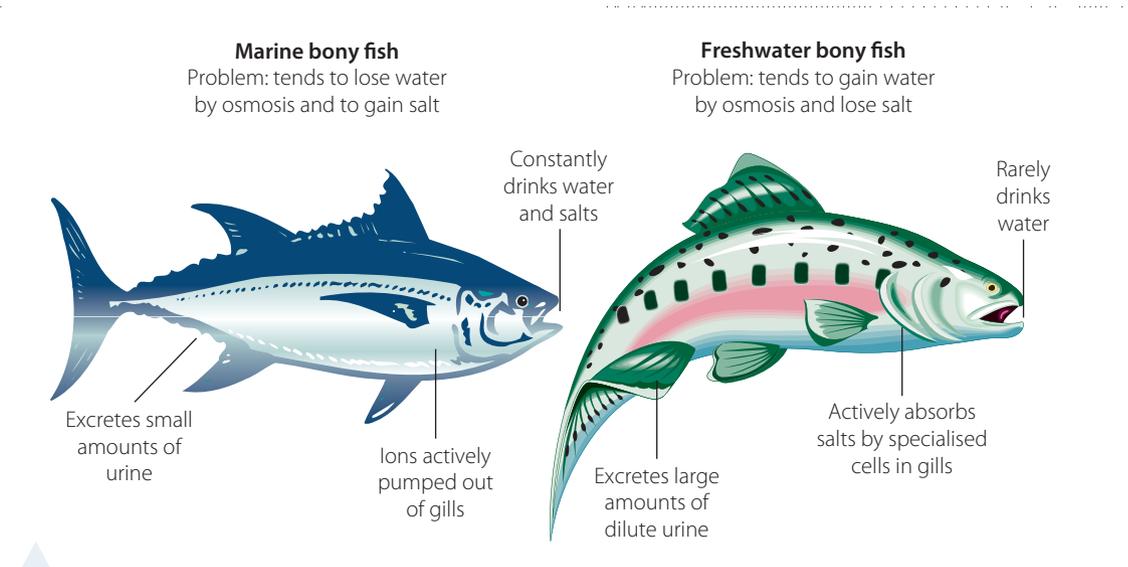


FIGURE 13.1.4 Solving the problem of water balance

Homeostatic mechanisms

The feedback mechanism for the maintenance of water balance in humans is determined by the osmotic pressure of the blood. 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 hormone (ADH)** (also called vasopressin) into the bloodstream. (Antidiuretic means urine-reducing.) 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 the urine is more concentrated.

antidiuretic hormone (ADH)
a hormone responsible for increased permeability of the distal tubules of the kidney, increasing water reabsorption and reducing urine volume

Urine production continues, although at a reduced rate. So increased reabsorption cannot increase the amount of water in the body; it only reduces 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 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, negative feedback decreases the release of ADH, less water is reabsorbed by the kidney and more copious and dilute urine is produced (Figure 13.1.5).

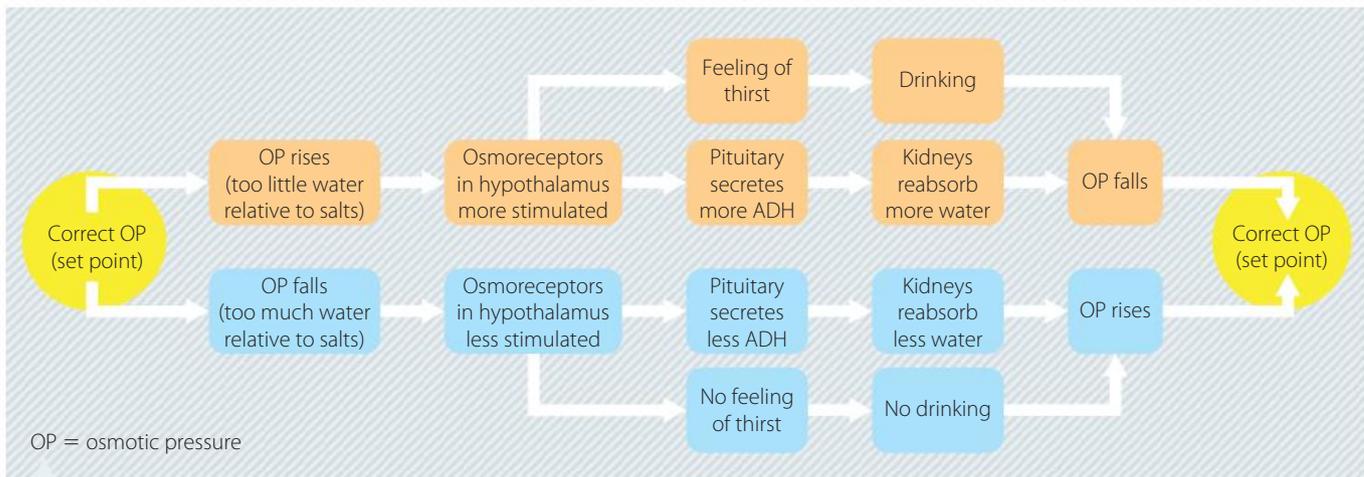


FIGURE 13.1.5 A flow diagram summarising osmoregulation in humans

SECTION REVIEW

13.1

REMEMBERING

- 1 Describe the function of osmoregulation.
- 2 Identify the difference between an osmoconformer and an osmoregulator.

UNDERSTANDING

- 3 Name the three types of nitrogenous waste excreted by organisms. Explain why it is essential to remove these wastes.
- 4 Describe one benefit of being an osmoconformer compared to being an osmoregulator.

APPLYING

- 5 Create an annotated diagram that demonstrates the role of ADH in human water balance.
- 6 Create a table that summarises the various mechanisms that osmoregulators use to maintain water balance.

13.2 Water balance in plants

Plants are also osmoregulators. Although water is essential for photosynthesis and the survival of the plant, water is continually being lost to the environment through the stomatal pores of the leaf surface. Unlike animals, plants cannot move to seek the additional water they require. Plants have a range of features that help them obtain and/or retain water to maintain their balance.

Structural features

If a plant cell loses water, it wilts and water-dependent events are disrupted. **Xerophytes** are plants that grow in dry conditions. They include cactus and other plants typically found in deserts. Xerophytes face the possibility of dehydration more regularly than other varieties of plants and they have developed special adaptive features to store and/or reduce the loss of water. By storing water and/or reducing the loss of water, xerophytes can still carry out photosynthesis and respiration.

Features that minimise water loss include:

- ▶ a thick waxy cuticle on the leaf surface
- ▶ reduced numbers of stomata on the top of the leaf and increased numbers on the bottom of the leaf
- ▶ sunken stomata
- ▶ cylindrical or rolled leaves
- ▶ reduced leaf numbers or no leaves
- ▶ hairs on leaves.

Waxy cuticle

Epidermal cells in the leaf secrete a translucent, water-impermeable **cuticle** layer, which coats cell wall areas exposed to the air (Figure 13.2.1). At the cuticle surface are deposits of waxes, which are water-insoluble lipids. The cuticle restricts water loss and at the same time allows light rays to pass through into photosynthetic parts of the plant.



FIGURE 13.2.1 The waxy cuticle reduces water loss.

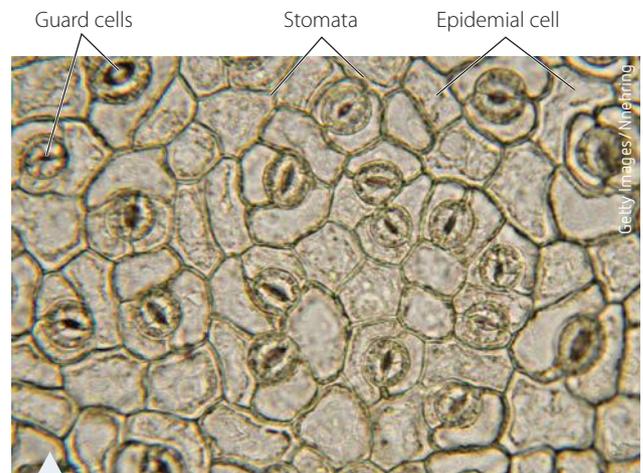


FIGURE 13.2.2 Water evaporates to the atmosphere through stomata.

xerophyte
a plant adapted to dry conditions



Chapter 8
discusses leaf
structure.

cuticle
a thin, transparent
layer of wax on the
outside of a leaf's
epidermis that reduces
water loss



Chapter 8 discusses the role of stomata and guard cells in controlling the movement of water vapour in leaves.

succulent
a plant with thick, fleshy, water-storing leaves or stems

Controlled water loss at stomata

The cuticle restricts the inward diffusion of carbon dioxide necessary for photosynthesis and the outward diffusion of oxygen by-products. Diffusion of these gases occurs in a controlled fashion at stomata (singular: stoma). Gas exchange and evaporation of water occur mainly at stomata (Figure 13.2.2, page 203).

Stomata are usually open in the day to support photosynthesis, even though water is lost. This water is replaced by water from the roots if there is enough water in the soil. The number and size of stomata varies from species to species. One way to reduce water loss in xerophytes is to reduce the number and size of stomata. An adaptation for many desert plants is to locate their stomata in the lower epidermis, the underside of a leaf, in sunken grooves or pits. Humid air tends to accumulate in these pits, thus reducing the rate of transpiration from the leaves. Some plants achieve humidity by surrounding the stomata with a hairy epidermis. The leaf hairs help create a microclimate, reducing transpiration through the stomata as the concentration gradient has been reduced, making it harder for water to evaporate out of the stomata.

Storing water in vacuoles

Some plants store water in cells in their stems or leaves. These types of plants are called **succulents**. Organs of succulents store water and increase the amount of available water. In most plant cells, the vacuole occupies 70–80% of the cell's volume, but in succulents this is around 90%.

Leaf shape

Leaf surface area of xerophytes is usually low. Xerophytes often have needle-like leaves or much reduced leaves. Some xerophytes show leaf curling, an adaptation seen in marram grass (*Ammophila arenaria*), which thrives on dry coastal sand dunes (Figure 13.2.3). Moist air is trapped around the stomata, thereby decreasing the rate of transpiration.

Eucalypts have leaves with a hard cuticle and which hang vertically, away from the direct heat of the sun. Less heat is gained in this position and therefore water loss is reduced.

The Australian mulga (*Acacia aneura*), one of the most common wattles in the Australian deserts, has a resourceful way to use every drop of rainfall. Leaves and branches are arranged so that water is channelled to the stem and onto the ground where the roots are able to access it.

Root systems

Some plants that live in dry places have long vertical roots that absorb water from deep down in the soil. Other plants, including most cactuses, have superficial roots which grow out horizontally just beneath the surface to absorb water quickly before it evaporates.



FIGURE 13.2.3 Stomata occur in the furrows on the inner side of a marram grass leaf (*Ammophila arenaria*) to conserve water. Hairs help to hold in water vapour. The outer side of the leaf has a thick cuticle and lacks stomata.

INQUIRING FURTHER

Investigate leaf orientation in plants in as many different environments as possible. Relate the arrangement of the leaves to the amount of water in that environment.

mesophyte
a plant that grows in an environment with medium conditions of moisture

hydrophyte
a plant that is adapted to aquatic conditions

halophyte
a plant that is adapted to salty conditions

Maintaining water balance in mesophytes, hydrophytes and halophytes

Only some plants live in dry environments. **Mesophyte** plants live in areas with adequate water, **hydrophytes** are aquatic and **halophytes** live in salty conditions. Each type of plant has their own special adaptations to maintain water balance in their specific environment.

Mesophytes live in environments that are neither too dry nor too wet, so they have not needed any extreme adaptations. Mesophytes generally have a thinner cuticle, a larger amount of stomata on the undersides of the leaves and leaves that are larger and thinner compared to xerophytes.

Hydrophytes grow in or on water. They do not need adaptations for water retention. As water contains much less oxygen than air, the problem for hydrophytes is lack of oxygen. Their leaves have an abundance of air-filled intercellular spaces through which air can move. Hydrophytes such as water lilies only have stomata on the upper surfaces of the leaves. Hydrophytes that are fully submerged have no stomata or waxy cuticle because these are not required.

Halophytes have to take up water from an external environment that has a higher salt concentration, and therefore lower water potential, than ordinary soil water. Halophytes living in these environments actively absorb salts into their roots, with the result that the solute concentration of their tissues is higher than that of the surrounding water. They can then take up water by osmosis in the usual way. As the habitat is physiologically dry due to salts, the halophytes show structural characteristics similar to xerophytes.

Homeostatic mechanisms

Stomata respond to water loss. Environmental stresses such as drought cause stomata to close. When guard cells surrounding the stomatal pore lose water, turgor pressure drops, the two guard cells collapse against each other, and the gap closes.

Abscisic acid (ABA) is a key hormone that regulates water status and stomatal movement. When a plant has a water deficiency, cells in roots and leaves respond by producing ABA. ABA accumulates in increased amounts in the guard cells. There is a rapid alteration of the osmotic potential in guard cells, causing them to lose turgidity and induce stomatal closure. Transpiration is reduced, conserving water in times of low water availability.

When stress signals are diminished, ABA is metabolised into inactive products, thus reducing the level in guard cells and allowing stomata to open.

abscisic acid (ABA)
a plant hormone produced in response to plant stress involved in stomatal closure

SCIENCE AS
A HUMAN
ENDEAVOUR

ABA AND FOOD PRODUCTION

To meet the food demands of a growing world population, food production must be increased. As the global climate changes, it is important that we understand water stress tolerance in crop plants. ABA acts as a central hormone regulator of responses to different plant stresses such as drought, low temperature and salinity.

Scientists are working towards a deeper understanding of the underlying mechanisms that involve ABA in stress tolerance.

Outline ways we could apply the knowledge of ABA homeostatic control to improve food production. Discuss problems associated with applying treatments of ABA to plants.

SECTION REVIEW

13.2

REMEMBERING

- 1 Describe three adaptations typically found in xerophytes that minimise water loss.

UNDERSTANDING

- 2 Describe the structure and function of a plant cuticle.
- 3 Outline how surrounding the stomata with a hairy epidermis reduces water loss.
- 4 Explain why adaptations typically found in halophytes are similar to those in xerophytes.

APPLYING

- 5 Predict the type of habitat of a xerophyte that typically has a root system with:
 - a long vertical roots
 - b horizontal superficial roots.
- 6 Relate the location of stomata in a plant's leaf to the plant's environment.

13.3 Manipulative skills

PREPARING A WET MOUNT OF LEAF CUTICLE TISSUE

Materials

- fresh green leaf
- light microscope
- microscope slides
- coverslips
- dissecting needle
- water dropper
- forceps



WHAT ARE THE RISKS IN DOING THIS EXPERIMENT?

Coverslips can break easily and can cut.

HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?

Take care with coverslips and do not push hard when placing them.

Procedure

- 1 Cut a fresh green leaf from a plant.
- 2 Fold the leaf and carefully pull along the fold as shown in Figure 13.3.1. This should leave a small area of very thin, transparent lower epidermis.
- 3 Pull off a section of this lower epidermis using forceps.
- 4 Put the section of tissue onto a microscope slide. Try to avoid getting folds in it. Add one or two drops of water and using the dissecting needle, carefully lower the coverslip.
- 5 Examine the slide under low power.

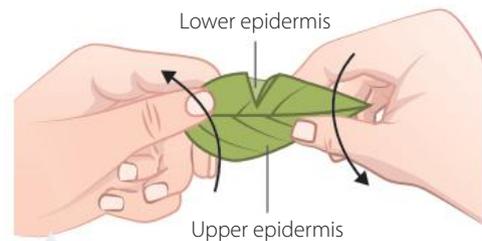


FIGURE 13.3.1 The method of exposing epidermal tissue

STOMATA AND GUARD CELL DISTRIBUTION

Introduction

Most plants have a waxy cuticle to prevent uncontrolled water loss. Stomata provide a way for the plant to exchange gases with the cells and control the release of water to the atmosphere. The more stomata per unit area (stomata density), the more water is lost to the environment. If water is not readily available, such as in dry, terrestrial environments, excessive water loss might lead to plant stress and reduction of metabolic functions.

Aim

To compare the distribution of stomata and guard cells in plants adapted to different environments

Materials

- freshly picked green leaves from a range of terrestrial and aquatic environments
- light microscope
- microscope slides
- coverslips
- tweezers
- water dropper
- dissecting needle
- clear nail varnish
- clear sticky tape

WHAT ARE THE RISKS IN DOING THIS EXPERIMENT?

Coverslips can break easily and can cut.

HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?

Take care with coverslips and do not push hard when placing them.

**Procedure**

- 1 Prepare wet mounts of both the upper and lower leaf cuticle tissue from each of the different species of plants provided.

If it is not possible to obtain a section of the cuticle tissue, you can make an impression of a leaf surface. Follow the procedure below to examine both upper and lower epidermal surfaces.

- a Apply a thick layer of clear nail varnish to a small area on the surface of the freshly picked leaf. The nail varnish will have made an exact replica of the leaf surface.
- b When the nail varnish is dry (about 5 minutes), stick a very clear piece of sticky tape to the area that contains the dried nail polish. Slowly peel off the tape with a pair of tweezers. The nail polish should come with it.
- c Without touching it, place the tape with the layer of dried nail polish on the microscope slide.



- » 2 Repeat step 1 using tissues from the different species of plants provided.
- 3 Examine each tissue under low power.
- 4 Add the name of the plant and type of environment it grows in (terrestrial or aquatic) to Table 13.4.1. Count all stomata whose guard cells are more than half contained in the field of view for each tissue.
- 5 Move the slide to another section of cells from the same tissue.
- 6 Repeat steps 4 and 5 for a total of three stomata counts from each tissue.
- 7 Find the average number of stomata from the three stomata counts from the upper side and lower side of the leaf.

Results

TABLE 13.4.1 Number of stomata on upper and lower leaf surfaces

PLANT NAME	TYPE OF ENVIRONMENT	AVERAGE NUMBER OF STOMATA – UPPER SURFACE	AVERAGE NUMBER OF STOMATA – LOWER SURFACE

- 8 Compare the number of stomata and guard cells in each of the environment types. How do your results compare to those of others in the class?

Discussion

- 1 Explain why counts of stomata were made in three separate fields of view and then averaged.
- 2 Outline why it might be adaptive for stomata to occur mostly on the undersides of leaves.
- 3 Name the plants for which stomata are only on the upper leaf surface. Explain why this is an adaptation for those plants.

Conclusion

Using your knowledge of osmoregulation in plants, relate the difference in the distribution of stomata and guard cells in leaves to the different environments plants grow in.

INQUIRING FURTHER

Given your knowledge of the evaporative water loss in plants, speculate upon the opening and closing features of stomata you would expect to evolve in plants adapted to dry environments with variable and unpredictable water supply. Research your answer and provide support for any mechanisms that have been identified as a way for stomata to respond to humidity and water availability.

CHAPTER REVIEW QUESTIONS

DETAIL QUESTIONS

- 1 Why does water balance need to be maintained in endotherms?
- 2 What types of osmoregulatory mechanisms contribute to maintaining water balance in animals?
- 3 What types of osmoregulatory mechanisms contribute to maintaining water balance in plants?

CATEGORY QUESTIONS

- 4 What structural features are associated with osmoregulation in animals?
- 5 What behavioural responses are associated with osmoregulation in animals?
- 6 What physiological mechanisms are associated with osmoregulation in animals?
- 7 What homeostatic mechanisms are associated with osmoregulation in animals?
- 8 What structural features are associated with osmoregulation in plants?
- 9 What homeostatic mechanisms are associated with osmoregulation in plants?
- 10 What mechanisms are common to both animals and plants?

ELABORATION QUESTIONS

- 11 How does osmoregulation maintain water balance?
- 12 What changes would you expect if an animal's osmotic concentration increased?
- 13 What changes would you expect if an animal's osmotic concentration decreased?
- 14 What changes would you expect if a plant's osmotic concentration increased?
- 15 What changes would you expect if a plant's osmotic concentration decreased?

EVIDENCE QUESTIONS

- 16 What, if any, external sources did you use to support your answers to Questions 11–15?
- 17 Explain your reasoning behind your answers to Questions 11–15.
- 18 What factors other than water loss or gain could affect osmoregulation mechanisms?
- 19 How could your answers to Questions 11–15 be improved?
- 20 What further evidence could you use to support your answers to Questions 11–15?



- 1 Which of the following is an osmoconformer?
 - A Shark
 - B Dog
 - C All vertebrates
 - D All mammals

- 2 Ammonia is a toxic nitrogenous waste that is produced in the breakdown of protein. Which of the following strategies for processing ammonia is incorrect?
 - A A possum produces small amounts of ammonia diluted in water.
 - B A freshwater trout produces large amounts of ammonia diluted in water.
 - C Sharks convert ammonia to urea, which is then released as urine.
 - D A chicken converts ammonia to uric acid, which has little water in it.

- 3 Animals that live in the desert must minimise the water they lose from their bodies. In these organisms, which part of the kidney is elongated in order to absorb more water by producing concentrated urine?
 - A Proximal tubule
 - B Collecting duct
 - C Loop of Henle
 - D All of the above.

- 4 Plants growing in salty conditions are called:
 - A xerophytes
 - B mesophytes
 - C hydrophytes
 - D halophytes.

- 5 A plant growing in a desert environment is likely to have:
 - A leaves that are large and thin
 - B stomata located in sunken pits
 - C stomata found only on the upper leaf surface
 - D a thick waxy cuticle on the lower leaf surface.

- 6 Describe one way in which a desert animal may reduce water loss.

- 7 Explain the significance of the ability to tolerate high levels of urea in body tissues in osmoregulation of some marine animals.

- 8** Antidiuretic hormone (ADH) is a protein that aids in the control of fluid levels in humans.
- Name the organ in which osmoreceptors detect the variations in the concentration of blood.
 - Name the gland that releases ADH.

ADH is carried in the blood to three target tissues: the distal tubules and collecting ducts of the kidneys, the sweat glands, and the smooth muscles of small blood vessels. Some of the effects of differing levels of ADH on body functions are shown below.

Concentration of ADH (pg/mL)	Output of urine (L/day)	Sweat gland activity	Blood pressure
0.5	15.0	High	Decreased
3.6	1.5	Moderate	No change
4.7	0.5	Low	Increased

- Predict what effects on urine output, sweating and blood pressure you would expect with an increase in ADH.
 - Describe and explain the effect on ADH levels in the blood after drinking lots of water.
- 9** Explain why a waxy cuticle is found more often on the upper side of a leaf.
- 10** Leaf curling is an adaptation found in some plant species such as marram grass (Figure 13.2.3, page 204). Explain the advantage in stomata being located in the furrows on the inner side of the leaf.
- 11** A key hormone regulates water status and stomatal movement in plants.
- Name this key hormone.
 - Explain how the action of this hormone contributes to conserving water in times of low water availability.

MAINTAINING THE INTERNAL ENVIRONMENT



Topic 2: Infectious disease

Humans are constantly being invaded by pathogens such as bacteria, viruses, fungi, protists, parasites and prions. Plants and other animals are also subject to pathogen invasion. The degree to which pathogens affect body functioning depends on their virulence and mode of transmission. Organisms have mechanisms to defend against these challenges. These range from barriers preventing the pathogen from entering the body in the first place, to mounting complex battles against the infectious agent once it has entered the body. Humans have developed ways to enhance their immune response through health programs.

SCIENCE AS A HUMAN ENDEAVOUR

Students should be given opportunities to investigate models of disease outbreak, how pandemics are managed in the Asia region and how Australia manages its biosecurity through quarantine.

14

INFECTIOUS DISEASE

Introduction

History tells of how diseases have repeatedly ravaged human populations. Tuberculosis (TB) has been the scourge of humans for many thousands of years and evidence of its presence has been found in Egyptian mummies dating from 1000 BCE. Cholera and smallpox epidemics were rife for centuries and the plague threatened to wipe out most of Europe during the 14th century.

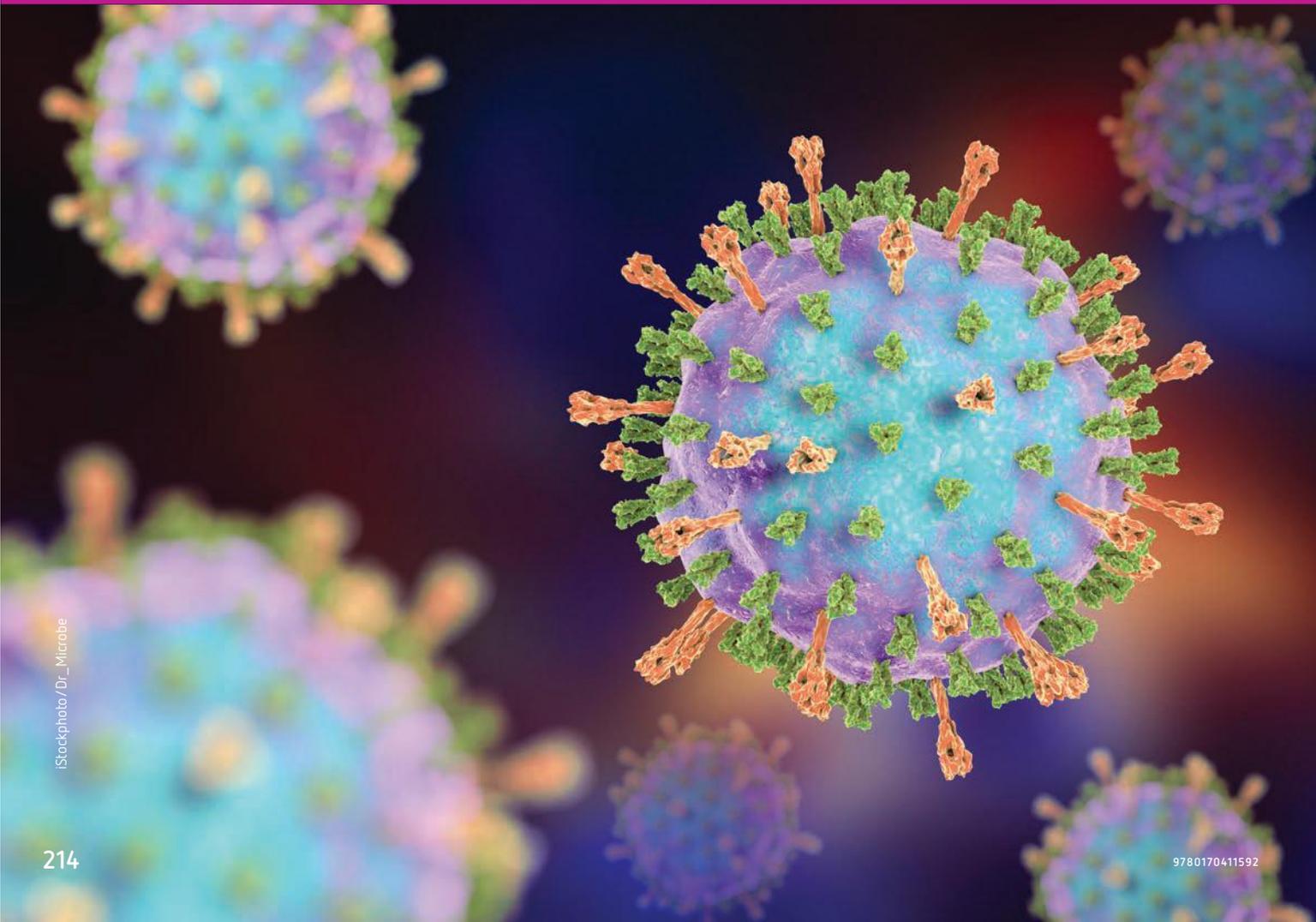
Emerging diseases – infections new to humans – are cause for concern. These include Zika virus disease, severe acute respiratory syndrome (SARS), Ebola virus disease and avian influenza (bird flu). Millions of people worldwide suffer from the acquired immunodeficiency syndrome (AIDS), caused by the human immunodeficiency virus (HIV), one of the top fatal diseases in the world. When epidemics sweep through a population, the impact can change the course of history.

Stimulus questions

What types of organisms cause disease?

What characteristics of pathogens assist them to infect new hosts?

How are pathogens transmitted from one host to the next?



14.1

What is disease?

A disease is any condition that interferes with how an organism, or any part of it, functions, hence the name 'dis'-ease'. Diseases can be grouped according to their cause.

An agent that causes an **infectious disease** is called a **pathogen**. The infected organism is the **host**. Infectious diseases such as colds and TB are caused by pathogens that can be passed from one organism to another. Pathogens include prions, viruses, bacteria, fungi, protists and parasites.

Non-infectious disease

Non-infectious diseases are not caused by pathogens and are not **communicable** – they cannot be transmitted from one individual to another. These include nutritional diseases, such as obesity, malnutrition and beri beri, and degenerative diseases, such as diabetes, osteoporosis and Alzheimer's disease. Factors in the environment may also cause disease. Intake of heavy metal particles such as lead interferes with the development of the nervous system, and overexposure to sunlight can trigger skin cancer.

Genetic diseases or disorders are due to mutations inherited from parents. They are numerous and include cystic fibrosis, phenylketonuria and haemophilia.

The **immune system** is responsible for detecting the difference between its own cells and those of other organisms. Sometimes a malfunction causes illness. When tissues are attacked by the body's own defence system, **autoimmune diseases** ('auto' = self) such as rheumatoid arthritis, multiple sclerosis and lupus can result.

Infectious disease

Individuals vary in their **susceptibility** to a pathogen; some have greater **resistance** than others. For example, if a cold is spreading through family and friends, every person does not necessarily become ill. Those in contact with the sufferer will have contact with the cold **virus**, but not everyone will develop cold symptoms. An individual's ability to avoid infection by a pathogen depends on factors such as their age, state of health and their natural resistance to that particular pathogen.

Symptoms are the effects of the pathogen on the host. For example, the measles virus causes a high temperature and a rash, and the early signs of a TB infection are an annoying cough and sore throat. Diseases usually have characteristic symptoms, which aid diagnosis.

For many infections, symptoms do not appear immediately. The time between infection and the onset of symptoms is known as the **incubation period**. This time lag (Figure 14.1.1, page 216) may occur for a number of reasons. Some pathogens may take time to reach the target tissues; others must reproduce to reach the number needed to cause disease. Toxins produced by bacteria may need to accumulate to a level that affects the host. Diseases are often communicable before the onset of symptoms, allowing the pathogen to be transmitted before the host is incapacitated by symptoms.

In most cases, the defence mechanisms of the host organism will fight off the pathogen and the host will recover. If this does not happen, disability or death may occur.

infectious disease
a disease caused by a pathogen that can be transmitted from one organism to another

pathogen
a disease-causing agent

host
an organism that is infected by a pathogen

non-infectious disease
a disease that is not transmitted from one organism to another

communicable
can be communicated (transmitted) from one organism to another

genetic disease
a disease arising from mutations inherited from parents

immune system
a complex network of cells, tissues and organs in the body that detects differences between 'self' and foreign organisms, and mounts an immune response

autoimmune disease
a condition where the immune system attacks the body's own tissues

susceptibility
the likelihood of an organism being infected by a pathogen

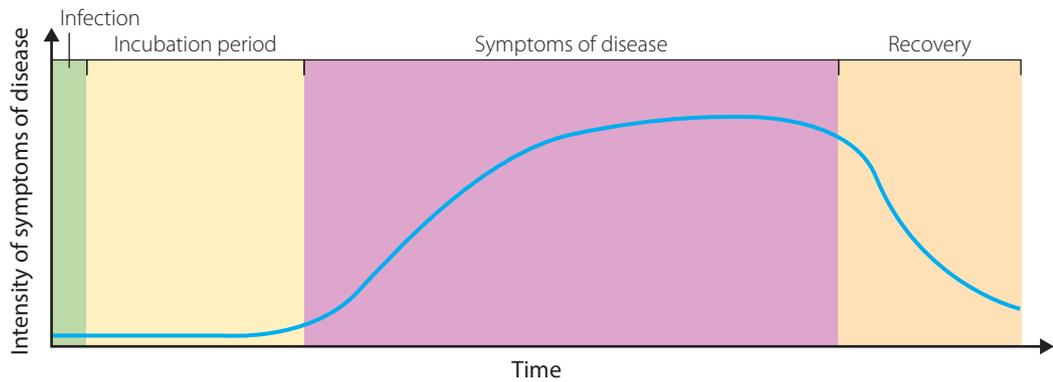
resistance
the extent to which an organism is or is not affected by an agent such as a pathogen or chemical toxin

virus
a non-cellular pathogenic agent with either DNA or RNA that can only reproduce inside a living host cell

symptom
a characteristic effect of a pathogen on the body

incubation period
the time between infection and the onset of symptoms

FIGURE 14.1.1 The various phases of an infection. Note the time lag between the time of infection and the onset of symptoms. This is known as the incubation period.



SECTION REVIEW

14.1

REMEMBERING

- 1 Define:
 - a disease
 - b pathogen
 - c communicable.
- 2 List the types of organisms that can cause disease.
- 3 Define:
 - a susceptibility
 - b incubation period.

UNDERSTANDING

- 4 Describe the relationship between a pathogen and its host.
- 5 Using examples, outline the difference between an infectious disease and a non-infectious disease.
- 6 Describe how doctors use their understanding of symptoms to help treat their patients.

14.2 Pathogens

14.2.1 How a few scientists transformed the way we think about disease

14.2.2 Infectious disease

In ancient times, some cultures believed that disease was caused by an imbalance in natural forces, while others saw disease as a punishment from the gods. Progress in understanding infectious disease was slow, even after 1847 when Ignaz Semmelweis reduced mortality in maternity wards by pioneering handwashing by doctors. It was not until the end of that century that the work of Louis Pasteur and Robert Koch provided convincing evidence that infectious diseases were caused by pathogens.

INQUIRING FURTHER

Explore the historical development of our understanding of the nature of disease transmission by researching the contributions of Koch, Pasteur and Semmelweis. Decide who made the most significant contribution to our understanding and use evidence to explain the reasoning behind your choice.

Viruses

It is a common misconception that you can catch a cold if you go out on cold, wet days. The common cold is caused by a virus, not by becoming cold and damp. A virus is a non-cellular agent composed of a protein coat and nucleic acid (Figure 14.2.1), either DNA (Figure 14.2.2) or RNA, but never both.

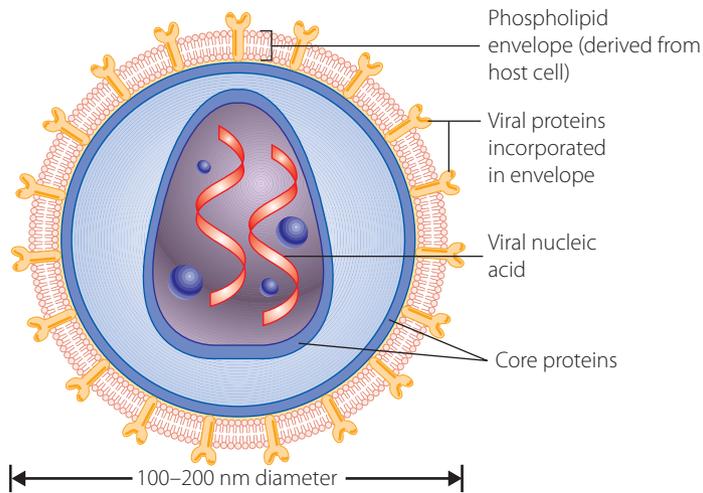


FIGURE 14.2.1 Viruses consist of a nucleic acid core surrounded by a protein coat.

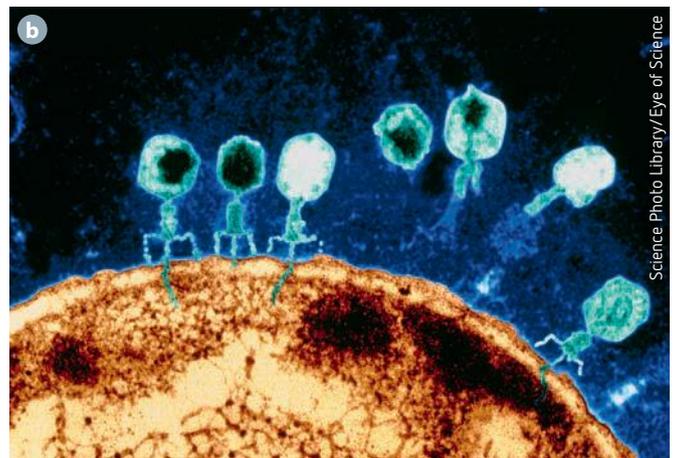
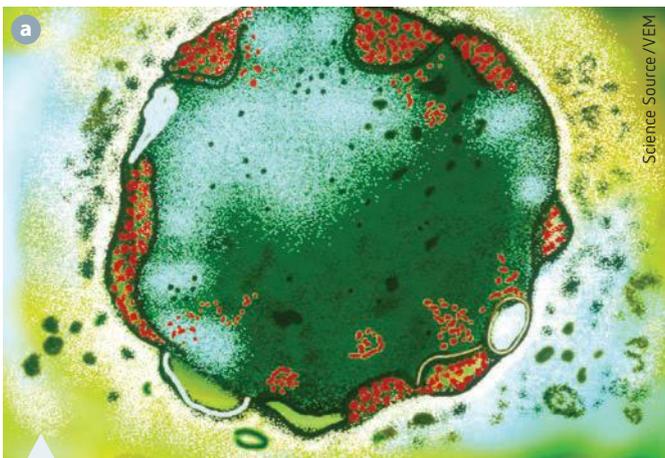


FIGURE 14.2.2 (a) The DNA virus that causes herpes in humans. (b) A coloured transmission electron micrograph of T-bacteriophage viruses attacking a bacterial cell of *Escherichia coli*. Seven virus particles are seen (blue), each with a head and a tail. Small blue tails of genetic material (DNA) are being injected into the bacterium.

When a virus infects an organism, it injects its nucleic acid into a host cell. Once inside, the viral nucleic acid takes over the host cell and instructs it to make multiple copies of the viral protein coat and nucleic acid. These then assemble into new viruses and are released when the host cell undergoes **lysis** (splits open). This releases many more viral particles, which can infect other cells within the host (Figure 14.2.3, page 218). Exposure to cold and wet conditions might lower a person's resistance to the virus but it is not the cause of the disease.

All viruses cause disease, as they completely rely on host cells for their reproduction. Unlike bacteria, viruses cannot be grown and studied outside live cells. This puts limitations on viral research.

Each virus is usually highly specific to the host cell or organism it can infect. For example, an adenovirus specifically infects epithelial cells in the upper respiratory tract, causing the common cold. This is because the virus is able to recognise and bind to receptors that are expressed only on respiratory tract epithelium.

lysis
the process of a cell bursting (verb: to lyse)



Chapters 1 and 15 discuss surface molecules as identification markers.

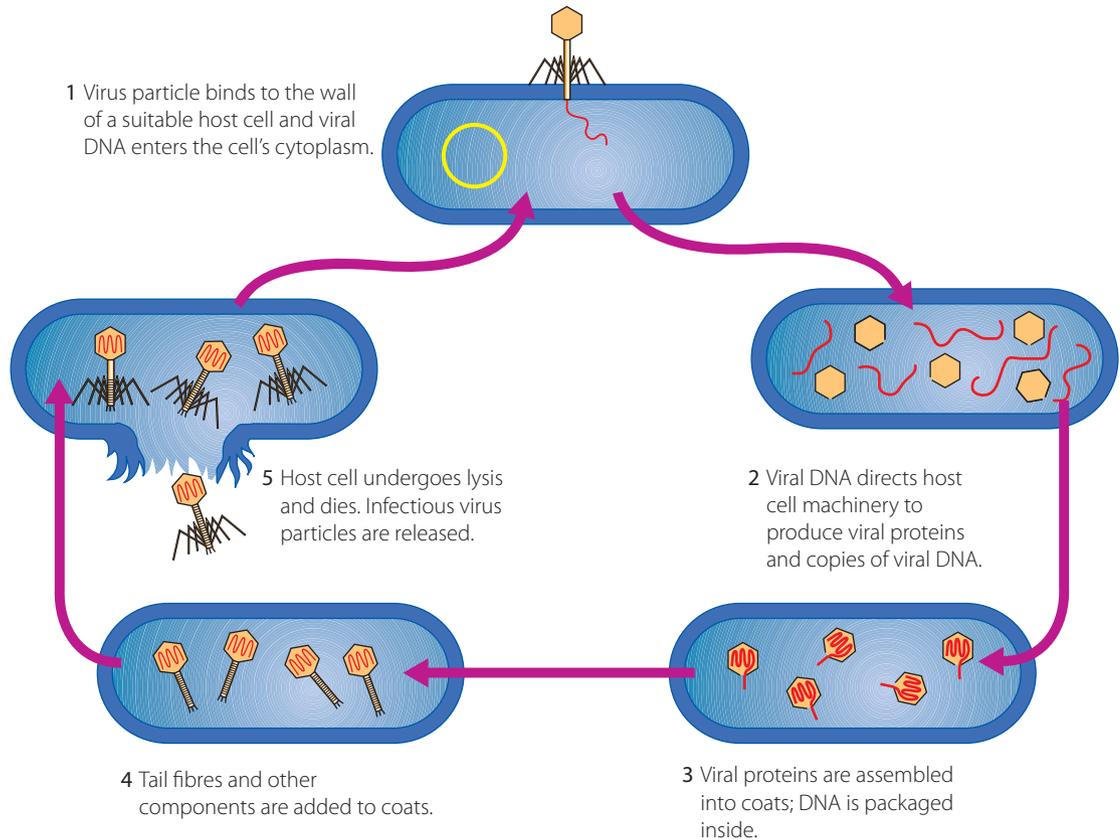


FIGURE 14.2.3 Viruses reproducing inside a live bacterial cell. New viruses are produced within the infected bacterium.

bacteriophage
a virus that invades bacteria



Visuals Unlimited/Nigel Cattlin

FIGURE 14.2.4 This apple tree is afflicted with the apple mosaic virus, one of the oldest known and most widespread apple viruses.

Virtually every type of organism on Earth is susceptible to viral infection (Table 14.2.1). Viruses are significant pathogens of many plants, sometimes resulting in the loss of crops such as potato, tobacco, corn and apples (Figure 14.2.4). Even bacteria have their own group of viral pathogens, known as **bacteriophages**.

Prions

In the United Kingdom in the late 1980s, there was an outbreak of 'mad cow' disease. The affected cattle became nervous and aggressive, lost coordination, and then fell into a coma (Figure 14.2.5). This had serious consequences for the British beef industry, and resulted in the slaughter of more than 4 million cattle. Mad cow disease is also known as bovine spongiform encephalopathy (BSE) because it belongs to a group of diseases called transmissible spongiform encephalopathies (TSE). The name comes from 'encephalo' meaning brain, 'pathy', meaning disease, and 'spongiform', meaning sponge-like, because the degeneration of brain tissue makes it look like a sponge. These diseases are caused by a small infectious protein called a **prion**

prion
a small infectious protein

(pronounced pree-on) that brings about degeneration of the nervous system and ultimately death. TSEs are a disease of humans and other mammals, such as sheep, cattle and cats.

Consumption of cattle products infected with the prion protein that causes BSE has now been linked to the occurrence of a new variant of the human TSE, variant Creutzfeldt–Jakob disease (vCJD). This disease, like BSE, is characterised by gradual loss of motor coordination, dementia and paralysis, eventually leading to death. More than 200 deaths in Britain and Europe have been attributed to this disease.

Prions are unique among pathogenic agents because they do not possess any genetic material, neither DNA nor RNA. They are much smaller than even viruses.

Prion proteins actually exist in our bodies normally and play important roles in memory, learning and passing signals from cell to cell. They are often found at the surface of neurons. There are two forms: the normal prion protein cellular form and the disease-causing prion protein form. When a prion protein encounters a normal protein, it converts it to the harmful form, which in turn converts other normal forms to harmful forms. When there are sufficient numbers of the pathogenic form, they aggregate into filaments. These fibres kill brain cells (Figure 14.2.6) consequently affecting muscle coordination and brain function.

The prion protein is very resistant to high temperatures, strong enzymes and ultraviolet radiation, and there is no effective treatment. The prion form of the protein can arise spontaneously, but it is usually transmitted by entering the body in infected food, most commonly brain tissue from an infected animal.



FIGURE 14.2.5 This cow is infected with mad cow disease, or BSE, which is caused by a prion.

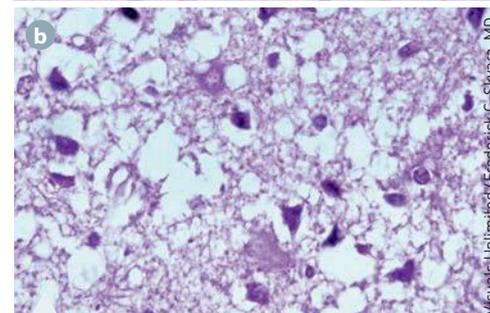
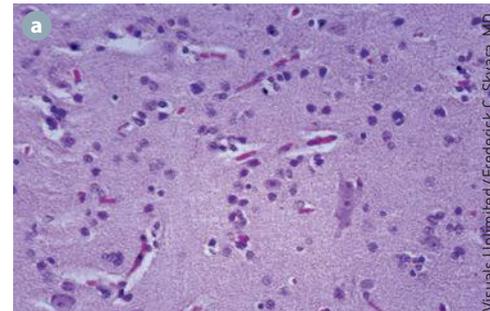


FIGURE 14.2.6 (a) Healthy brain tissue; (b) brain tissue from a victim of Creutzfeldt–Jakob disease. Note the plaques, and the holes that give the brain tissue a spongy appearance.

TABLE 14.2.1 Some diseases caused by viruses

VIRUS	DISEASE	SYMPTOMS
<i>Herpes simplex</i> type I	Cold sores	Recurring blisters on skin, usually around mouth
<i>Herpes simplex</i> type II	Genital herpes	Recurring blisters in genital area; affects both males and females
<i>Varicella zoster</i>	Chickenpox	Fever, pink spots that blister and burst
Hepatitis A virus (a retrovirus)	Hepatitis A	Inflammation of liver, kidney, spleen; jaundice, fatigue, aching limbs, headache
HIV (a retrovirus)	AIDS	Fatigue, loss of appetite and weight, immune system impaired so prone to many infections
Adenovirus	Respiratory infections	Sore throat, coughing, sneezing
Flaviviruses	Yellow fever, dengue fever	Fever, chills, jaundice, severe muscle pain
Rhinoviruses	Common cold	Sore throat, sneezing, coughing, headache
Pox viruses	Smallpox, cowpox	Sores, fever

Bacteria

It is thought that bacteria were the first life form on Earth, and today they are still the most abundant and most diverse group of organisms. Only a relatively small number of bacteria cause disease (Table 14.2.2). There are billions of bacteria living in and on our bodies and in the environment that are not pathogenic; instead, they are often beneficial.

capsule

a slimy layer sitting outside the cell wall of some species of bacteria

flagellum

a whip-like appendage that helps bacteria move

endospore

a tough, dormant structure formed by many bacteria to help them resist unfavourable conditions and disperse to new hosts

binary fission

the division of a cell into two without mitosis; a prokaryotic cell splits to form two daughter cells

TABLE 14.2.2 Some diseases caused by bacteria

BACTERIA	DISEASE	SYMPTOMS
<i>Clostridium tetani</i>	Tetanus	Sustained, severe muscle contractions due to blocking of nerve impulses by tetanus toxin
<i>Legionella pneumophila</i>	Legionnaire's disease	Fever, coughing, lung congestion
<i>Vibrio cholera</i>	Cholera	Severe dehydration, diarrhoea
<i>Yersinia pestis</i>	Bubonic plague	Swollen lymph nodes, fever, ulcers
<i>Corynebacterium diphtheriae</i>	Diphtheria	Headache, vomiting, spots on throat and tonsils
<i>Mycobacterium leprae</i>	Leprosy	Lesions on skin, loss of pigmentation, nerve damage that causes numbness – leads to muscle weakening and damage to affected areas due to lack of feeling
<i>Bacillus anthracis</i>	Anthrax (in cattle)	Boil-like lesions on skin, swelling of lymph glands, respiratory distress, fever, possibly death

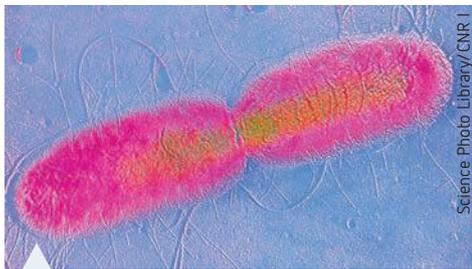


FIGURE 14.2.7 A transmission electron micrograph of *E. coli* dividing into two by binary fission

Typically, bacteria are very small (1–10 μm long). They have a cell wall outside their cell membrane. Some species have an outer protective **capsule**; others have a whip-like **flagellum** for movement. Many bacteria can form tough, dormant structures called **endospores**, which are resistant to extreme temperatures, chemicals and drying out. An endospore consists of a bacterium's DNA, ribosomes and other cytoplasmic substances. This adaptation helps bacteria withstand unfavourable conditions and facilitates dispersal to new hosts.

Some bacteria reproduce by **binary fission** (Figure 14.2.7), in which one cell splits into two. Others reproduce by budding off spores. These asexual forms of reproduction allow bacteria to reproduce very rapidly when conditions are favourable. Some species can reproduce every 20 minutes; others take 12 hours to divide.

To study bacteria in detail, you need to view them under a powerful electron microscope. However, you still obtain useful information by using a light microscope after staining. This reveals a variety of different shapes of bacteria, namely:

- spherical, known as coccus (plural: cocci) (Figure 14.2.8a)
- rod-shaped bacillus (plural: bacilli) (Figure 14.2.8b)
- spiral (plural: spirilli) (Figure 14.2.8c)
- vibrio, rather like a comma.

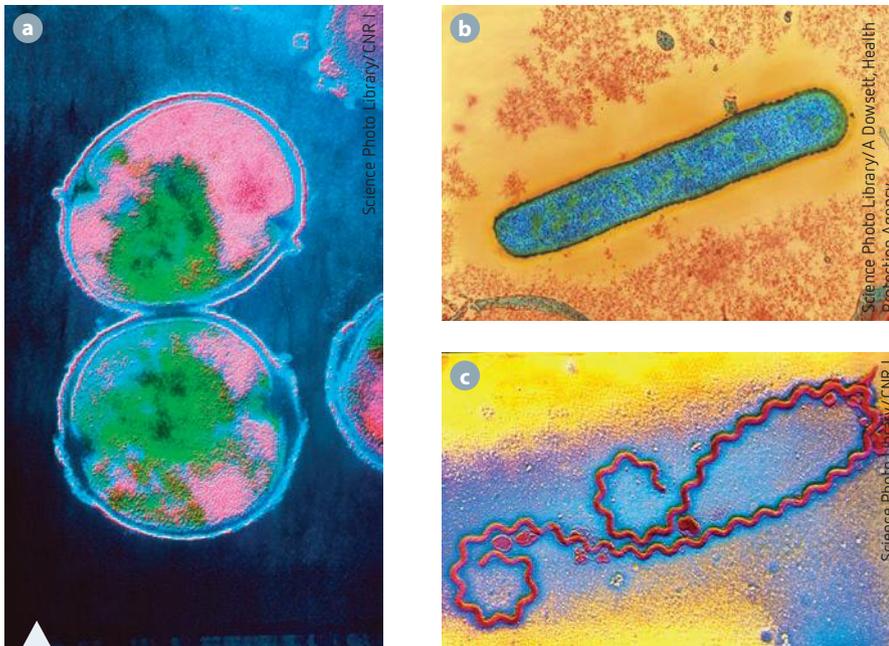


FIGURE 14.2.8 Transmission electron micrographs of (a) cocci-shaped bacteria, *Streptococcus pneumoniae* (magnification $\times 30\,000$); (b) a rod-shaped bacterium, *Bacillus anthracis*, which causes anthrax in sheep and cattle (magnification $\times 10\,500$); (c) a spiral-shaped bacterium, *Leptospira* (magnification $\times 4\,400$)

Although it is difficult to distinguish visually between the different strains of each shape, their reaction to stains can be used to classify them (Figure 14.2.9). Differences in the structure and composition of their cell walls cause them to take up different colours in the Gram stain.

Large numbers of bacteria can be grown by inoculating a small sample of a particular strain into a medium containing all their nutrient needs. This medium may be a liquid broth or a solid gel called agar (Figure 14.2.10). When one bacterium lands on a plate, it divides many times to form a visible colony. The appearance of these colonies can differ in colour, texture and shape, depending on the particular strain. Individual strains can then be isolated and grown in pure culture. In this way, microbiologists can study the responses of different strains to antibiotics and chemicals.

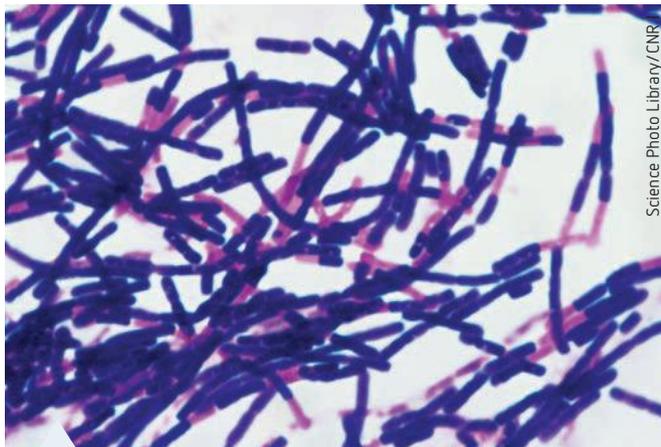


FIGURE 14.2.9 These bacteria have been stained by the Gram stain technique. The Gram-positive bacteria stain purple and the Gram-negative bacteria stain pink (magnification $\times 1\,000$).



FIGURE 14.2.10 Haemolytic bacterial pathogens infect blood cells, so they must be grown on agar plates that contain blood.



Science Photo Library/Dr. Jeremy Burgess

FIGURE 14.2.11 These grapes are infected with the fungus *Botrytis cinerea*.

Fungi

Fungi include large organisms, such as mushrooms and toadstools, as well as minute forms that can only be seen under a microscope. Microscopic fungi include unicellular yeasts and moulds. Fungi are eukaryotes that reproduce by spores and have cell walls made of **chitin**, rather than cellulose. Microscopic fungi are generally larger than bacteria. Some of them are pathogenic, causing disease in a wide range of organisms, including plants (Figure 14.2.11) and animals. Like bacteria, not all fungi cause disease.

Fungi secrete enzymes into their host, digest their food externally and absorb nutrients directly through their cell walls. Most fungal diseases in animals are external, where they irritate and inflame the skin. A common example is ringworm, a fungal skin infection of rabbits, dogs, cats, horses and humans (Table 14.2.3). Tinea is another fungal skin disease of humans. Symptoms include a rash and itchy skin. If the spores the fungi release come into contact with damaged or broken skin, they may cause new infections elsewhere.

Fungal infections in plants can cause serious disease. For example, *Phytophthora cinnamomi*, the cinnamon fungus, is devastating jarrah forests in Western Australia and affecting susceptible native vegetation in Tasmania. Rusts, which infect crops such as wheat and barley, are significant pathogens. The hyphae of fungi penetrate the external surface of the plant and extend into its tissues, depriving it of valuable nutrients and reducing crop yield. The production and release of large quantities of spores effectively transmit these fungal pathogens to new hosts.

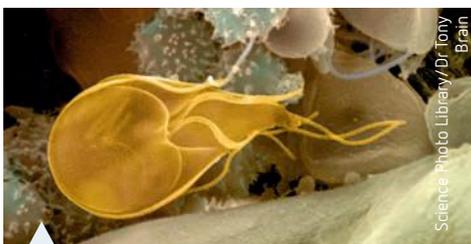
chitin

a polysaccharide that is the main component of fungal cell walls and the exoskeletons of insects and other arthropods

nutrients and reducing crop yield. The production and release of large quantities of spores effectively transmit these fungal pathogens to new hosts.

TABLE 14.2.3 Some diseases caused by fungal infections

PATHOGEN	DISEASE	SYMPTOMS
<i>Candida albicans</i>	Thrush (candidiasis)	White patches in mouth, itchiness in vaginal area, inflamed skin
<i>Tinea pedis</i>	Tinea (athlete's foot)	Itching and blisters between toes, peeling and cracking skin; secondary bacterial infections in the cracks
<i>Trichophyton rubrum</i>	Ringworm	Red blisters on skin, often in a circular pattern
<i>Diplocarpon roseae</i>	Black spot in roses	Black spots on leaves, leading to leaf damage
<i>Botrytis cinerea</i>	Dieback in many plants	A grey mould that destroys plant tissues, causing parts of the plant to die back
<i>Puccinia graminis</i>	Rust in cereal crops, such as rye and wheat	Reduces photosynthesis and productivity
<i>Claviceps purpurea</i>	Fungus produces toxins in rye that cause ergotism	Vomiting, diarrhoea, hallucinations, convulsions, gangrenous limbs; if untreated, death



Science Photo Library/Dr. Tony Brain

FIGURE 14.2.12 A scanning electron micrograph of *Giardia lamblia* (yellow) in the human small intestine. This flagellated protist contaminates drinking water, causing intestinal upsets.

Protists

Protists are unicellular, eukaryotic organisms. They reproduce both sexually and asexually. Of the 65 000 known species of protists, fewer than 24 species cause diseases in humans, but these few infect hundreds of millions of people each year. This includes *Giardia* (Figure 14.2.12) and *Cryptosporidium*, both of which produce symptoms of fatigue, nausea and diarrhoea. These two species also produce environmentally resistant cyst stages that are passed in the faeces of a host and transmitted to a new host in drinking water. Amoebic dysentery is also caused by pathogenic protists transmitted in contaminated water.

Malaria has been plaguing humans for many thousands of years. It is caused by protists from the *Plasmodium* genus. These are transmitted to the host by the bite of a female *Anopheles* mosquito. *Plasmodium* has a complicated life cycle that includes both sexual and asexual reproduction and infection of the red blood cells (Figure 14.2.13). The symptoms include headaches, chills and a burning fever. Symptoms may eventually subside, but can recur when infected red blood cells rupture and release more pathogen. Today, malaria is still one of the most serious diseases in tropical and subtropical countries.

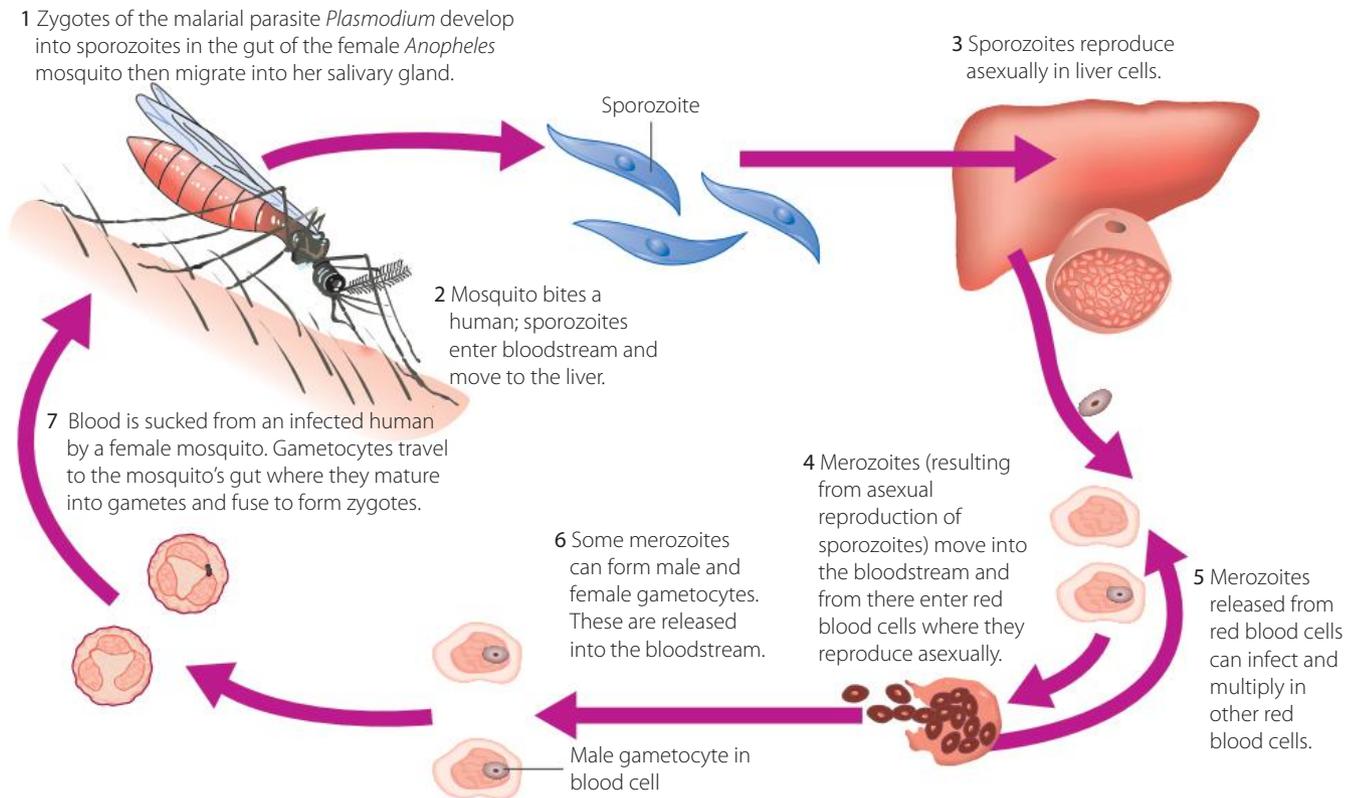


FIGURE 14.2.13 The life cycle of *Plasmodium*, the pathogen that causes malaria

Parasites

A **parasite** is an organism that lives on or in its host for all or part of its life, causing harm and gaining nutrition from the host. Because parasitism is a relationship between organisms in which one organism, the parasite, benefits at the expense of the other organism, the host, by definition all parasites are pathogens.

Endoparasites

Multicellular internal parasites (**endoparasites**), such as tapeworms, roundworms and flukes, cause untold misery and illness throughout the world. Most live in our intestines, where they consume nutrients, reproduce and release huge quantities of eggs into the faeces. Often, they cause significant illness and blood loss. For example, hookworms (Figure 14.2.14) parasitise more than 900 million people worldwide, causing daily combined blood loss of 7 million litres.

parasite
an organism that lives on or in its host for all or part of its life, causing harm and gaining nutrition from the host

endoparasite
a parasite that lives inside another organism



FIGURE 14.2.14 Hookworms are so-called because of their 'hooks' – tooth-like structures that enable them to cling to the host's bowel.

intermediate host
an organism in which a pathogen or parasite undergoes development and spends a small portion of its life cycle

encyst
when organisms produce a covering around themselves and enter a resting stage

definitive host
a host in which the adult phase of a parasite produces gametes

ectoparasite
a parasite that lives on the surface of another organism

Some tapeworms that parasitise humans use other animals as **intermediate hosts**, such as pigs, freshwater fish and cattle. There they undergo development, but do not reach sexual maturity. After the eggs hatch, juvenile larval stages migrate to the tissues to **encyst**. Humans can become infected when they eat contaminated pork, fish or beef that is raw or improperly cooked. Once the parasites reach the human intestine, they mature and excrete fertilised eggs in the faeces. Humans are called the **definitive host** because the adult phase of the parasite produces gametes in us. When eggs are eaten by grazing animals, they become intermediate hosts, completing the life cycle.

Ectoparasites

Ectoparasites are parasites that live on the surface of another organism. The most common are fleas, ticks (Figure 14.2.15) and lice, which belong to the arthropod group. While their biting may cause discomfort at times, most ectoparasites only produce minor symptoms that can be easily treated. Ectoparasites often act as carriers for the real villains; for example, the bacteria that cause the plague and Lyme disease.



FIGURE 14.2.15 A tick feeding on a dog. Ticks and fleas usually cause only minor skin irritations, but they may also transmit dangerous pathogens.

SECTION REVIEW

14.2

REMEMBERING

- 1 List two diseases that are classified as TSEs.
- 2 Outline how altered prion proteins affect the brain.
- 3 Define 'binary fission'.
- 4 Describe the way in which fungi feed.
- 5 Name and describe two fungal diseases of plants.
- 6 Describe both the route of infection and symptoms caused by *Giardia lamblia*.

UNDERSTANDING

- 7 Distinguish between ectoparasites and endoparasites. Give two examples of each.
- 8 Justify this statement: 'All viruses are pathogens'.
- 9 Describe the unique feature of a prion that distinguishes it from other non-cellular infectious agents.
- 10 Viruses infect only specific host cells. Explain how this specificity comes about.
- 11 Describe two methods by which different strains of bacteria can be identified.
- 12 Describe the difference between malaria and *Plasmodium*.

14.3 Virulence factors

pathogenicity
the capacity of a pathogen to cause disease

virulence
a measure of a pathogen's ability to cause disease within its host

Most microorganisms are not pathogens. Pathogens differ in their disease-causing capacity or **pathogenicity**. **Virulence** is the measure of the pathogenicity of an organism. It can be thought of as the intensity of the effect of the pathogen on the host. A micro-organism is pathogenic as a result of special characteristics of the organism. This includes the ability to stick to or invade a particular cell type, produce toxins, or cope with or avoid the host immune system. These characteristics that promote the establishment and maintenance of disease are called **virulence factors**. It is largely these virulence factors that bring about the disturbances in body function that is known as disease.

Adherence factors

When a pathogen colonises a new host it first must bind to host cell surfaces. Virulence factors that facilitate adherence are known as **adhesins**. As adhesins bind to specific epithelium receptors in the host, they ensure that the pathogen attaches to the tissue type in which it can survive.

Bacteria have evolved a variety of attachment mechanisms. Many pathogenic bacteria recognise and attach to epithelial surfaces by using pili (singular: **pilus**). Pili, also called fimbriae, are fine filaments of protein, up to several micrometres in length. Under the electron microscope, they resemble fine hairs distributed all over the surface of the bacterial cell (Figure 14.3.1). In some cases, the actual adhesin is a minor subunit protein at the tip of the pili.

virulence factor
a characteristic that helps bacteria to invade the host, cause disease and evade host defences

adhesin
a characteristic that helps bacteria to bind to host cell surfaces

pilus
a surface appendage in some bacteria that functions in adherence

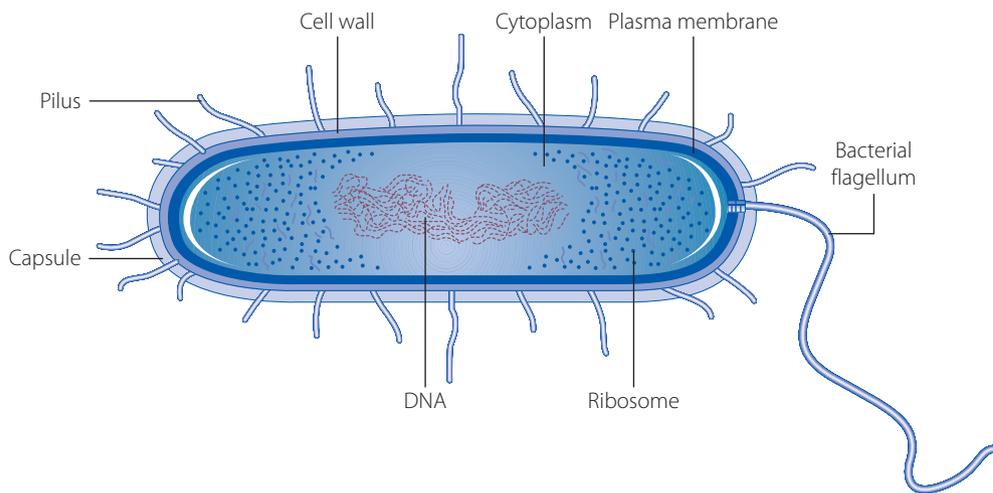


FIGURE 14.3.1 Generalised structure of a bacterium showing the outer capsule and hair-like pili

Adhesins also include a wide variety of other surface proteins, as well as bacterial cell walls and bacterial capsules. Adhesins can potentially be used in vaccines because they are often essential to infection and are surface-located, making them readily accessible to antibodies.

Invasion factors

Invasion factors are virulence factors that facilitate bacterial invasion of a host. They play a role in enabling entry into the cells and tissues of the host in order to ensure its colonisation.

Invasion factors are often enzymes secreted by bacteria. In animals, the extracellular matrix forms a scaffold in which the body cells reside. Certain enzymes released by bacteria degrade and destroy the extracellular matrix. This brings about tissue destruction, thereby promoting the spread of the pathogen. The action of another invasion factor, also an enzyme, degrades a structural component of blood clots, which facilitates bacterial transport across epithelial layers and penetration into the surrounding tissues.

A successful invasion by **intracellular pathogens** means penetrating host cell membranes. Surface proteins found on some bacteria allow them to invade mammalian cells via trans-membrane proteins.

invasion factor
a characteristic that helps pathogens to invade the host

intracellular pathogen
an organism that lives inside host cells

Capsules

The capsule is a large, well-organised layer made of thick polysaccharide gel that forms part of the outer structure of many bacterial cells. Not all species produce capsules. Encapsulated strains of bacteria have been shown to be more virulent than non-encapsulated strains. Research has shown that capsules inhibit phagocytosis by host immune cells, thereby protecting bacteria against host defences.

toxin

a poisonous substance produced by living organisms

endotoxin

a poisonous molecule attached to the outer membrane of certain bacteria that is usually released upon lysis of the bacterial cell.

lipopolysaccharide

a lipid-sugar compound that forms the outer surface of some types of bacteria

exotoxin

a protein toxin or enzyme actively secreted by pathogenic bacteria into their surroundings

cytotoxin

a toxin that disrupts or kills cells

neurotoxin

a toxin that disrupts the functioning of nerves

enterotoxin

a toxin that disrupts intestinal function

Toxins

Toxins were the first bacterial virulence factors to be identified. Toxins are poisonous substances formed during the metabolism and growth of certain microorganisms, which cause disease when introduced into the host body tissues.

Endotoxins

An **endotoxin** is a molecular complex of lipid and polysaccharide called a **lipopolysaccharide**. It is attached to the outer membrane of certain bacteria and is usually released upon lysis of the bacterial cell. The lipid component is the main toxin, causing fever, changes in blood pressure, inflammation, lethal shock and many other toxic events. These events can culminate in sepsis and may lead to death.

Endotoxins don't always have negative effects on the host. Some potentially beneficial responses include activation of the immune system and stimulating division of white blood cells.

Exotoxins

Exotoxins are more toxic than endotoxins. They may act locally or in distant tissues removed from the site of bacterial growth. Their action is often confined to particular cell types or specific cell receptors. Exotoxins are protein toxins and enzymes actively secreted by pathogenic bacteria into their surroundings. They are among the most toxic of all substances and have a wide range of effects in the host. Major categories include **cytotoxins**, **neurotoxins** and **enterotoxins**.

The most toxic substance known is an extremely potent neurotoxin, the botulinum toxin, secreted by *Clostridium botulinum*. This bacterium may infect wounds or occur after improper heating during the canning of foods. The botulinum toxin blocks nerve function. This prevents muscle contraction and leads to paralysis. Death is usually caused by respiratory failure, but heart failure can also be the primary cause. The toxin is used to treat a variety of conditions, for example migraine headaches, by taking advantage of its effect as a specific muscle relaxant. It is the active ingredient in Botox, which reduces wrinkles by paralyzing facial muscles.

Cytotoxins lead to cell death by splitting open the host cells with enzymes such as phospholipases that break down the phospholipids of the cell membrane. Cholera bacteria cause disease after attaching to the lining of the small intestine and secreting enterotoxins. These toxins stimulate secretion of Na^+ and HCO_3^- ions from the intestinal epithelium, causing massive water loss by osmosis. The resulting diarrhoea may be fatal, especially if water and electrolytes are not replaced.

Lifestyle changes

Lifestyle changes can be considered a virulence factor because they can result in increased pathogenicity. Spore formation is an important way in which a pathogen can improve its chances of transmission to a new host. *Clostridium tetani*, which causes tetanus, can last for years in soil as an inert endospore (see page 220) that will resume growth when conditions become more favourable inside a new host.

INQUIRING FURTHER

Formulate an inquiry question based on the claims you see in relation to the safety of using Botox injections to remove wrinkles. For example, does Botox have measurable side effects? Or does Botox have any long-term negative health effects? Research the questions, identifying scientific evidence to support the claims.

SECTION
REVIEW

14.3

REMEMBERING

- 1 List three factors that determine the pathogenicity of an organism.
- 2 Define 'virulence factor' and provide two examples.
- 3 Describe the role of an adherence factor.

UNDERSTANDING

- 4 Explain the difference between pathogenicity and virulence.
- 5 Explain the role of invasion factors in pathogenicity.
- 6 Compare and contrast endotoxins and exotoxins.

14.4 Modes of disease transmission

To be able to persist and survive, pathogens must follow a repeating cycle of **transmission** from current to future host. This cycle can simply be direct transmission from one host to the next, or may involve one or more steps through an intermediate host or a vector. The first step requires the pathogen to escape from the body of its current host. It must then gain transport to a suitable new host, enter their body, establish itself in their tissues and finally ensure it is once again passed to a new host. In order to identify suitable strategies to control pathogens it is critical that we understand their infectious cycles.

Table 14.4.1 lists some common infectious diseases and their methods of transmission.

transmission
the passing of an infectious disease from an infected host to another individual



14.4.1 Understand how infectious disease spreads

TABLE 14.4.1 Common infectious diseases and their general methods of transmission

DISEASE	PATHOGEN TYPE	PATHOGEN NAME	MODE OF TRANSMISSION
Common cold	Virus	Rhinoviruses and coronaviruses	Body fluids: coughs and sneezes
Tinea (athlete's foot)	Fungus	<i>Trichophyton rubrum</i>	Direct contact
Plague	Bacteria	<i>Yersinia pestis</i>	Insect vector: flea
Influenza	Virus	Influenza virus	Body fluids: coughs and sneezes
Ringworm	Fungus	<i>Microsporum canis</i>	Direct contact
Typhoid	Bacteria	<i>Salmonella typhi</i>	Contaminated food and water
AIDS	Virus	HIV	Body fluids
Food poisoning	Bacteria	<i>Staphylococcus aureus</i> and <i>Salmonella</i>	Contaminated food
Cold sores	Virus	<i>Herpes simplex</i>	Direct contact
Giardiasis	Protozoan	<i>Giardia lamblia</i>	Contaminated food and water
Gonorrhoea	Bacteria	<i>Neisseria gonorrhoeae</i>	Direct contact during sexual intercourse

Transmission by direct contact

contagious
able to be transferred
by direct contact

Diseases that are easily transmitted by direct contact with an infected organism are called **contagious**. Examples of these types of diseases are cold sores (*Herpes simplex* virus), chickenpox (*Varicella zoster* virus) and impetigo (*Staphylococcus aureus* or *Streptococcus pyrogenes* bacteria). An important adaptation for this mode of transmission is the formation of fluid-filled skin blisters teeming with millions of copies of the pathogen. These lesions are often very itchy. This prompts scratching, which spreads the infection to new areas or to a new host.

asymptomatic
without signs or
symptoms

Transmission of *Herpes* is also enhanced by **asymptomatic** shedding of the virus. This may be early in the infection, before any signs or symptoms of the disease are apparent or between the occurrence of visible sores. Skin-to-skin contact at this time can lead to transmission, even though the host is unaware that they are contagious.

zoonotic
a disease that animals
pass to humans;
infections that are
naturally transmitted
between vertebrate
animals and humans

Zoonotic diseases can be transmitted between animals and humans. Ringworm can be spread between humans, but it is also commonly transmitted to people from pets such as cats and dogs, and domesticated animals such as sheep and cattle. This fungal infection gives rise to raised red rings on the skin. Like impetigo and other skin diseases, ringworm spores can also be transmitted during close contact sports such as rugby and wrestling.

Transmission via body fluids

body fluid
a liquid that comes
from inside the body

A cold can be caught by shaking hands with an infected person who has just used their hand to wipe their dripping nose. This mucus will be teeming with cold virus particles. Once contaminated, the fingers of the second person can transfer virus into their nose or mouth. This is transmission via a **body fluid**. Body fluids are any liquids that come from inside the body, including sweat, tears, vomit, nasal secretions, blood, saliva and urine.

If you share drink bottles, eating utensils or lip balms, you may be exposing yourself to saliva containing pathogens that could include the Epstein–Barr virus. This pathogen causes glandular fever (or kissing disease), leading to fever, sore throat and swollen lymph nodes. Some healthy adults become long-term carriers because the virus can continue being secreted from the throat for months, or even years,

after recovery. There is no treatment for this disease, so the best way to avoid infection is to treat all body fluids, including saliva, as potentially infectious.

Pathogens that cause diseases such as chickenpox, measles and the common cold stimulate excessive nasal secretions that irritate the mucous membranes. The resultant coughing and sneezing can release droplets of mucus or saliva containing millions of microbes (Figure 14.4.1). These tiny particles can travel considerable distances before landing on the mucous membranes of another person's mouth, nose or eyes, where they can set up a new infection. Crowded, indoor environments may promote the chances of airborne transmission, which explains the increase in respiratory infections during winter months. This type of transmission is highly effective; for example, 90% of people without immunity to measles will catch the disease if they share a living space with an infected person.



FIGURE 14.4.1 A short-duration flash photograph of a sneeze, showing the number of droplets expelled. Each droplet may contain thousands of bacterial or viral pathogens.

A wide variety of pathogens can be spread when body fluids are exchanged during sexual contact. Sexually transmitted infections (STIs) caused by viruses include HIV, hepatitis B virus, human papillomaviruses (HPV) and *Herpes simplex* virus. STIs caused by bacteria include syphilis (*Treponema pallidum*), gonorrhoea (*Neisseria gonorrhoeae*) and chlamydia (*Chlamydia trachomatis*). STIs cause significant illness and contribute greatly to increasing healthcare costs. In many cases, the infected person remains contagious but asymptomatic, an adaptation that would favour the transmission of infection.

Foodborne transmission

One of the easiest ways for a pathogen to gain entry into the body is via the gastrointestinal tract, often by hitching a ride on our food. Bacteria such as *Salmonella*, *Campylobacter*, *Escherichia coli* and *Staphylococcus aureus* and viruses such as norovirus, hepatitis A and rotavirus cause these foodborne illnesses, commonly referred to as food poisoning. Although they have been recognised as diseases of humans for thousands of years, they are still common, affecting an estimated 5.4 million Australians each year. Sometimes it is the toxins and sometimes the pathogen itself that give rise to the disease.

Food can become contaminated in a number of ways. Pathogens can be transferred to food by sneezing or coughing or if an infected person touches their nose or mouth and handles food without washing their hands. In some cases, harmful microbes are spread to food from the faeces of an infected person. Rotavirus gastroenteritis causes symptoms of watery diarrhoea, nausea and vomiting and can generate 10 000 million (10^{10}) virus particles per millilitre of faeces. When a person visits the toilet or changes the nappy of an infected infant, their hands can easily become contaminated. As the infective dose is only 100–10 000 virus particles, enough pathogen to cause infection can be transmitted via food unless very strict handwashing procedures are followed.

Bacteria, in contrast to viruses, have the advantage of being able to reproduce to an infective dose outside the host. This makes it important to keep food out of the **temperature danger zone** of 5–60°C, where most bacteria can grow and reproduce. Thorough cooking of meat, poultry and eggs at temperatures above 60°C kills pathogens, but undercooked food may contain live bacteria that can transmit disease to humans. To prevent food becoming contaminated after cooking, it should be stored below 5°C.

In the developed world, more people are consuming more take-away meals. This trend makes food poisoning an increasingly important problem. Food should be eaten immediately after purchase or kept hot enough to kill bacteria. If it is to be stored, the food must be cooled very quickly.

Waterborne transmission

Travellers to Africa or Asia often become ill from drinking local tap water. This is because in many developing countries untreated sewage is discharged into the environment or onto cropland. Several important diseases are transmitted in contaminated water. These include bacterial diseases such as typhoid, cholera and *Shigella* infection, and viral diseases such as hepatitis A. Amoebic dysentery, caused by a protist, and endoparasites such as intestinal worms, can also be transmitted in contaminated water.

The South-East Asian blood fluke is carried by more than 200 million people worldwide and is one of several species of flukes that causes the chronic, parasitic disease schistosomiasis. Its complex life cycle, shown in Figure 14.4.2 (page 230), includes a human definitive host and an aquatic snail as an intermediate host. Control of schistosomiasis must be based on drug treatment, improved sanitation, health education and snail control that includes draining swamps, because the flukes depend on water to complete their life cycles.

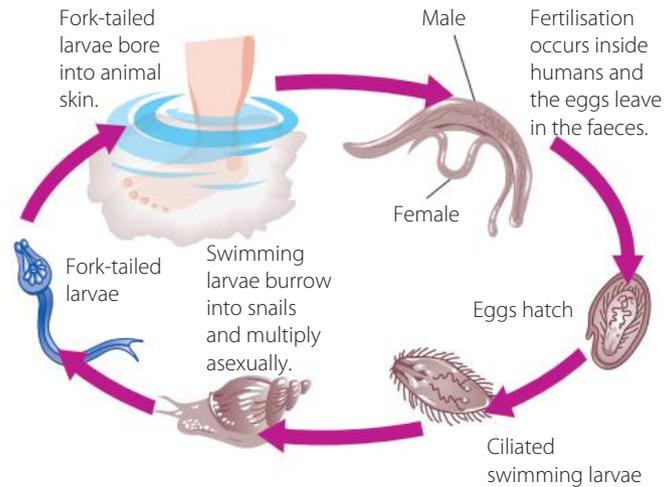
INQUIRING FURTHER

Formulate an inquiry question based on the claims you have seen in relation to the health benefits of antiseptic hand washes. For example, do antiseptic hand washes remove more pathogens than ordinary soap? Research the question, identifying scientific evidence to support the claim.

temperature danger zone

the range of temperatures at which harmful bacteria can grow and reproduce in food

FIGURE 14.4.2 The life cycle of the blood fluke, *Schistosoma japonicum*, which causes schistosomiasis



Transmission by vectors

vector

a living organism that transmits pathogens from one host to another; a vehicle used to transfer DNA sequences from one organism to another

A **vector** is a living organism that transmits pathogens from one host to another. Pathogens may need vectors if they do not easily come into contact with a new host. Or a vector may enable a pathogen to penetrate the outer defences of the host in a way that would not be possible unassisted. For example, viruses would be unable to penetrate the cellulose cell walls of plant cells without the help of insects such as aphids. Mosquitoes, ticks, fleas, lice and flies are other examples of vectors. Often, the pathogen depends on the vector to complete its life cycle.

Biting insects are vectors for many diseases. The plague (also known as the Black Death) is often thought to be a disease of the past, but each year 1000–2500 cases occur globally. It is a bacterial disease of rodents caused by *Yersinia pestis* that can be spread to humans and other animals by infected rat fleas. Deer ticks may carry the bacterium that causes Lyme disease and female mosquitoes may carry malaria parasites and dengue fever.

The mosquito is also a vector for *Wuchereria bancrofti*, a filarial roundworm. Figure 14.4.3 shows the results of prolonged, repeated infections by this parasite. Adult worms become lodged in the body's lymph nodes, where they obstruct the flow of lymph. This causes fluid to accumulate in legs and other body regions which undergo grotesque enlargement, called elephantiasis.



Science Photo Library/R Umesh Chandran, TDR, WHO

FIGURE 14.4.3 Elephantiasis is a result of infection with the roundworm *Wuchereria bancrofti*, which causes gross enlargement of the legs or external genitals, and the formation of ulcers and tubercles.

REMEMBERING

- 1 Summarise the five forms of disease transmission by copying and completing Table 14.4.2. One has already been done for you.

TABLE 14.4.2 Modes of disease transmission

MODE OF TRANSMISSION	PATHOGEN ADAPTATIONS	EXAMPLE OF PATHOGEN
Direct contact	Reproduction in skin causing itchy skin lesions, asymptomatic virus shedding	<i>Varicella zoster virus</i> <i>Herpes simplex virus</i>

- 2 Define:
 - a contagious
 - b asymptomatic.
- 3 By referring to the temperature danger zone, describe how bacteria can be prevented from growing on food.
- 4 Define 'body fluids' and give four examples of human body fluids.

UNDERSTANDING

- 5 Use an example to describe the transmission of a zoonotic disease and suggest how it benefits the pathogen.
- 6 Distinguish between the features of an intermediate host and the features of a vector.
- 7 Describe the ways in which a lack of running water, sanitation and garbage collection could increase the spread of disease.
- 8 Identify and describe two benefits to a parasite of using a vector.

APPLYING

- 9 Interpret the following evidence and use it to answer the questions.
Female filarial roundworms produce young that move actively through the bloodstream near the skin at night. If a mosquito sucks blood from this infected human, these juveniles may enter the insect's tissues. In time, they move near the insect's proboscis, ready to enter a new host when the mosquito bites another human.
 - a Suggest the mode of transmission of this pathogen and explain its benefit for the roundworm.
 - b Predict an advantage of the juveniles moving near the skin of the host at night.
 - c Describe the advantage gained by the juveniles migrating to the mosquito's proboscis.
- 10 Refer to Figure 14.4.2, which shows the life cycle of the blood fluke that causes schistosomiasis. Use evidence from the diagram to describe two adaptations of this species.

14.5 Mandatory practical

BIOCHEMICAL WARFARE

mast ring
a ring of paper with small circular 'offshoots' impregnated with different antibiotics

Antibiotics are killer molecules produced by bacteria and fungi to defend themselves from other microbes. These antibiotics are used to treat disease, but not all antibiotics are effective against all bacteria. To select the best treatment for a given disease, we need to know which bacteria are susceptible to which antibiotics. If bacteria are grown on agar plates, they produce a bacterial 'lawn', a cloudy film of millions of bacterial colonies. When paper discs containing antibiotics (**mast rings**) are placed on the agar before the bacteria have had a chance to grow, they produce clear areas where they have killed the bacteria.

Aim

To investigate the effect of a variety of antibiotics on the growth of two species of bacteria

Materials

- broth cultures of *Escherichia coli* and *Staphylococcus epidermidis*
- incubator set to 25°C
- 2 nutrient agar plates
- 2 antibiotic mast rings
- 2 sterile 5 mL pipettes
- forceps
- glass spreader
- Bunsen burner
- sticky tape
- ruler
- disinfectant solution; for example, bleach
- lab coats
- safety glasses
- gloves



WHAT RISKS ARE THERE IN DOING THIS EXPERIMENT?	HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?
Bacteria may cause disease; assume them to be pathogenic.	Wear lab coats, gloves and safety glasses; wash hands thoroughly at the end. Decontaminate benches before and after activity. Flood spills with bleach. Avoid contamination by not touching your hands to your mouth or face.
Microorganisms will grow on the agar plates.	Do not open plates once they are securely taped. Dispose of plates appropriately in autoclave or pressure cooker.
Bleach may leave a corrosive residue and discolour clothes.	Wear lab coats and gloves. Wipe the bleach off the bench after decontamination.



» Procedure

- 1 Work in groups. Before starting, ensure the bench is swabbed down with bleach to minimise contamination.
- 2 Label the bases of plates with the date, name of your group and the type of bacteria.
- 3 Remove 0.1 mL of *E. coli* culture with the pipette, lift the lid off the labelled plate and transfer the bacteria to the surface of the agar.
- 4 Either replace the lid quickly and spread the liquid evenly by swirling, or spread the liquid evenly with the glass spreader, then replace the lid. Leave the plate on the bench for 2 minutes to allow the bacteria to penetrate agar.
- 5 Repeat steps 3 and 4 using *S. epidermis* culture on the second plate.
- 6 Sterilise the forceps in the flame of the Bunsen burner, allow them to cool and then use them to place a mast ring on the surface of each of the plates. Each lobe of the mast ring is impregnated with a different antibiotic, as shown by the code on the packet.
- 7 Replace the lid and seal both plates with sticky tape and incubate them at 25°C for 24 hours.
- 8 Ensure the bench is swabbed down with bleach and wash your hands thoroughly.
- 9 The next day, observe for the presence or absence of growth near the discs.
- 10 Carefully avoiding contamination, measure the diameter of zone of inhibition: the clear area around each disc. This shows the degree of sensitivity of the bacteria to each antibiotic.

Results

Copy and complete Table 14.5.1, adding as many rows as needed.

TABLE 14.5.1 Results table

ANTIBIOTIC	DIAMETER OF ZONE OF INHIBITION (mm)	
	<i>Escherichia coli</i>	<i>Staphylococcus epidermidis</i>

Analysis of results

Describe the trend of your results, ensuring that you compare the effects of each antibiotic on the two different species of bacteria.

Discussion

- 1 Which antibiotic would be most suitable to treat an infection by *Staphylococcus epidermidis*?
- 2 Which antibiotic would you use if you were unsure of the pathogen in an infection? Explain your answer.
- 3 Explain why a control was not used in this experiment. If you were asked to use a control, what would you set up?
- 4 State four variables that you kept constant in this experiment and describe how you controlled them.
- 5 Explain the benefit of pooling data from different class groups and finding average areas of inhibition for each antibiotic.
- 6 Why have antibiotics become a less effective treatment for infection in recent years?

CHAPTER REVIEW QUESTIONS

DETAIL QUESTIONS

- 1 What places are associated with transmission of pathogens?
- 2 What happens during transmission of pathogens?
- 3 What other organisms are associated with transmission of pathogens?

CATEGORY QUESTIONS

- 4 What locations are associated with pathogens?
- 5 What physical traits are associated with pathogens?

ELABORATION QUESTIONS

- 6 Describe the effect of virulence factors on host functioning.
- 7 Predict the effect of drought on the waterborne transmission of pathogens.
- 8 Suggest two benefits of transmission using a vector.

EVIDENCE QUESTIONS

- 9 Explain your reasoning behind your answer to Question 7.
- 10 Give reasons for your answer to Question 8.

- 1 The reason for keeping cold food below 5°C and hot food above 60°C is to:
 - A prevent the reproduction of viruses on the food
 - B inhibit conversion of normal proteins to prion proteins
 - C stop denaturation of the food
 - D prevent binary fission of bacteria.

- 2 Which of the following correctly describes a pathogen and the disease it causes?
 - A Influenza caused by a bacterium
 - B Protist causing amoebic dysentery
 - C Mad cow disease caused by a virus
 - D Food poisoning from fungi

- 3 Figure 14.6.1 shows infection by a pathogen responsible for rust in wheat and rye. The group to which this pathogen belongs is:
 - A protist
 - B virus
 - C fungi
 - D bacteria.

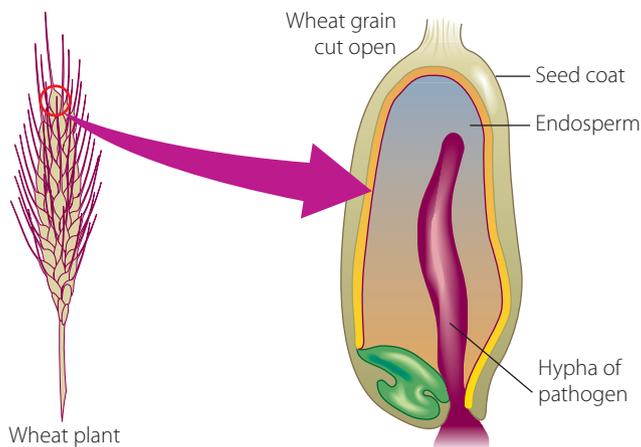


FIGURE 14.6.1
A wheat plant and magnified cut wheat grain, showing infection by a pathogen

- 4 Name the time between infection and the onset of symptoms of a disease.
- 5 Name the mode of transmission used by pathogens that induce a runny nose and sneezing.
- 6 Define 'non-infectious disease'.
- 7 Name the vector of *Plasmodium* and describe its role in the life cycle of this organism.

8 Figure 14.6.2 shows the number of cattle infected with the prion causing BSE in Britain for the years 1985–95. Since 1992, feedstuff containing sheep offal has been banned.

- Describe the trend in numbers of BSE-infected cattle in Britain from 1985 to 1995.
- Describe the action of a prion when it causes disease.
- Suggest a reason for the decline in the incidence of BSE since 1992.

9 Figure 14.6.3 shows the life cycle of the liver fluke, *Fasciola hepatica*.

- In what group of organisms would you classify this pathogen?
- Name the definitive host of *Fasciola hepatica*.
- How does the liver fluke enter its definitive host?
- The adult liver fluke is hermaphroditic; that is, it possesses both male and female reproductive organs. Describe the advantage of this feature for the parasite.
- Describe the advantages for the liver fluke in having an intermediate host.

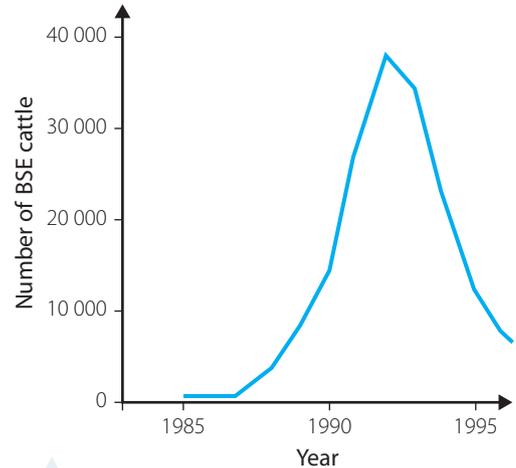


FIGURE 14.6.2 Number of cattle infected with BSE from 1985 to 1995

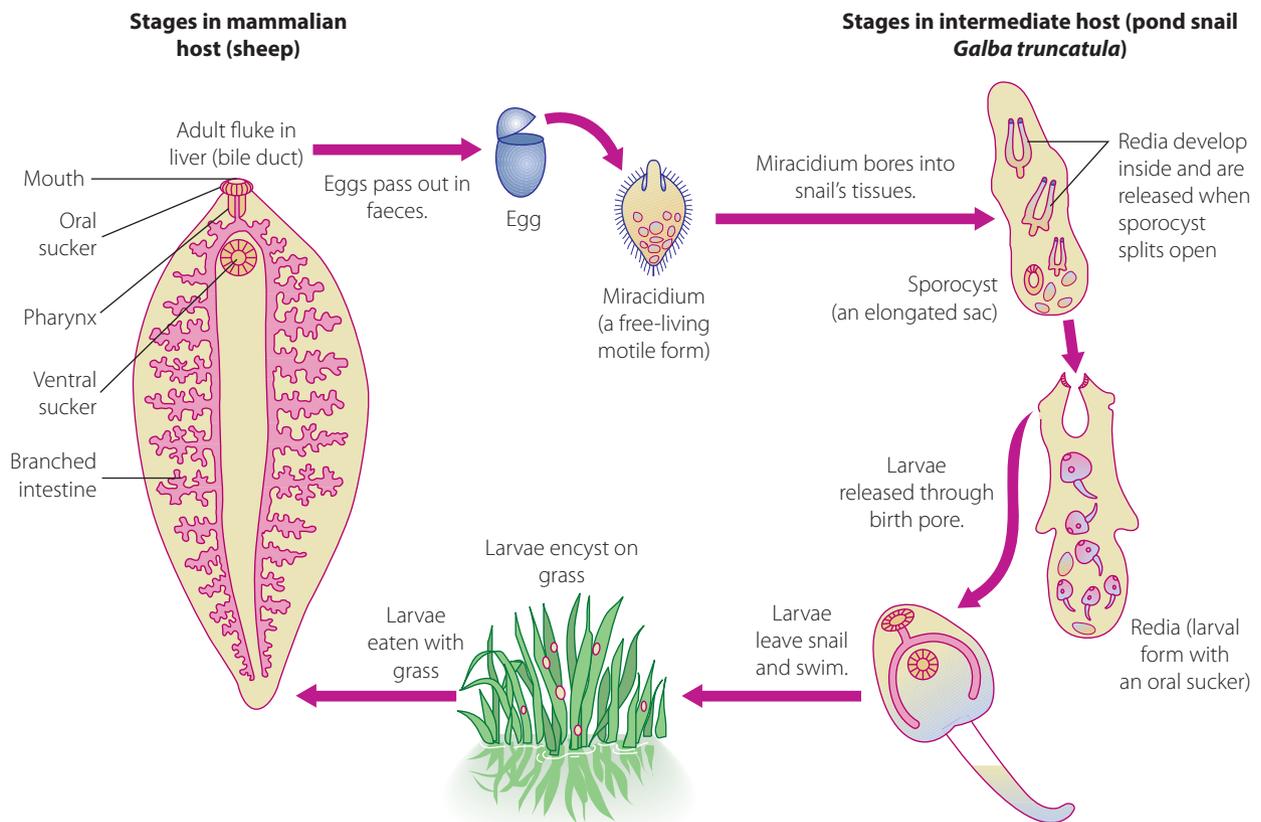


FIGURE 14.6.3 The life cycle of the liver fluke, *Fasciola hepatica*

15

IMMUNE RESPONSE AND DEFENCE AGAINST DISEASE

Introduction

Disease is often described in terms of battles and wars: attacks on the body and invasions by pathogens. The immune system is commonly referred to as the defence system, fighting invaders. Despite significant exposure to invading micro-organisms and parasites, in most cases we are able to resist infection. In what has been referred to as an evolutionary arms race between pathogens and their hosts, all organisms have evolved various types of defence mechanisms to inhibit the entry of pathogens and deal with them should they gain a foothold. Even simple single-celled organisms such as bacteria can defend themselves by producing enzymes to destroy invading viruses (bacteriophages). In this chapter, the ways in which plants and animals detect and respond to attack by pathogens are discussed.

Stimulus questions

How do organisms detect invasion by a pathogen?

What physical and chemical strategies do plants use to avoid disease?

Why have many innate defence strategies been conserved over millions of years of evolution?

Why is the immune memory such an important development in vertebrates?



self

an agent (for example, cells, organisms, substances) that is recognised by the immune system of an organism as being part of that organism

non-self

an agent (for example, cells, organisms, substances) that is not recognised by the immune system as being part of the organism itself; it is foreign

antigen

a large molecule, usually a protein or polysaccharide, that generates an immune response

toxin

a poisonous substance produced by living organisms

pattern recognition receptor

a cell receptor that recognises molecular patterns commonly shared by a number of pathogens

pathogen-associated molecular pattern (PAMP)

a broad molecular pattern commonly shared by a number of pathogens

epitope

a small part of a larger molecule that binds to a receptor site and is antigenic

flagellin

the material that makes up bacterial flagella

15.1

Stimulating an immune response

To be able to defend itself from invasion by pathogens, an organism must be able to distinguish between what belongs in that organism and what is foreign. It must be able to distinguish between **self** and **non-self**. If a substance is identified as 'non-self', it is likely to stimulate an immune response.

Any substance that triggers an immune response is called an **antigen**. Both plants and animals are alerted to the invasion of bacteria and viruses by physical and chemical changes that occur in their cells or tissues. Antigens are generally protein or polysaccharide molecules foreign to the host. Their presence, either on the outer surface of the invaders or in the **toxins** and enzymes they secrete, stimulates host immune responses that usually lead to the destruction and removal of the pathogen.

Pattern recognition receptors are proteins used by nearly all organisms to identify molecules associated with pathogens. These receptors are commonly found on the surface and in the cytoplasm of host body cells. They recognise specific substances and molecular patterns that are characteristic of a wide variety of pathogens, but not found on host cells. These molecules are called **pathogen-associated molecular patterns (PAMPs)** and include lipopolysaccharides (a bacterial endotoxin described in section 14.3, page 226), peptidoglycans, chitin, some glycoproteins and particular protein sequences on the surfaces of invaders. Even a small part of a molecule, called an **epitope**, may be antigenic (Figure 15.1.1).

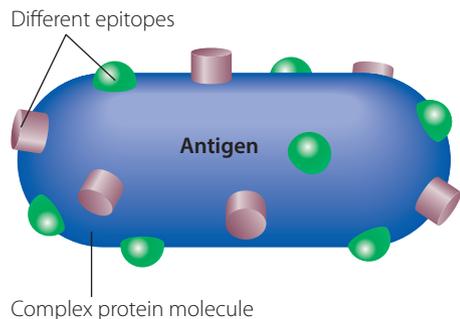


FIGURE 15.1.1 The distinction between an antigen and an epitope. Large complex protein molecules may have several different antigenic determinants called epitopes. The different epitopes are specific chemical groups or structures.

A particular receptor can recognise a variety of different pathogens if all of them display the same molecular pattern. For example, the material that makes up bacterial flagella, called **flagellin**, is found in a wide variety of bacteria. This enables a flagellin receptor to recognise many different types of bacteria as invaders. Intracellular pattern recognition receptors inside host cells are able to detect viral ribonucleic acid (RNA) and DNA in the cytoplasm because both differ from the host forms.

Host cells have evolved to recognise these broadly shared molecules because they are unique to pathogens and have remained largely unchanged during evolution. This system of recognition has the advantage of activating a rapid response to invaders but it lacks a high degree of specificity.

SECTION REVIEW

15.1

REMEMBERING

- 1 Define 'antigen'.
- 2 Outline the role of pattern recognition receptors and name three materials that bind to these receptors.
- 3 **a** Define 'PAMP'.
b Describe the role of PAMPs in the host immune response.

UNDERSTANDING

- 4 Describe the difference between an epitope and an antigen.
- 5 Describe the importance of an organism being able to distinguish between 'self' and 'non-self'.

15.2

Innate and adaptive immune responses

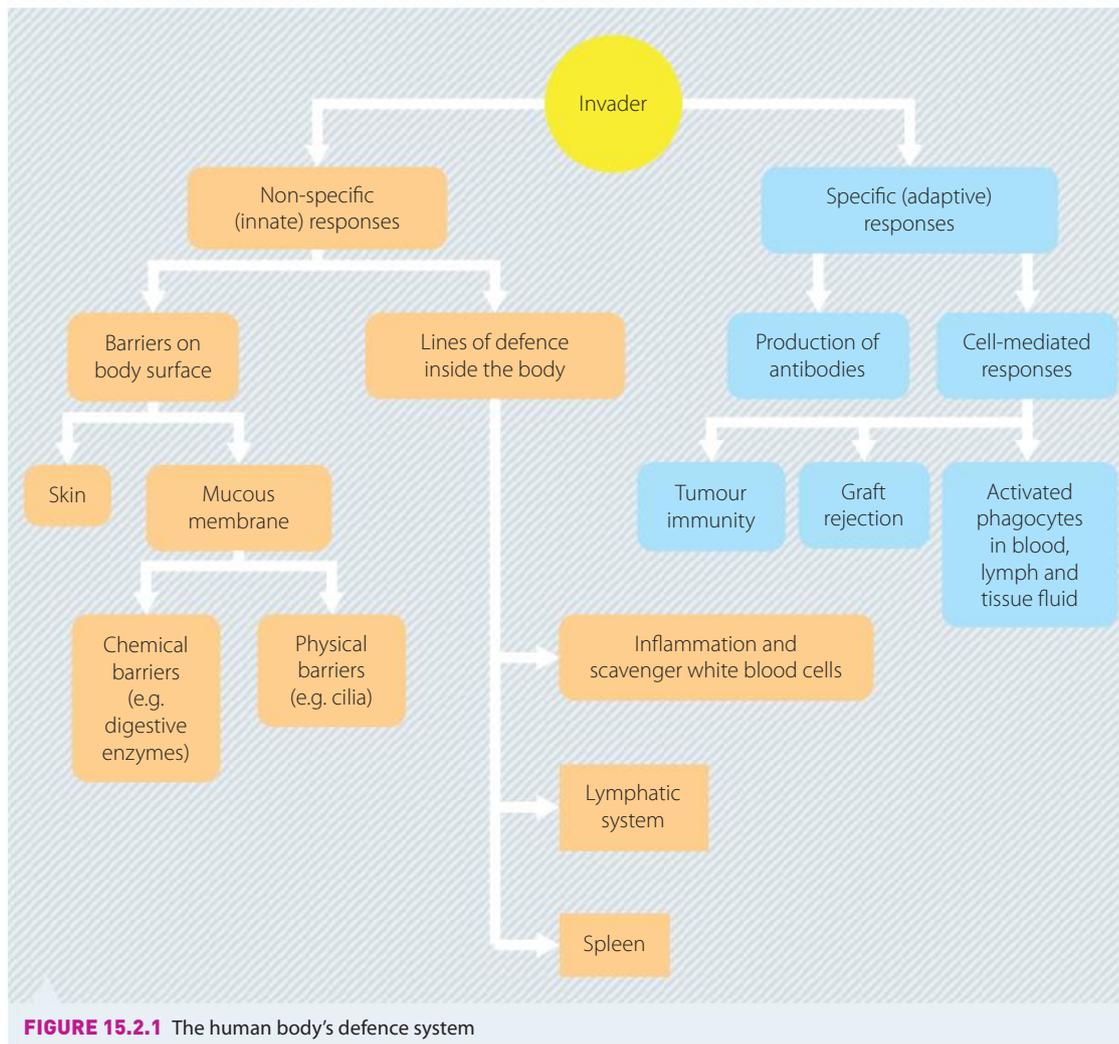
When the immune system detects a pathogen, it responds in a variety of different ways (Figure 15.2.1). **Innate immune responses** are inborn features of the way the body works. The **adaptive immune response** reacts in a specific way to an invader. The two types of response are closely linked: the detection of invaders and subsequent initiation of an innate immune response is required for an adaptive immune response to occur, and signalling molecules produced in an adaptive response can further stimulate an ongoing innate response.

innate immune response

a non-specific response to pathogens that is not learned and does not have memory

adaptive immune response

an acquired immune response; after an initial response to a pathogen, the immune system creates a 'memory' that leads to an enhanced response to subsequent encounters with the same pathogen



Innate immune responses in plants and animals

Innate immune responses are general and **non-specific**. This means that the immune system responds to any invader rapidly and regardless of its type. The responses are not learned and not influenced by our own past experience, although they have been shaped by evolution, following past experiences of our ancestors. This type of immunity is the natural resistance with which any organism is born. As with all genetically determined traits, there is significant individual variation in the effectiveness of the innate immune responses. This explains the wide variation in natural resistance, and hence disease susceptibility, between individuals, whether they are people, plants, insects or other organisms.

non-specific

when the response is the same regardless of the type of pathogen

The innate responses of plants, invertebrates and mammals are remarkably similar. It seems likely that this similarity reflects a common ancestry. In fact, scientists believe that the mechanisms evolved hundreds of millions of years ago in ancient eukaryotes, and remain in the same defensive role in their modern descendants. Although the innate responses to infection have ancient origins, they are still highly effective at preventing an infection from being established. It is difficult to know how many infections are repelled in this way, because the body defeats the invader before there are any symptoms of disease.

Adaptive immune responses in vertebrates

Adaptive responses, which exist only in vertebrates, target pathogens only after they have been specifically identified by particular components of the immune system. They are termed 'adaptive' and 'acquired' because they are capable of changing the organism after the experience of an antigen. These responses are highly **specific** because they attack only the pathogen that stimulated the response. Because of this specificity, the body requires some time to tailor its custom-made response, meaning that adaptive responses are not as rapid as innate responses.

specific
when the response
is directed against a
particular pathogen

People surviving diseases such as smallpox and the bubonic plague seldom contract the disease again, becoming immune to the effects of that pathogen. This feature of the adaptive immune response is called immunological memory. Retaining memory acquired from previous experience of that specific pathogen is an important feature of adaptive immunity.

SECTION REVIEW

15.2

REMEMBERING

- 1 Describe what it means to say innate responses to infection are non-specific.
- 2 **a** Define 'adaptive responses to infection'.
b State the type of organism that can generate these responses.

UNDERSTANDING

- 3 Describe one similarity and one difference between innate and adaptive immune responses.
- 4 Explain the value of immunological memory.

15.3 Defence strategies in plants

Plants are prone to attack by parasites, pests and disease. They are subject to attack by a huge array of mites, insects, roundworms, fungi, bacteria and viruses (Figure 15.3.1), yet the plants usually survive. They too have innate defence mechanisms.

We depend on plants for food, as well as for valuable materials including wood, textiles, medicines, dyes, inks and industrial chemicals. Reducing crop losses by understanding plant defences is critical to the wellbeing of all people. Similarly, crop-breeding programs can select plants with strong innate defences that can provide resistance to one or more important plant diseases.

Physical barriers

Plants have physical barriers that prevent pathogens from attacking living cells. These include the thick outer bark on stems and roots that contains high amounts of waxy, water-resistant materials and the cell wall that surrounds the cell membrane of all plant cells. Both provide an excellent structural barrier against fungal and bacterial pathogens.

15.3.1 An overview of
plant defences against
pathogens and
herbivores



FIGURE 15.3.1 Leaves of a (a) healthy tobacco plant, *Nicotiana sylvestris*, and (b) plant infected with tobacco mosaic virus

Plant cells also respond to microbial attack by rapidly synthesising and depositing a polysaccharide called **callose** between the cell wall and cell membrane adjacent to the invading pathogen. This impedes cellular penetration at the site of infection. Several other mechanisms help stop the spread of infection through the plant. Unlike animals, plants can shed infected parts such as leaves and branches. Wounds caused by a pathogen can be quickly plugged by resin and cells can thicken and fortify their walls, thereby preventing the spread of pathogens into nearby cells.

callose
a polysaccharide formed in plant cell walls in response to injury

Leaf structure provides a number of physical barriers to invaders (Figure 15.3.2). A thick waxy cuticle prevents entry of pathogens. Waxy cuticles and vertically hanging leaves also prevent the formation of moisture films on leaves. This inhibits bacteria and roundworms that require water for motility,

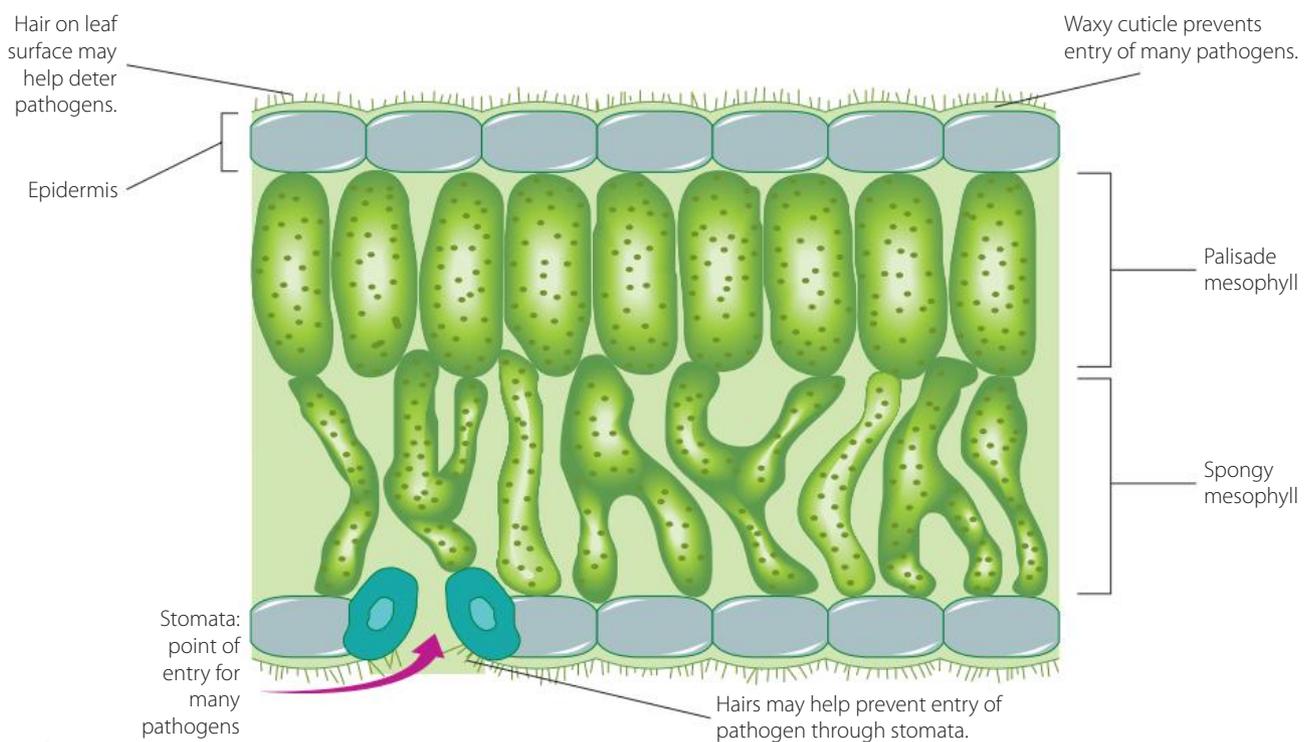


FIGURE 15.3.2 A cross-section of a typical dicotyledon leaf showing some barriers to pathogens found in plants

and fungal spores that germinate only in water. Hairs and thorns may also deter vectors of particular pathogens. Stomatal openings are weak spots, offering an entry point. Many plants have hairs that guard these openings, or have sunken stomata in the leaf that make access difficult.

defensin

a small antimicrobial peptide secreted by virtually all plants and animals

companion plant

a plant grown with another plant because one species improves the growth of the other

pyrethrin

a potent insecticide produced by chrysanthemum flowers

Chemical defence strategies

Plant **defensins** are small, stable peptides that are able to inhibit the development of fungi, as well as bacteria, viruses and insects. More than 300 defensin-like genes have been identified in plants. Defensins may constitute up to 10% of the total proteins in some types of seeds; they are also present in the cells of flowers, leaves, fruit, bark and tubers. Their antimicrobial action includes reducing membrane permeability and inhibiting the action of enzymes and ribosomes. Because defensins can stop feeding by insects, they also provide a defence against insect-transmitted viruses.

Some of the chemicals synthesised by plants can act as toxins against pathogens. These substances may be released into the environment. For example, asparagus plants and marigolds secrete chemicals into the soil that are toxic to nematodes. This makes them good **companion plants** for tomatoes, which are commonly attacked by these parasitic roundworms.

Humans rely on some of the chemicals that plants produce to defend themselves from attack. Many of our spices, seasonings, condiments and perfumes are made from essential plant oils that function as insect toxins and protection against fungal or bacterial attack. The bitter-tasting tannins that give tea its characteristic colour and taste are widespread throughout the plant kingdom and are toxic to insects. Caffeine, the alkaloid found in plants such as coffee, tea and cocoa, is toxic to both insects and fungi, while **pyrethrins** are compounds produced by chrysanthemum flowers that act as insect neurotoxins.

INQUIRING FURTHER

Pyrethrins are claimed to be very safe for humans because they are naturally occurring insecticides. Formulate an inquiry question based on this claim. For example, is an insecticide containing pyrethrin safer than other types of insecticides? Research the question, identifying scientific evidence to support the claim.

SECTION REVIEW

15.3

REMEMBERING

- 1 Provide three reasons that explain why it is important for us to understand plant disease and defence.
- 2 Describe three ways, not related to the leaf, that plants physically prevent the entry and growth of pathogens.
- 3 Summarise the chemical defences of plants in a suitable table, including their names and the ways in which they act.
- 4 Describe the interactions of a companion plant with a crop plant.

UNDERSTANDING

- 5 Describe the mechanism by which defensins kill invading micro-organisms.
- 6 Choose three structural features of leaves that are barriers to infection by pathogens. Explain how each prevents invasion.

15.4

Innate immune response in vertebrates

The innate immune response in vertebrates consists of two lines of defence. The first line of defence is provided by effective surface barriers that reduce the chance of pathogens gaining entry. If a pathogen breaches this first line of defence, it is dealt with by the host's second line of defence, inflammation and the complement system.

15.4.1 Introduction to innate immune response

The most effective way of preventing the colonisation of an organism by pathogens is to keep them out of the body in the first place. The skin of vertebrates provides various physical, chemical and biological barriers that stop the entry of pathogens and other foreign substances.

Skin as a physical barrier

As the largest organ in humans, the skin acts as a tough physical barrier between the body and the outside world. Like all the inner and outer linings of vertebrates, the skin is made from **epithelial cells**. After becoming **keratinised**, a process in which the structural protein **keratin** is deposited, the epithelial cells form a hard outer layer of the skin that is impervious to water and pathogens.

Cuts and abrasions that damage skin can allow the entry of pathogens and become ideal sites for infection. When the skin is wounded, blood vessels are damaged and cell fragments in the blood, called **platelets**, are quickly attracted to the site. They stick to the damaged tissue, sending out chemical messages that trigger the formation of a web-like mesh of **fibrin** protein. The mesh stabilises the aggregation of platelets and traps red blood cells to form a clot. This plugs the break in the vessel wall, forming a scab that seals the wound and keeps out pathogens while the skin is healing.

Skin as a chemical barrier

As well as being a physical barrier to infection, the skin produces chemical substances that destroy or inhibit the growth of micro-organisms. Glands in the skin (Figure 15.4.1) produce secretions such as sweat and oil. This gives the skin a pH ranging from 3 to 5, which is acidic enough to prevent colonisation by many pathogenic species. The skin is also protected by small defensins similar to those in plants. They are powerful natural antibiotics with antimicrobial, antiviral and antitoxic properties.

epithelial cell
a cell in a sheet of cells covering any external or internal surface in a multicellular organism

keratinised
a process by which keratin is deposited in skin cells; the surface becomes tough and waterproof

keratin
a strong, stable structural protein found in skin, hair, horn and nails

platelet
a cell fragment in blood that helps blood to clot

fibrin
an insoluble, fibrous protein mesh that impedes the flow of blood during clotting

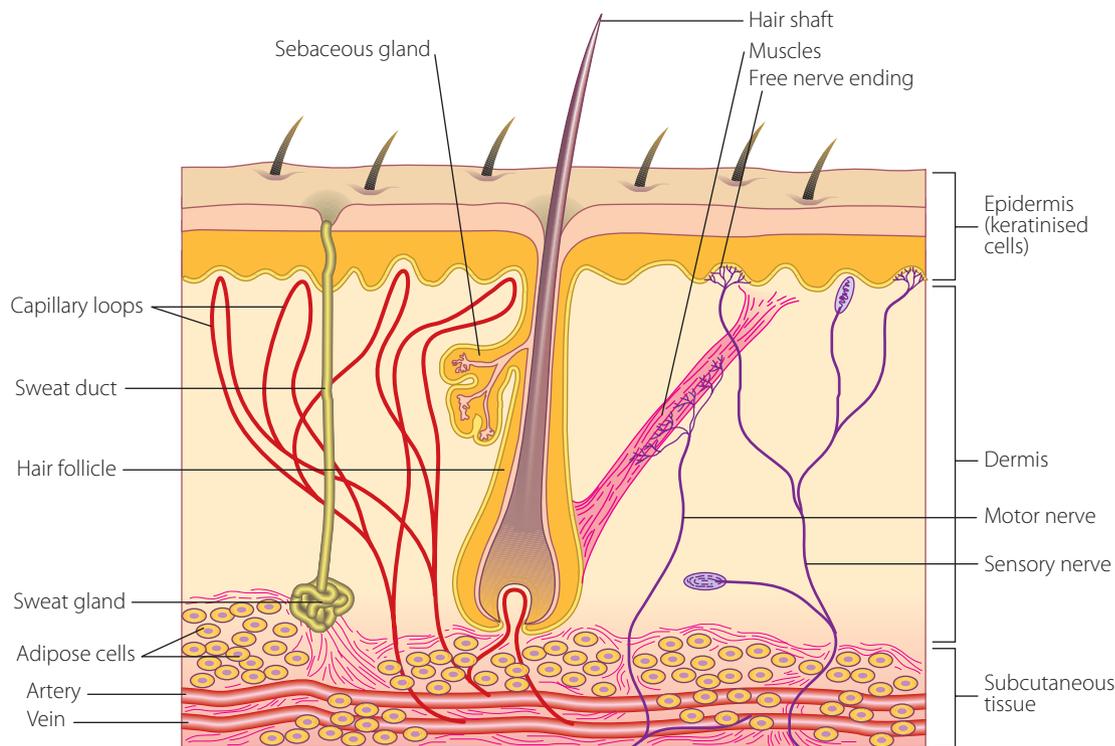


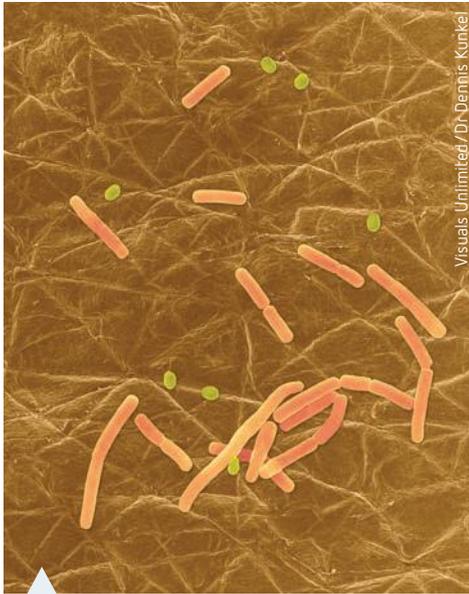
FIGURE 15.4.1 A cross-section of human skin; note the sweat gland and sebaceous gland.

sybiotic
a type of relationship between two individuals where at least one organism benefits

microflora
a community of micro-organisms, including fungi and bacteria, that live in or on another living organism

lysozyme
an antibacterial enzyme found in tears, saliva and other body fluids

lyse
to burst



Visuals Unlimited/Dennis Kunkel

FIGURE 15.4.2 Bacteria living on the surface of the skin

Skin and biological barriers

During birth, a baby acquires various micro-organisms that will become permanently associated with it. These **sybiotic** micro-organisms become the normal **microflora** that live on and in our bodies, but do not cause disease (Figure 15.4.2). By taking up space and using nutrients, the microflora prevent colonisation by other pathogenic micro-organisms. Their importance should not be underestimated – around 100trillion micro-organisms live on the surface of our skin and mucus membranes; that is ten microbial cells for every human cell in our body!

Mucous membranes and cilia

As long as it remains unbroken, our tough waterproof skin is an effective barrier against invaders. However, the external openings of the respiratory, digestive, excretory and reproductive systems provide ideal entry points into any organism. Various mechanisms exist to physically trap and expel invading micro-organisms and other foreign particles. The vertebrate respiratory, gastrointestinal and reproductive tracts are lined with mucous membranes that secrete mucus and defensins. The thick, sticky mucus traps invaders and prevents them from entering the tissues and gaining a foothold. Coughing and sneezing is one way that mucus containing potentially harmful micro-organisms and foreign substances can be removed from the nasal passages and upper respiratory tract. Another way to remove mucus is by the beating of slender hair-like structures called cilia that line the respiratory tract (Figure 15.4.3). This beating action pushes mucus up to the throat, where it can be coughed out or swallowed.

Passing urine and the flow of tears also help to flush out micro-organisms (Figure 15.4.4). **Lysozyme**, which is an enzyme contained in tears, saliva and mucus, acts as an antimicrobial agent, breaking down the cell wall of certain types of bacteria and causing them to burst (**lyse**).



Science Source/Biology, Pics

FIGURE 15.4.3 A light micrograph of a mammalian trachea, showing, in vertical section, the cilia lining the wall. Cilia help to trap pathogens and move them up and out of the body.

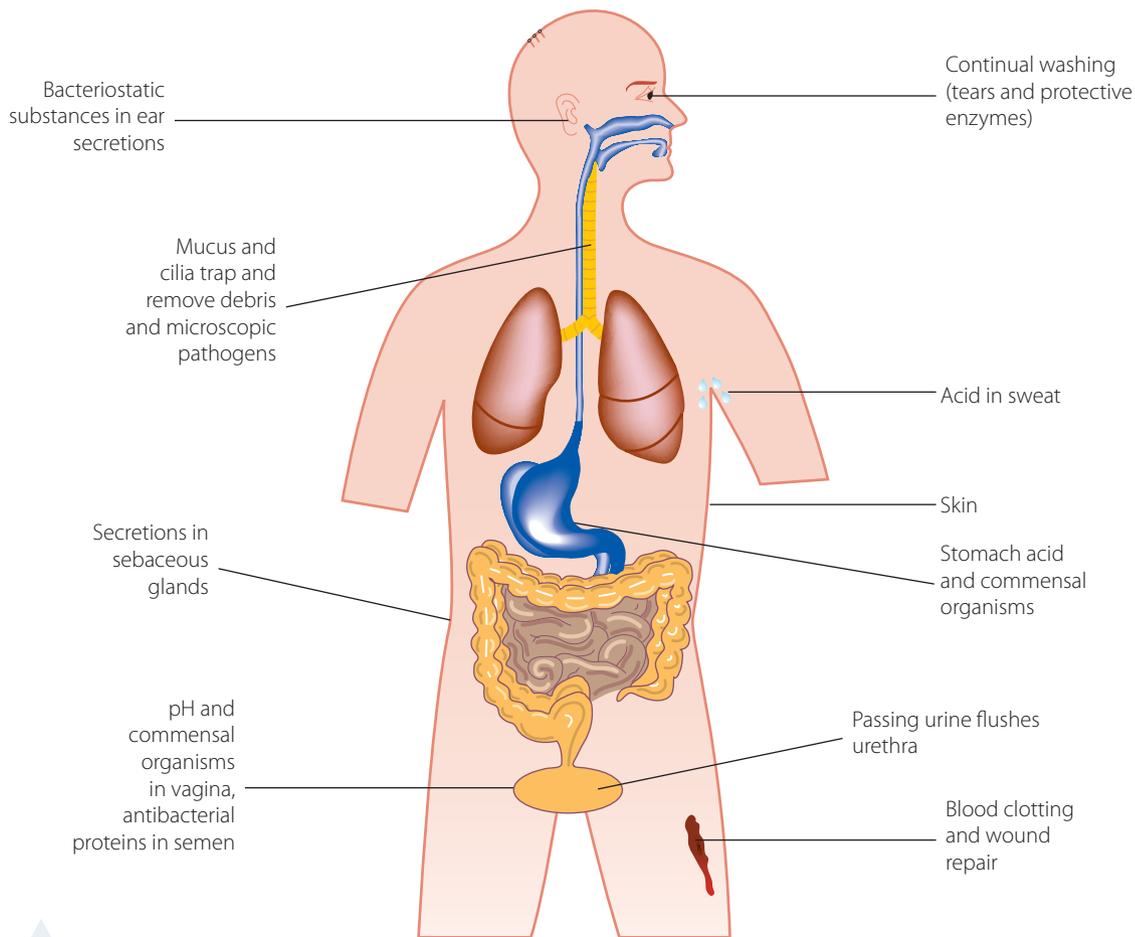


FIGURE 15.4.4 A summary of the physical and chemical barriers to pathogenic infections in a human

**SECTION
REVIEW**

15.4

REMEMBERING

- 1 Name the three major parts of the innate response in vertebrates.
- 2 State the benefits of the secretions from two types of glands in the skin.
- 3 List the three types of barriers provided by the skin.
- 4 Outline the role of mucous membranes in defence.

UNDERSTANDING

- 5 Explain the benefit of keratin in the skin.
- 6 Describe the role of platelets in blood clotting.
- 7 Describe three ways in which the body can flush out micro-organisms.
- 8 Predict the effect of washing your skin excessively.

15.5 Inflammatory response

inflammation

an innate response to infection or damage that causes swelling, pain and redness

macrophage

a large white blood cell in tissues that phagocytoses pathogens

cytokine

a small signalling molecule that coordinates inflammation and immune responses, and that leukocytes use to communicate with one another; includes interleukins and interferons

mast cell

a cell located in the tissues, which when activated releases granules containing histamine

histamine

a chemical released by mast cells that increases blood flow and the permeability of capillaries

prostaglandin

a group of lipids that can cause vasodilation, fever, and pain

vasodilation

dilation (widening) of blood vessels, particularly arterioles

arteriole

a small blood vessel that carries oxygenated blood to the tissues

chemotaxis

the movement of an organism or cell along a chemical concentration gradient either towards (positive chemotaxis) or away from (negative chemotaxis) the chemical stimulus

chemokine

a molecule that induces chemotaxis; some cytokines are chemokines

When cells are killed or damaged by invading pathogens or physical injury, inflammation and the complement system are key weapons in the innate immune response. They are rapid, general and non-specific responses, occurring in the same way every time a pathogen invades the body.

Prostaglandins, vasodilation and phagocytes

Inflammation is characterised by swelling, redness, heat and pain. It is triggered when invading pathogens are encountered by **macrophages** that are strategically distributed in all body tissues. Macrophages act as resident sentinels, detecting pathogens and switching on inflammation in other immune cells by producing a range of cell signalling molecules called **cytokines**.

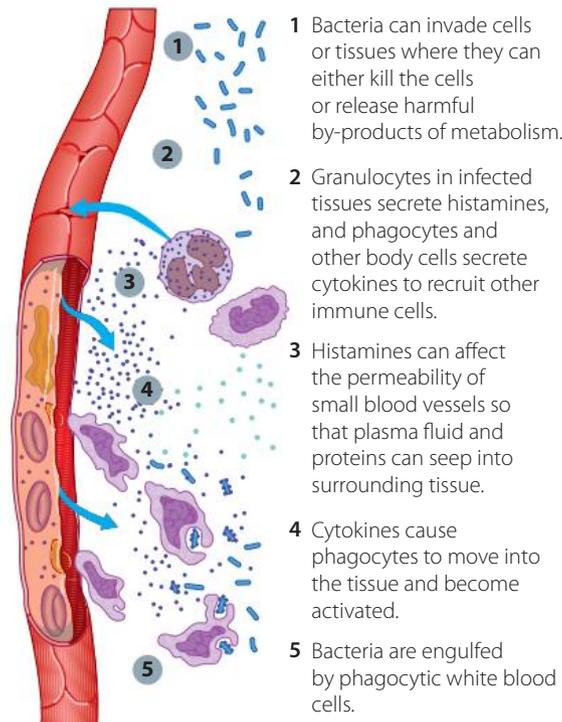
Mast cells are also located in the tissues and their cytoplasm is packed with intracellular granules containing **histamine** and **prostaglandins**, both powerful, defensive chemicals important in inflammation. Histamine induces **vasodilation**, while prostaglandins are a group of lipids that can cause vasodilation, fever, and pain.

Vasodilation is widening of blood vessels, specifically **arterioles**, allowing increased blood flow to the area and leading to redness, swelling and increased heat. Histamine also increases the permeability of capillaries in the inflamed area, making it easier for leukocytes, blood plasma and blood proteins to squeeze out through the walls and into affected tissue. This further enhances swelling and causes some pain. Pain is important because it reduces voluntary movement in that area, thus speeding up the repair process.

Chemotaxis is an important way that immune cells in blood are recruited to sites of infection or tissue damage. In this directed migration, white blood cells move towards increasing concentrations of **chemokines**, which are molecules that induce chemotaxis. Chemokines include molecules released by micro-organisms, activated macrophages and other immune cells (Figure 15.5.1).

FIGURE 15.5.1

The steps that occur in acute inflammation after invasion by a bacterial pathogen



In response to chemokines, two types of leukocytes – **monocytes** and **neutrophils** – squeeze out through the capillary walls into the tissues. Here, **monocytes** mature into macrophages. As both macrophages and neutrophils engulf invaders by phagocytosis, they are called **phagocytes** (Figure 15.5.2). The pathogen is taken in within a membrane-bound vesicle called a **phagosome**. A lysosome fuses with the phagosome to form a **phagolysosome**, which becomes increasingly acidic. An array of digestive enzymes and antimicrobial compounds helps to destroy the invader (Figure 15.5.3). Macrophages also clear up dead body cells and damaged tissue.

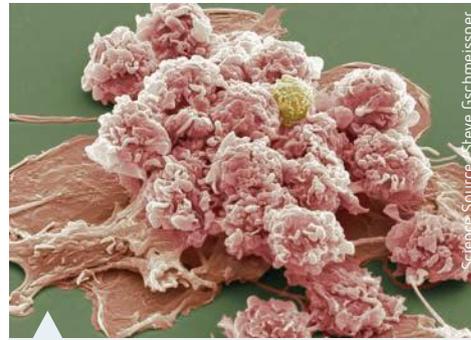


FIGURE 15.5.2 A scanning electron micrograph of a macrophage with cytoplasmic extensions. It uses these to engulf the foreign particle (yellow) that it encounters.

monocyte
a white blood cell that circulates in the blood and matures into a macrophage when it moves from the blood into the tissues

neutrophil
a phagocytic leukocyte found in the blood and tissues

phagocyte
a cell that is capable of phagocytosis; includes macrophages and neutrophils

phagosome
a membrane-bound vesicle formed around a particle during phagocytosis

phagolysosome
a membrane-bound vesicle formed from the fusion of a phagosome and lysosome

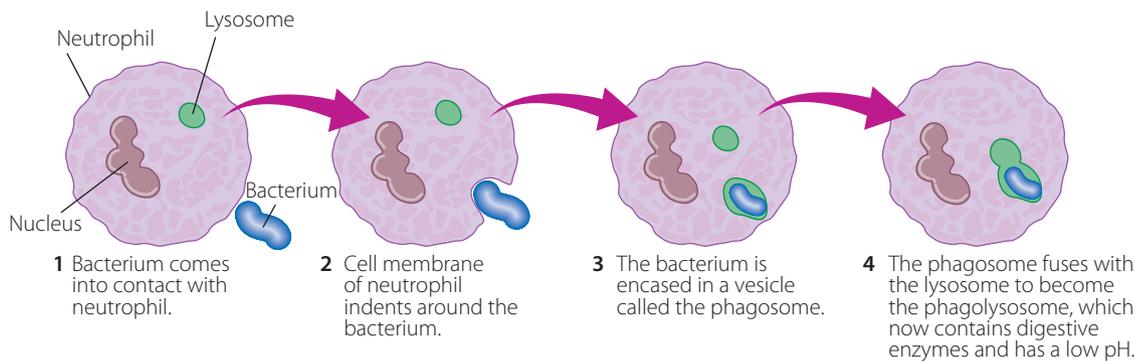


FIGURE 15.5.3 The stages of phagocytosis: a neutrophil ingesting a bacterium

Complement system

The **complement system** consists of a number of small proteins with an important role in inflammation. Approximately 20 different kinds of complement proteins circulate in the blood as inactive precursors. These precursors become activated when they encounter a foreign body, such as an invading bacterium. Activation of one complement protein has a cascading effect, stimulating the activation of other complement proteins, which then activate other proteins in turn. These proteins produce a range of effects for defending the body (Figure 15.5.4, page 248).

In a process called **opsonisation**, complement proteins bind to the surface of pathogens, acting as a tag to facilitate detection and uptake of the pathogen by phagocytes. Complement proteins induce chemotaxis to the damaged or infected site. They also activate phagocytes, increasing their ability to ingest and destroy pathogens and stimulate mast cells to release histamine. An important product of the complement cascade is the **membrane attack complex (MAC)**. The MAC forms pores in the membranes of target cells, disrupting the phospholipid bilayer. With membrane integrity destroyed, osmotic cell lysis and death follow.

complement system
a number of small proteins found in the blood that, when activated, promote chemotaxis, cell lysis and phagocytosis

opsonisation
a process in which a pathogen is coated with antibodies and marked for ingestion and destruction by phagocytes

membrane attack complex (MAC)
a complex of complement proteins that form pores in the membranes of target cells, disrupting the phospholipid bilayer

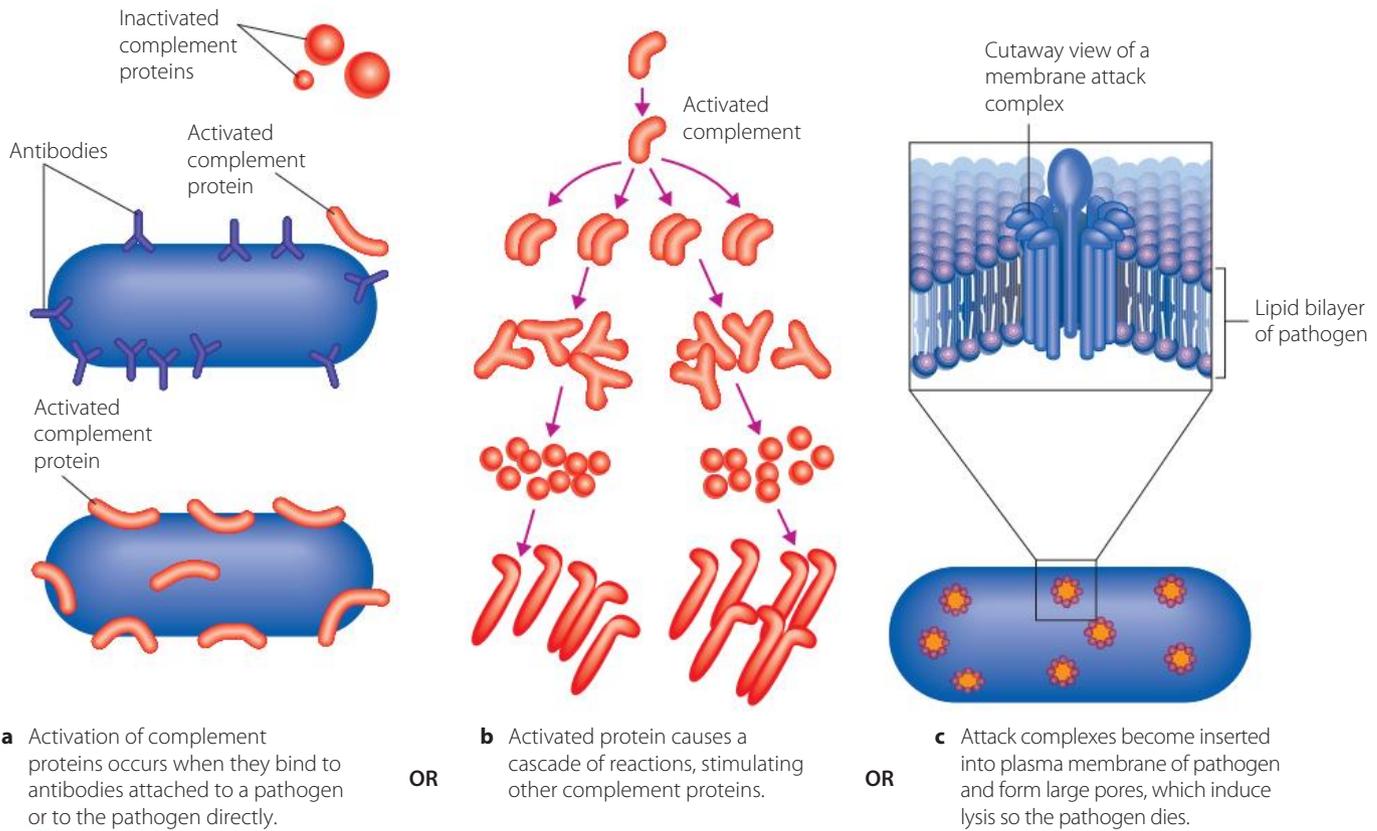


FIGURE 15.5.4 Activation of complement proteins can: (a) encourage phagocytosis, (b) enhance inflammation or (c) cause pathogens to lyse.

SECTION REVIEW

15.5

REMEMBERING

- 1 Describe three effects that follow activation of complement.
- 2 List the four characteristics of inflammation.
- 3 Describe the role of mast cells in inflammation.

UNDERSTANDING

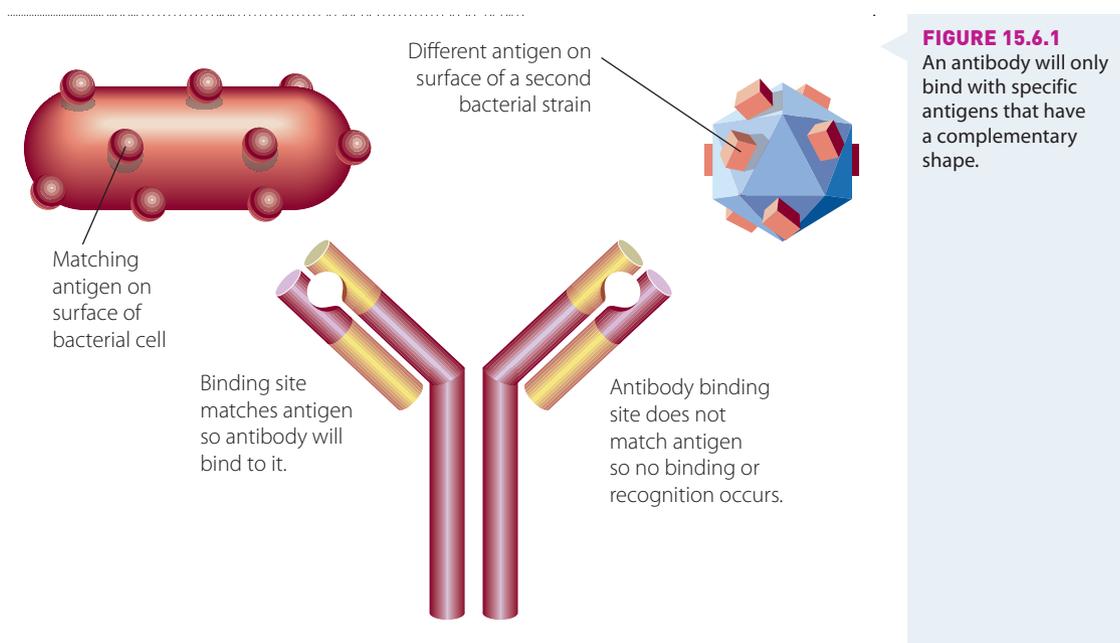
- 4 Describe chemotaxis and explain its importance.
- 5 Suggest why phagocytes, such as macrophages, typically contain large numbers of ribosomes and lysosomes.
- 6 Explain the importance of vasodilation.
- 7 Arrange the following points in order, to illustrate the sequence of events that would occur when a macrophage encounters a bacterium.
 - Lysosome fuses with vacuole.
 - Macrophage recognises bacterial surface molecules as 'non-self'.
 - Powerful enzymes digest bacterium.
 - Vacuole forms around bacterium.
 - Macrophage envelops bacterium with its cell membrane.

15.6 Adaptive immune response in vertebrates

The third line of defence is the adaptive immune response, which develops into a potent action against a pathogen and involves the activation of specific immune cells called **lymphocytes**. These cells have the capacity to 'remember' the pathogen and make a faster, stronger response to it the next time it appears.

B lymphocytes – humoral immunity

The **humoral** immune response is brought about by **B lymphocytes**, or B cells, producing large numbers of different proteins called **antibodies**. An antibody molecule consists of four subunits arranged in the shape of a Y (Figure 15.6.1). All antibodies are the same except for two matching antigen-binding sites at the two ends of the Y. These binding sites are able to attach to complementary (matching) antigens with a lock and key specificity (Figure 15.6.1), similar to that of enzymes binding with their substrate (see Chapter 3).



lymphocyte
a type of leukocyte involved in adaptive immune responses

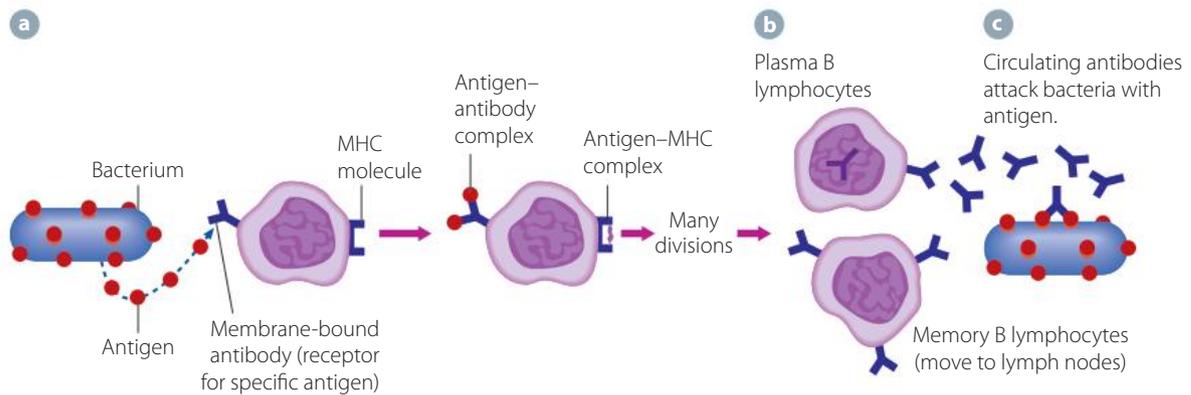
humoral
an immune response brought about by antibodies that circulate freely in the bloodstream and can lead to the destruction of pathogens

B lymphocyte
a class of lymphocytes; once activated, they are characterised by the production of antibodies

antibody
a Y-shaped protein produced by plasma cells that binds to a specific antigen; also called immunoglobulin

plasma cell
an effector B cell that has differentiated to become highly specialised for producing antibodies

Although each type of B cell only produces one type of antibody, at least 10 million different types of antibodies are produced within our bodies, none of which react against the body's own antigens. This amazing cell specialisation develops within the bone marrow, where each B cell divides rapidly to produce many identical cells that are clones of it. These clonal cells make many copies of their specific antibodies. Once the antibodies are embedded in the cell membrane, they act as receptors that bind their specific antigen. This activates the cell, triggering cell division to form two types of B lymphocytes – **plasma cells** and **memory cells** (Figure 15.6.2).



a An immature B lymphocyte presents its specific antibody mounted on its membrane. The immature B lymphocyte encounters the specific antigen recognised by its antibody. The antigen and antibody bond and form an antigen-antibody complex. This is assisted by cytokines and contact-dependent signalling provided by helper T lymphocytes that recognise the antigen-MHC complex.

b A series of reactions occur and the activated B lymphocyte divides many times. This is assisted by cytokines from helper T lymphocytes.

c Some of the activated B lymphocyte clones become plasma cells that produce and secrete large amounts of antibody molecules that help to destroy the pathogen. Others can become memory B cells.

FIGURE 15.6.2 An example of an antibody-mediated immune response to a bacterial pathogen, summarising the steps of B lymphocyte activation

memory cell
a lymphocyte that is stored in the lymph nodes long after infection and recognises a pathogen it has already been exposed to

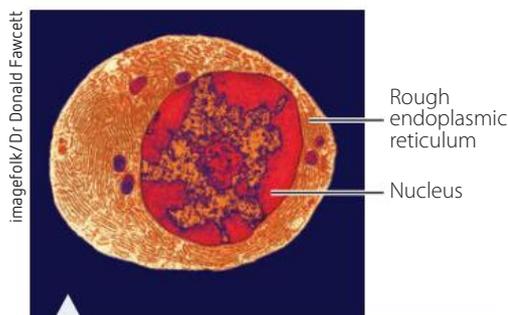


FIGURE 15.6.3 A transmission electron micrograph of a plasma cell. The extensive rough endoplasmic reticulum allows for the production of antibodies.

The resulting large numbers of plasma cells secrete into the blood up to 10 000 molecules of specific antibody per second (Figure 15.6.3), each capable of neutralising the antigen that induced its production in the first place. In this way, the antigen itself selects which of the millions of different B cell clones becomes active and secretes antibodies. In 1960, Australian Sir Macfarlane Burnet was awarded a Nobel Prize for developing this theory, known as clonal selection (Figure 15.6.4).

Antibodies, once bound to an antigen, can lead to the destruction of pathogens in four ways, all of which may occur simultaneously (Figure 15.6.5). First, antibodies that are bound to antigens are potent activators of the complement cascade; this is called complement activation. The second way is opsonisation – bound antibodies are able to attract phagocytes, effectively ‘tagging’ pathogens for phagocytosis and destruction. Some antigens can act as toxins and cause cellular damage. In these cases, antibodies neutralise toxins by preventing them from binding to their target. This is known as neutralisation and is the third way that antibodies can act. Finally, the binding of antibodies can also cause agglutination of pathogens, meaning that they become stuck together in an antibody–pathogen net. In other words, the pathogens are immobile and cannot spread. Being clumped together in one spot also makes them more susceptible to destruction by phagocytosis.

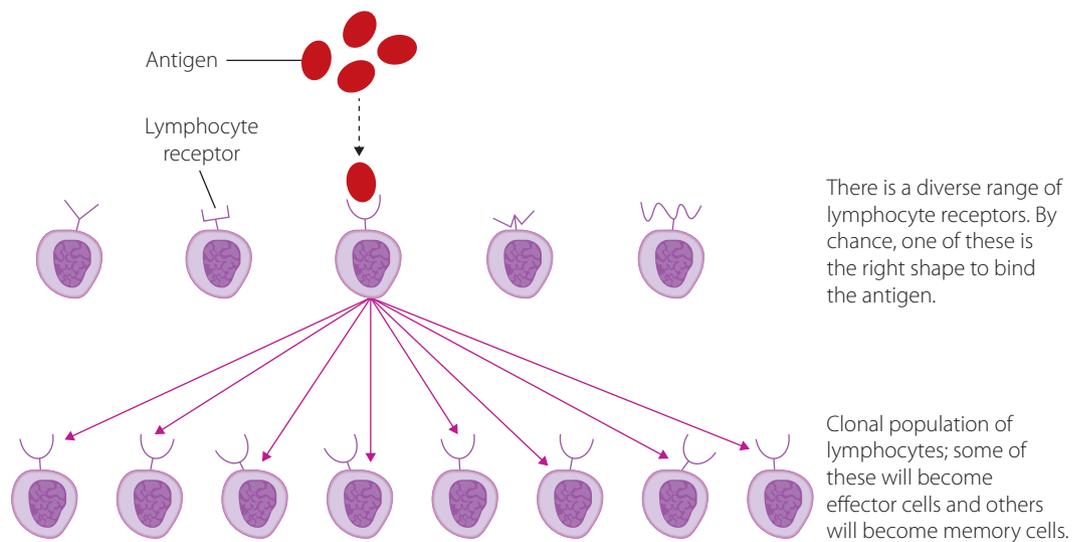


FIGURE 15.6.4 The rapid division of a particular lymphocyte clone, once it has bound to an antigen, is termed clonal selection.

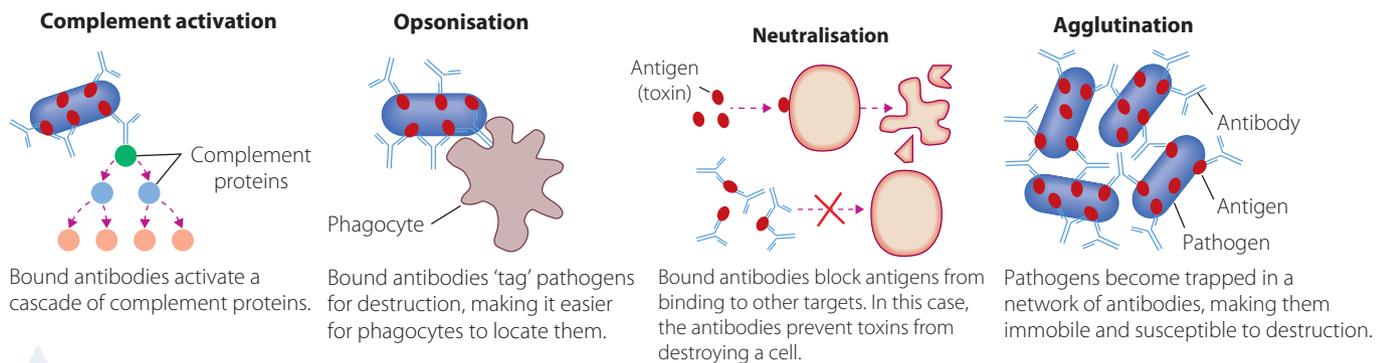


FIGURE 15.6.5 Antibodies can cause the destruction of pathogens in four ways: agglutination, opsonisation, neutralisation and complement activation.

cell-mediated immunity

when cytotoxic T cells recognise and destroy virally infected and cancerous cells

cytotoxic T lymphocyte

a class of lymphocytes that destroys virally infected or cancerous cells by secreting proteins that cause cell death

thymus gland

a gland sitting inside the rib cage that is involved in the development of mature T lymphocytes

cytotoxin

a compound released by cytotoxic T cells that kills infected or cancerous body cells

immunosuppressant

a drug that inhibits the immune system, particularly cell-mediated immunity

The large quantities of antibody provide protection for up to 28 days. In addition, significant numbers of memory B cells persist within the body for years, not secreting antibodies but still displaying them on their membranes. Any antigen-specific pathogen reinvading the host activates the B memory cells to divide and rapidly produce large quantities of antibody. This destroys the pathogen before any symptoms appear, which is why most people only experience chickenpox or measles once in their lives. After an initial infection and bout of the disease, people become immune to future infections.

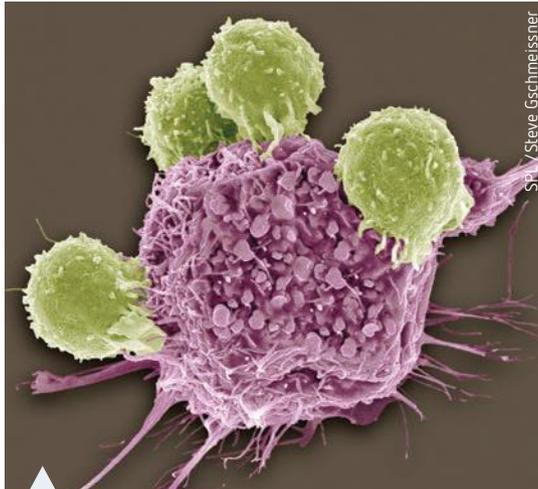


FIGURE 15.6.6 A scanning electron micrograph showing cytotoxic T lymphocytes attacking a cancer cell

Cell-mediated immunity

Cell-mediated immunity involves the direct killing of virally infected and cancerous cells by **cytotoxic T lymphocytes**. T lymphocytes originate in the bone marrow but mature in the **thymus gland**, where they become 'programmed' to recognise the antigen of a specific pathogen.

Once activated by an invader, cytotoxic T cells divide many times to form an army of clones. Some of these clones become effector cells, while others remain as memory cells that can be activated quickly upon a second encounter with the same pathogen. Cytotoxic T cells are amazing killers; they can eliminate infected body cells or tumour cells by releasing powerful **cytotoxins** (Figure 15.6.6).

Although these cells are indispensable to our immune system, they can also cause problems for patients requiring organ transplants. These cells are the primary cause of transplant tissue rejection. Transplant patients must take high levels of **immunosuppressant** drugs to ensure the new organ is not destroyed by the immune system.

Other types of T cells include helper T and regulatory T lymphocytes. Helper T cells enhance the activity of other immune cells by releasing T cell cytokines. Regulatory T lymphocytes suppress or regulate immune responses, preventing the immune system overreacting to a stimulus.

INQUIRING FURTHER

It has been suggested that a solution to Australia's low rate of organ donation is to make organ donation compulsory. Formulate an inquiry question around this topic. For example, should organ donation be mandatory in Australia? Research the question, ensuring you address individual, social and cultural considerations.

SECTION REVIEW

15.6

REMEMBERING

- 1 Identify what type of compound an antibody is.
- 2 Describe how an antibody differs from an antigen.
- 3 Describe four ways in which an antibody can act to fight off a pathogen.

UNDERSTANDING

- 4 Plasma B lymphocytes have an extensive rough endoplasmic reticulum and many mitochondria. Relate the structure of these cells to their function.
- 5 The adaptive immune system is often described as having memory. Explain what this means, using killer T cells as an example.
- 6 Explain how antibodies are similar in action to enzymes.

15.7

Interpreting data: immune response

When you interpret data, you are often asked to first describe trends in the data and then to explain what caused the changes noted. The following scenarios provide examples of how data can be interpreted and explained.

Developing immunity

Figure 15.7.1 shows antibody production after an initial and then a subsequent exposure to an antigen. Imagine that the antigen in this diagram is from the varicella zoster virus, which causes chickenpox. When first exposed to the virus the body produces antibodies, but there is a delay before enough are produced to fight off the virus. This is why people develop symptoms of chickenpox when first exposed to the virus.

An analysis of the data in the graph in Figure 15.7.1 shows three differences between the response to the initial exposure and subsequent exposure to the chickenpox virus. Compared with the **primary response**, the **secondary response** shows a greater production of antibody, which occurs faster and remains at higher levels for much longer.

These three differences can be explained as follows. When a person is first exposed to the virus, activated B cells develop into both plasma and memory cells. The plasma cells secrete antibody. The second exposure to the antigen activates the memory cells, allowing them to produce antibodies much more rapidly and in much greater amounts. This means that the person is now effectively immune to chicken pox, explaining why most people only experience chickenpox once in their lives. After an initial infection and bout of the disease, they become immune to future infections.

primary response
the response generated when an antigen is encountered for the first time

secondary response
the response generated when the body encounters a pathogen to which it has previously generated an immune response

Immunosuppression

Human immunodeficiency virus (HIV) is one of the most significant infectious diseases of modern times. This viral infection results in a severe form of **immunodeficiency** known as acquired immunodeficiency syndrome (AIDS). Conditions where a defective immune system renders someone vulnerable to infection are known as immunodeficiency.

immunodeficiency
a state in which the immune system does not function properly, leaving a person susceptible to infections the immune system could normally fight off

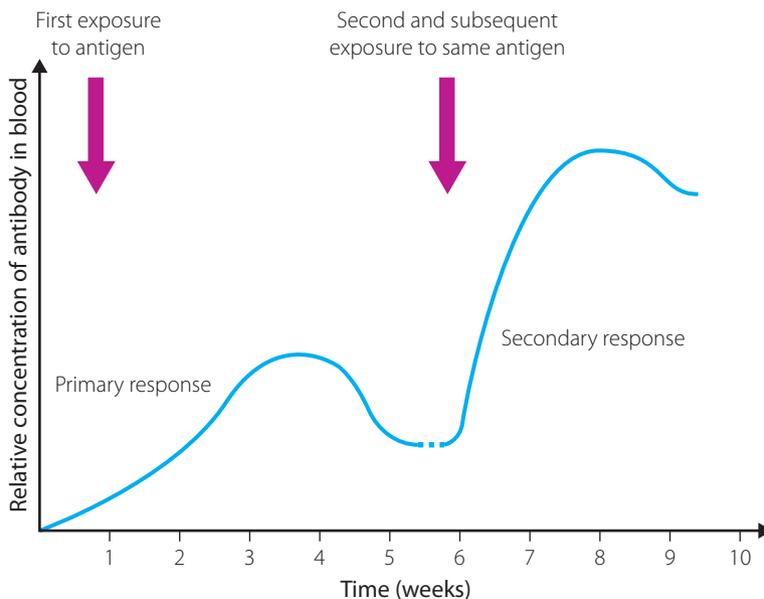


FIGURE 15.7.1
Antibody levels after an initial exposure to an antigen and after a second exposure to the same antigen

HIV generally targets helper T cells by binding to specific receptors on these cells and injecting its RNA. The helper T cell is then stimulated to produce more viral particles, which bud from the host cell's own plasma membrane, ready to infect other helper T cells (Figure 15.7.2).

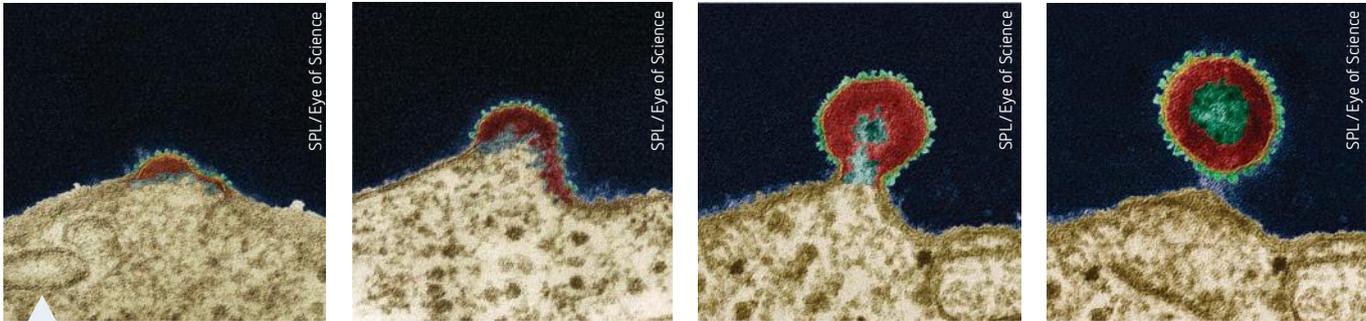


FIGURE 15.7.2 Transmission electron micrographs of HIV budding out of a helper T lymphocyte

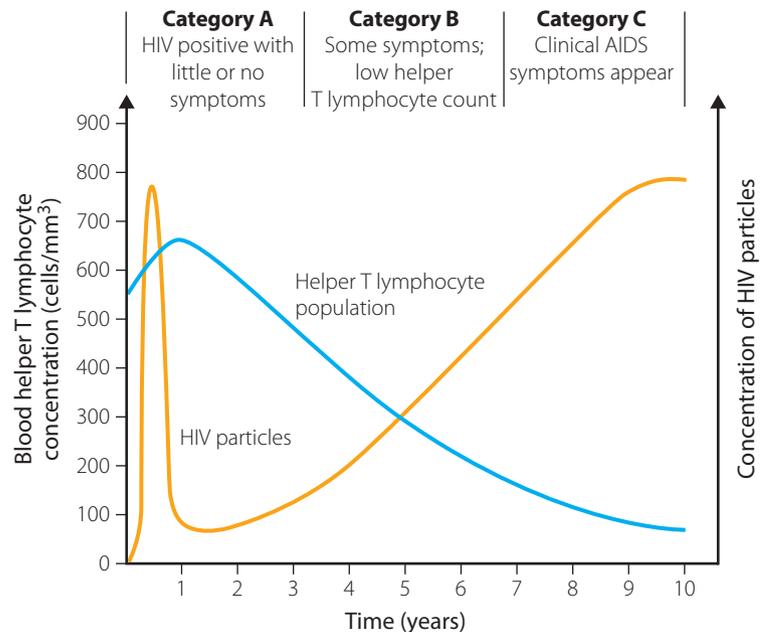
After several years, an infected individual becomes prone to multiple infections from pathogens that would normally be relatively harmless. Many sufferers die from simple yeast or bacterial infections, pneumonia or unusual tumours and cancers.

The graph in Figure 15.7.3 shows the number of helper T cells and viral particles over a 10-year period after infection. An analysis of the data in the graph shows an increase in the numbers of helper T lymphocytes in the first year after infection. This is followed by a steady decrease in numbers over the next 9 years. Over the first 6 months after infection, the numbers of HIV viral particles rapidly increase, then rapidly decrease. During the following 9 years, their numbers gradually and steadily increase to a maximum 10 years post infection.



15.7.1 WHO: HIV
15.7.2 CDC: HIV/AIDS
15.7.3 AFAO

FIGURE 15.7.3
The stages of infection by HIV



These trends can be explained as follows. Early on during HIV infection, the immune system is capable of producing a response against the virus. This explains the rise in helper T cells and the decrease in viral particles. However, as more and more helper T cells are infected with the virus and killed, the effectiveness of immune responses decreases and the number of viral particles present increases.

SECTION REVIEW

15.7

REMEMBERING

- 1 Define 'immunodeficiency'.

UNDERSTANDING

- 2 Explain why people develop symptoms of chickenpox when first exposed to the virus, but not on the second encounter.
- 3 Given that viruses are intracellular pathogens, suggest a reason why antibodies are unable to fight infection by HIV.
- 4 Explain why it is difficult to know exactly when a person moves from a Category A to a Category B infection.

15.8

Active versus passive immunity

Even before scientists really understood the nature of disease, attempts were made to protect people by the artificial development of immunity.

Active immunity

When the body is infected by a pathogen, memory T and B cells are produced. They lie in wait in the lymph nodes, ready to be rapidly activated if that antigen is encountered again. Once activated, they will destroy the pathogen before symptoms of the disease arise. This kind of immunity, stimulated by natural exposure to a pathogen, is an example of **active immunity** and generally lasts many years.

Unfortunately, it can often take some time for the combined forces of the immune system to locate the invader and mount a defence. Serious illness and even death may occur before a defence is mounted. We now have ways to take advantage of immune memory so that memory cells can exist before the first invasion of a pathogen.

active immunity
the immunity formed when the immune system is stimulated by an antigen and effector and memory cells are generated

vaccine
an injected solution of antigens or pathogens that is designed to elicit a primary response and promote the formation of memory cells

Vaccines

Vaccines have been developed that trick the immune system into responding as if it is being invaded by a pathogen. To do this, vaccines must contain some form of antigen. Once administered, this antigen stimulates the immune system and memory B and T cells are formed. They wait in the lymph nodes ready to detect and attack the real pathogen carrying these antigens, as soon as it invades. Vaccines may involve injecting a dead version of the pathogen or a weakened (attenuated) strain that produces only mild symptoms of disease.

Vaccination gives an organism the experience of a particular pathogen's antigens without the host actually developing symptoms of the disease itself. It generates active immunity as both the innate and adaptive immune responses are stimulated. This kind of immunity generally lasts many years, although the immune system may need booster injections periodically to enhance its army of memory cells.

Passive immunity

passive immunity
immunity characterised by the transfer of antibodies from one individual to another; this type of immunity does not show memory

Passive immunity occurs when antibodies are transferred from an external source (Table 15.8.1). This provides protection from the pathogen, but only for as long as those antibodies last. Because there are no memory cells, if the person encounters the pathogen again, they will not be immune.

TABLE 15.8.1 Comparison of active and passive immunity

	ACTIVE	PASSIVE
Naturally occurring	Exposure to a pathogen	Transfer of antibodies from mother to foetus via the placenta Transfer of antibodies from mother to baby via breast milk
Artificial	Vaccination	Anti-venom Antibodies against particular pathogens; for example, rabies

Antibodies gained via the placenta

Passive immunity occurs naturally when antibodies pass from a mother to her foetus through the placenta or during breastfeeding. These antibodies are essential for protecting the young baby from pathogens soon after it is born. A baby is most vulnerable to infection 2–3 months after birth because its own immune system is not yet fully developed and the antibodies it received from its mother have disappeared.

Antibody serum injection

antibody serum injection
an injection of serum containing antibodies, given to provide immediate protection from a toxin or pathogen

In some diseases, there is insufficient time for antibodies to be produced actively by the patient before death or serious injury occurs. In such instances, an **antibody serum injection** is given. This is when a dose of antibodies, targeted to a specific antigen, is injected into the patient who has been exposed to a pathogen or toxin. Rabies is a fatal viral disease that is spread in the saliva of infected animals. Rabies can be prevented by administering antibodies against the rabies virus when somebody has been bitten by an infected animal. Similarly, the anti-venom given after a snake or spider bite is a solution of antibodies against the venom (Figure 15.8.1).

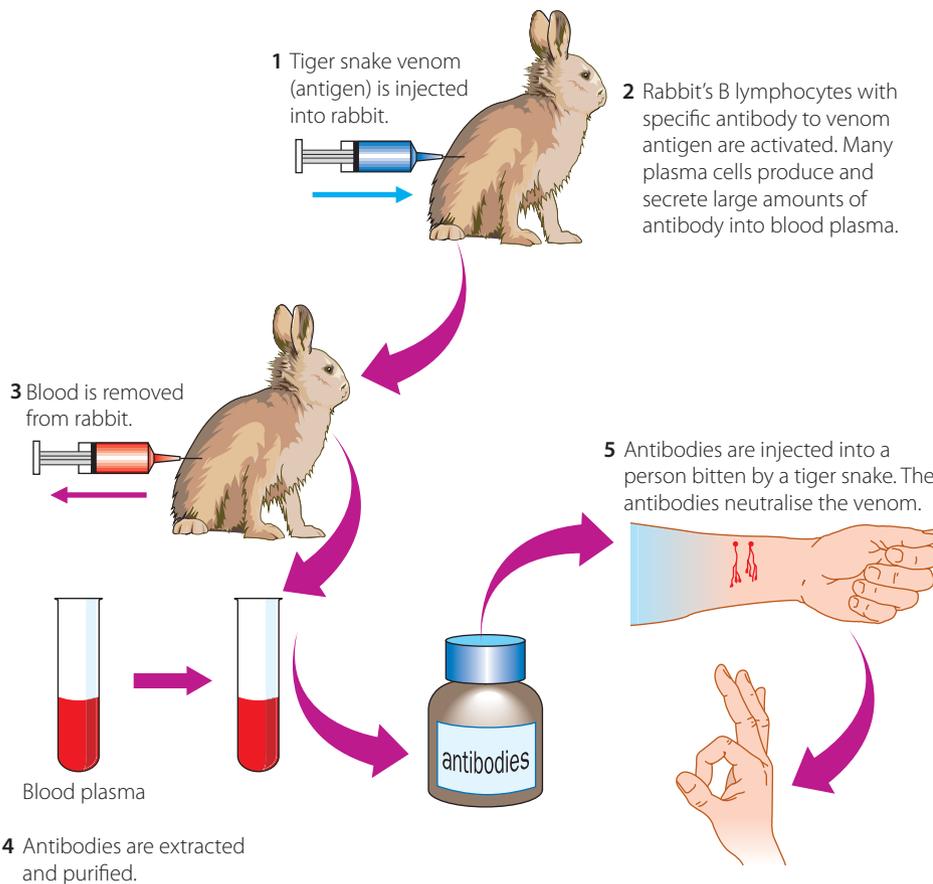


FIGURE 15.8.1
Anti-venom for a tiger snake bite can be produced by collecting antibodies from a rabbit that has been injected with small amounts of venom.

Comparing active and passive immunity

Active and passive immunity share some features. Both types of immunity can occur naturally and disease is stopped when antibodies attack the pathogen. A significant difference is that in active immunity, antigens stimulate the production of antibodies, and memory cells produced in this process provide long-term immunity. In passive immunity, antibodies not antigens are responsible for immunity, no memory cells are produced and immunity begins as soon as the antibodies enter the host's body.

SECTION REVIEW

15.8

REMEMBERING

- 1 List two examples of passive immunity and two examples of active immunity.
- 2 Describe two different materials that can be used in a vaccine.
- 3 Distinguish between passive and active immunity.

UNDERSTANDING

- 4 Explain why passive immunity lasts only about 28 days.
- 5
 - a Name the type of immunity passed from a mother to her baby.
 - b Describe the benefits of this type of immunity.
- 6 Explain the action of vaccines.

CHAPTER REVIEW QUESTIONS

DETAIL QUESTIONS

- 1 What places in the body are associated with innate defence barriers.
- 2 Describe two consequences associated with breaching innate defence barriers.
- 3 What are the causes of the innate defence response of inflammation?

CATEGORY QUESTIONS

- 4 What actions are associated with innate defence barriers?
- 5 What causes and consequences are associated with breaching innate defence barriers?
- 6 What purpose is associated with physical actions of inflammation?

ELABORATION QUESTIONS

- 7 Explain why innate defence barriers are an important part of defence against pathogens.
- 8 Predict what would happen if cilia were unable to beat.
- 9 Suggest what might result from an inability to switch off inflammation once the danger has passed.

EVIDENCE QUESTIONS

- 10 Predict ways in which pathogens could evade or breach innate defence barriers.
- 11 Explain the reasoning behind your answer to Question 8.



- Some pathogens can evade death during phagocytosis. *Streptococci* cause lysosomal granules to explode. This would:
 - surround the pathogen with a protective membrane
 - kill the phagocyte and release the pathogen
 - enable the pathogen to form protective clumps in the blood
 - deactivate neutrophils.
- The production of which of the following is not part of the innate immune response?
 - Prostaglandins
 - Mucus
 - Defensins
 - Antibodies
- Surface molecules that can detect an invader include:
 - epitopes
 - pattern recognition receptors
 - pathogen-associated molecular patterns
 - microbe-associated molecular patterns.
- Name the innate immune response that leads to redness and swelling.
- Name the immune product of B lymphocytes.
- Describe a chemical defence of plants.
- Interpret the immune response data shown in the graph in Figure 15.9.1 and identify three ways in which the secondary response differs from the primary response.
- Complement proteins are found in the blood in an inactive form. Describe the sequence of events that leads to their activation.

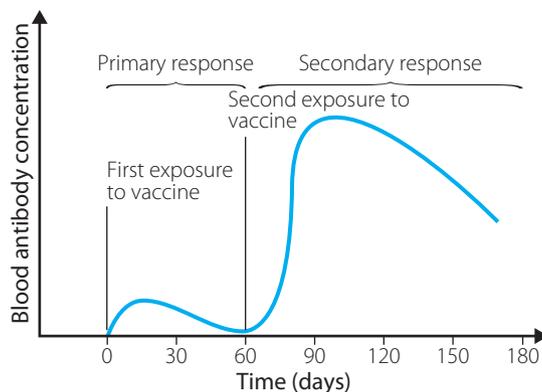


FIGURE 15.9.1
The response to vaccination against tetanus

16

TRANSMISSION AND SPREAD OF DISEASE

Introduction

The 1918–19 Spanish influenza outbreak spread rapidly throughout the world, killing up to 100 million people. Despite intensive efforts to stop the disease, the Spanish influenza outbreak killed around 12 000 Australians, many of them healthy, young people. There were many reasons for the devastation caused by this disease. The population was exhausted by the war and transportation of soldiers around the world rapidly spread the disease. War had also disrupted normal healthcare programs, leaving countries unprepared to respond.

Spanish influenza provides a strong example of the way that many factors contribute to the spread of disease. This chapter explores the factors that affect disease transmission, how disease spread is monitored and how outbreaks are managed.

Stimulus questions

What factors affect the spread of disease?

How is the spread of disease monitored?

How can potential outbreaks be predicted?

What is the best way to manage outbreaks of disease?



istockphoto/anatchant

16.1 Regional and global movement of organisms

The movement of individuals and populations can facilitate the spread of disease. This is because individuals carrying disease are able to infect other individuals in the areas they are travelling to, allowing diseases to spread faster and over larger geographical areas than they otherwise could.

The effect of the movement of infected hosts can be seen by the example of the spread of measles as a result of European exploration and colonisation of the Americas. In the 16th century, native populations in Mexico, Cuba and other parts of Central America were ravaged by measles following exposure to European explorers. In the mid-1800s, measles was taken to the Pacific, with 20% of the population of Hawaii and one-third of native Fijians dying from the disease. Once introduced, this disease devastated local populations because there was no prior exposure or immunity.

Travel has changed significantly since the ship voyages of world exploration. People are now able to travel large distances by aeroplane quickly and frequently. Increasing mobility means that emerging infectious diseases now have the potential to spread worldwide very rapidly. The severe acute respiratory syndrome (SARS) epidemic in 2003 is a striking example of how air travel can facilitate the rapid transmission of infectious diseases.

In late 2002 and early 2003, reports of a new respiratory illness that would later be named SARS began to emerge in China. Infected individuals developed a variety of symptoms including very high temperatures and a cough or difficulty breathing (Figure 16.1.1). Almost 1 in 10 of those infected died.



FIGURE 16.1.1 Residents of Hong Kong used facial masks to try to protect themselves from SARS during the 2003 epidemic.

epidemiologist
a scientist who studies the causes and effects of diseases at a population level

The pathogen causing SARS was identified as a type of coronavirus. Figure 16.1.2 demonstrates how SARS was able to spread so rapidly. **Epidemiologists** determined that the disease was initially carried by a doctor from Guangdong province in China to Hong Kong and then spread among other guests staying on the same floor of the doctor's Hong Kong hotel. These guests then flew to various destinations, including Toronto, Hanoi, Bangkok and Singapore, rapidly spreading the disease.

16.1.1 WHO: SARS
16.1.2 CDC: SARS

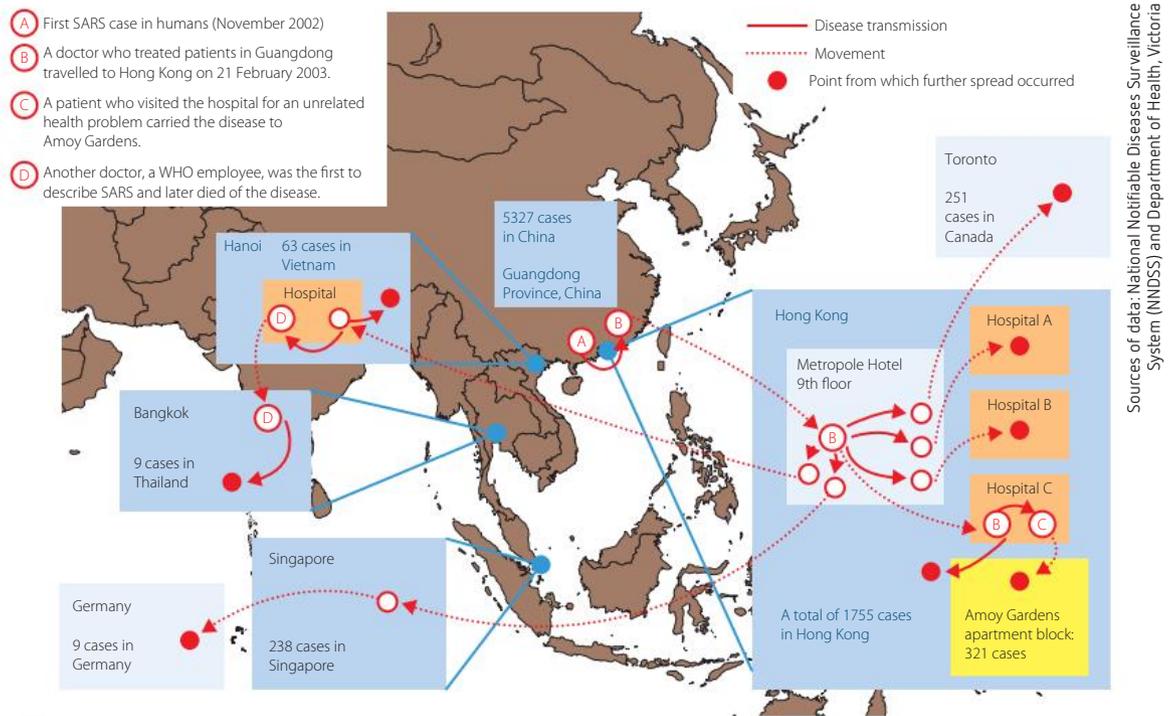


FIGURE 16.1.2 A map showing the initial spread of SARS infection. The rapid worldwide spread was facilitated by infected individuals travelling by plane.

While the impact was substantial, SARS did not become as widespread as was initially feared and the epidemic was over within a few months. However, it did demonstrate the potential of air travel to facilitate the spread of disease. This has important implications for the control of infectious diseases. In the wake of SARS, public health authorities such as the World Health Organization (WHO) have been able to review and improve global systems for responding to new infectious diseases.

SECTION REVIEW

16.1

REMEMBERING

- 1 State the full name of the disease SARS.
- 2 Describe the symptoms of SARS.
- 3 Calculate the percentage mortality rate of SARS.

UNDERSTANDING

- 4 Describe what it means to say 'the rapid transmission of disease by air travel has implications for the control of infectious diseases.'
- 5 Explain why measles killed such high numbers during exploration of Central America.

16.2

Factors affecting the spread of disease

The rate of disease transmission is not constant and varies with different diseases, populations and time. However, there are several recognisable patterns of disease transmission, as shown in Figure 16.2.1. An **endemic** disease is one that occurs at a relatively constant rate within a population. In contrast, diseases that are uncommon and occur irregularly are said to occur **sporadically** within a population. **Epidemics** occur when there is an increase in the number of **cases** of a disease within a population to above what is considered normal. Sometimes an epidemic may spread across multiple continents or throughout the world, in which case it is referred to as a **pandemic**.

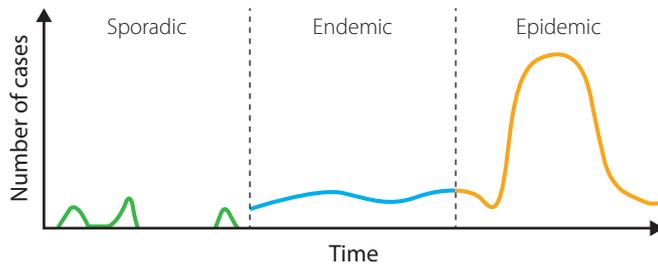


FIGURE 16.2.1

Within a population, a disease may occur sporadically, at an endemic level or, occasionally, as an epidemic.

Mechanism of transmission

The mechanism of transmission of a disease strongly affects the ability of a pathogen to spread within a particular population. Some modes of transmission restrict the spread of disease to particular climates or geographic areas. For example, malaria is a disease caused by protists from the *Plasmodium* genus and transmitted between human hosts by the *Anopheles* mosquito, which acts as a **vector**. Malaria is found only in parts of South America, Africa and Asia that are near to the equator because these are the only areas where that species of mosquito can live. By contrast, influenza is able to spread throughout the world because its droplet transmission is not dependent on a vector or specific environmental conditions.

The transmission of disease is also influenced by a pathogen's **infectivity**: the ability of a pathogen to spread from one host to another host. Diseases with a high infectivity, such as influenza, are readily spread through a population. It is important to understand that the infectivity of a pathogen is distinct from its **virulence** – the capacity of a pathogen to cause severe disease within its host. For example, rabies kills all people who are infected with the virus once symptoms begin, making it an extremely virulent disease. Some pathogens with a high level of virulence may have low infectivity, and vice versa.

Persistence of pathogens within hosts

The persistence of a pathogen within its **definitive host** or **intermediate hosts** can also contribute to the spread of the disease. Some pathogens may persist in asymptomatic **carriers** who are still capable of transmitting infection to others.

endemic
broadly, common to a particular area; specifically, a pathogen that is prevalent at a constant rate within a population

sporadically
refers to a disease that occurs infrequently and irregularly within a population

epidemic
an increase in the occurrence of a particular disease above the baseline level for that population; tends to refer to larger, more serious events than an outbreak

case
an individual who is infected with an infectious disease

pandemic
an epidemic that has spread across multiple continents or worldwide

vector
a living organism that transmits pathogens from one host to another

infectivity
the ability of a pathogen to spread from one host and infect another host

virulence
refers to the ability of a pathogen to cause severe disease within its host

definitive host
a host in which the adult phase of a parasite produces gametes

intermediate host
an organism in which a pathogen or parasite undergoes development and spends a small proportion of its life cycle

carrier
an individual who harbours a pathogen but who does not show symptoms of disease and is capable of transmitting the infection

At the beginning of the 20th century, a number of outbreaks of the diarrhoeal disease typhoid were traced back to food prepared by a single cook, Mary Mallon, in New York City. An asymptomatic carrier of the bacterium *Salmonella typhi*, Mallon was unaffected by typhoid but was still able to pass on the disease. Mallon, infamously known as ‘Typhoid Mary’, refused to give up work as a cook and was held in isolation for much of her life on North Brother Island to prevent spread of the disease.

Proportion of population that are immune

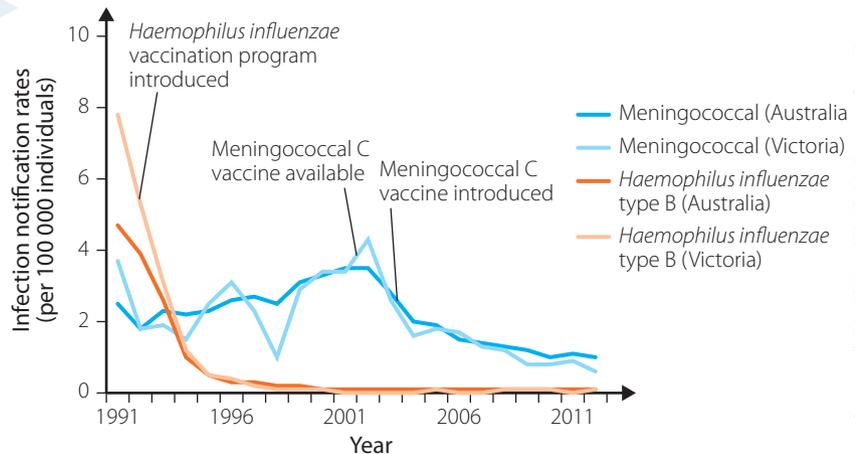
The spread of a disease is also affected by the proportion of the population that is immune to that disease. Reducing the number of susceptible individuals to a given disease is the basis for immunisation.

Immunisation is a highly effective public health intervention that has substantially reduced worldwide **morbidity** and **mortality** from infectious diseases. In Australia, children are routinely vaccinated against a large number of infectious diseases, including hepatitis B, pertussis (whooping cough), measles, tetanus and poliomyelitis. Groups that are at high risk of infection, such as the elderly or chronically ill, may also need additional vaccinations. Figure 16.2.2 shows the effectiveness of immunisation. The rates of infection of *Haemophilus influenzae* and meningococcal C dropped significantly after vaccination against these pathogens was introduced.

morbidity
the impact of a disease within a population, measured by the number of people affected by that disease

mortality
the impact of a disease within a population, measured by the number of deaths caused by that disease

FIGURE 16.2.2 Rates of *Haemophilus influenzae* type B and meningococcal infection since the introduction of vaccines against these organisms



Sources of data: National Notifiable Diseases Surveillance System (NNDSS) and Department of Health, Victoria



FIGURE 16.2.3 A child infected with smallpox. As a result of vaccination programs, the disease was declared to have been eliminated in 1980.

Immunisation programs also have the potential to eradicate diseases by making spread impossible. Smallpox (Figure 16.2.3), the first disease for which a vaccine was created, was also the first disease to be eradicated through vaccination. A coordinated global strategy to eliminate the disease involved mass vaccination and intense targeted vaccination. In 1980, WHO declared the successful worldwide eradication of smallpox.

Movement of carriers and infected individuals

The movement of diseases can occur when carriers or infected individuals travel into unexposed populations. Contact can be devastating because the previously unexposed individuals usually have no immunity. The colonisation of Australia by Europeans introduced smallpox, measles, influenza and typhoid into the previously isolated populations of Indigenous Australians with disastrous effects.

SECTION REVIEW

16.2

REMEMBERING

- 1 Recall the term that best describes the frequency of occurrence of disease for each of the following.
 - a In India, tuberculosis (TB) occurs at a high but relatively constant rate within the population.
 - b In 2009, a new strain of influenza (H1N1) spread rapidly across the globe.
 - c An unusually high number of cases of listeriosis was noted by public health authorities.
- 2 List the four types of factors that may affect the spread of a disease, providing an example for each.

UNDERSTANDING

- 3 Explain how persisting for a long time within a host may be a selective advantage to a pathogen.
- 4 Using an example, explain why the way a pathogen is transmitted from one individual to another affects the spread of disease in a community.

16.3 Predicting potential outbreaks

Human actions can substantially increase the possibility of disease outbreaks. For example, the building of dams or irrigation networks in malaria-prone regions may promote infection through the creation of new breeding sites for mosquitoes. Natural changes in the environment, such as increases in temperature, can also be important. Sometimes it is possible to predict the effect of these changes on potential disease outbreaks, but in other cases the complex interplay of factors makes such predictions difficult or impossible.

Extreme events, such as earthquakes, tsunamis, floods and droughts, have the potential to cause an outbreak of disease. In these situations, displacement of populations and/or the breakdown of usual sanitation, food and health infrastructures are major contributing factors. For example, outbreaks of diarrhoeal illnesses such as hepatitis A, cholera and typhoid can occur with both floods and droughts. During flooding, water supplies can become contaminated with human waste containing bacteria or eggs of parasites (Figure 16.3.1). In drought, the lack of fresh water can lead to break down in hygiene practices and promote disease spread.

Some diseases, such as dengue fever, are particularly prone to transmission in urban environments. Dengue fever is a mosquito-borne viral illness that can cause fevers, muscle aches, headaches and rashes, and in severe cases can result in death. The vector for dengue fever, the mosquito *Aedes aegypti*, is well adapted to living in urban environments and breeds in artificial water pools such as water tanks or buckets. This, along with a high population density in urban areas, contributes to the spread of this disease.

The proportion of the population that has been immunised is an important factor in potential outbreaks. Not all individuals within a population need to be vaccinated to prevent the spread of disease.

16.3.1 WHO: Hepatitis A
16.3.2 WHO: Cholera
16.3.3 WHO: Typhoid

16.3.4 WHO: Dengue



FIGURE 16.3.1 An increase in diarrhoeal illness in Pakistan was observed following extensive flooding in 2010, when water supplies were contaminated with human waste.

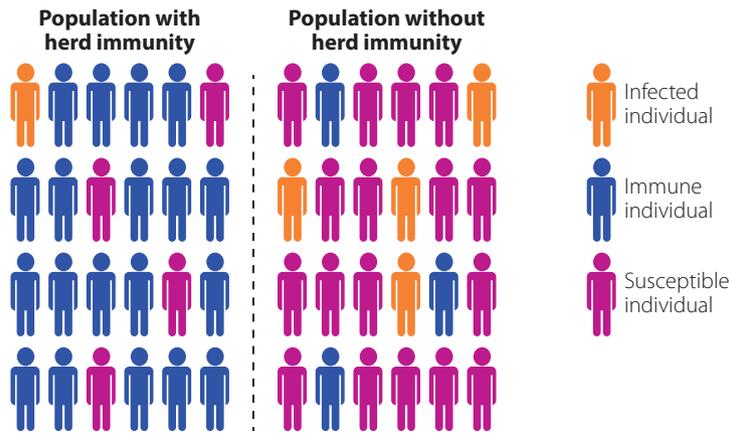
herd immunity

a form of protection from disease that occurs once a large enough proportion of a population is immune, which means susceptible individuals are better protected from the disease

If a large enough proportion of the population is immune to a disease, there are too few susceptible individuals to sustain disease spread. This effect is known as **herd immunity**. Figure 16.3.2 demonstrates why this is the case. Imagine that infected individuals (orange) are only able to spread the disease with those they come into contact with. When there are enough immune individuals (blue), the chance of an infected individual coming into contact with a susceptible individual (purple) is so low that the disease cannot spread. For herd immunity to prevent the spread of disease, a high proportion of the population needs to be immune. The exact proportion depends on the virulence and infectivity of a particular disease. Some individuals have health conditions that mean that they cannot be immunised and rely on herd immunity for protection from infection.

FIGURE 16.3.2

Herd immunity occurs when a large enough proportion of a population is immune to a disease. Disease spread cannot occur as there are too few susceptible individuals.



Some people object to immunisation of children. Their reasons may vary, but a major concern raised is the safety of vaccines. While vaccines can have side effects, these are usually mild (such as pain or swelling at the site) and serious reactions occur very rarely. Overall, vaccines are far safer than the diseases they protect against.

One of the conditions erroneously linked to vaccination is autism. A small, unsubstantiated report was released in 1998 suggesting that the measles, mumps, rubella (MMR) vaccine could cause autism. The report was later discredited and further research has not shown any link between vaccination and autism. Despite the lack of scientific evidence for a link between vaccination and autism, vaccination rates dropped substantially and measles infections rose following the publication of this report.

In some cases, levels of immunity within the population have dropped so low that herd immunity is no longer sustained. In 2013, several measles outbreaks in the United Kingdom were linked to low vaccination rates following the MMR scaremongering. The risk of potentially devastating infectious diseases re-emerging is substantial if high vaccination rates are not maintained. In attempts to combat this risk, several states in Australia have legislation requiring that children be vaccinated before they can be enrolled in childcare or school.

SECTION REVIEW

16.3

REMEMBERING

- 1 Describe two ways in which human activity can affect the spread of disease.

UNDERSTANDING

- 2 Explain why dengue fever is more common in urban areas.
- 3 State two kinds of natural events that can increase the spread of disease and explain how they support the transmission of pathogens.
- 4 Explain how herd immunity can protect an entire population from a serious disease.

16.4

Strategies to control the spread of disease

In order to predict and control disease outbreaks, public health authorities need to know when and where particular infections are occurring. In Australia, the number of cases of a particular disease is monitored by health authorities in each state. WHO is the organisation that monitors and coordinates global responses to outbreaks. In addition, authorities need to evaluate which strategies are the most effective in controlling the spread of disease.

Personal hygiene measures

Regular handwashing and the use of sterile equipment are key elements in effective health care. Regular handwashing can prevent individuals from contracting infections, particularly those that are spread by faecal–oral or direct contact routes. On a global scale, handwashing can significantly reduce the mortality from certain infections, such as diarrhoeal illnesses.

Good handwashing practices are also important in preventing the spread of infections in hospitals. Infections spread by healthcare workers are known as **nosocomial infections** and can be a cause of significant morbidity and mortality. Of particular concern is the potential for spread of antibiotic-resistant bacteria between patients. Effective and frequent handwashing is a key strategy for preventing these infections.

Other personal hygiene measures include staying home when ill, covering the mouth when coughing and sneezing and keeping a metre away from people who are sick. As well, people are advised to limit actions such as shaking hands, hugging and kissing and to avoid touching surfaces and objects that are used and shared by others.

nosocomial infection
an infection that is spread in a healthcare setting

Contact tracing and quarantine

If an outbreak of disease occurs, investigators need to find affected people. An important component of this is **contact tracing**, whereby recent contacts of an infected individual are contacted and screened for the infection. The type of contacts sought will vary with the mechanism of transmission. For example, if the disease is sexually transmitted, only sexual contacts of the infected individual will be contacted by investigators. On the other hand, for an airborne disease such as tuberculosis (TB), investigators will contact all people who have been in close proximity with the infected individual.

Another way to locate people with an infectious disease is by notifying public authorities upon diagnosis. In Australia, the list of **notifiable diseases** contains a diverse mix of more than 70 conditions, including chickenpox, syphilis, rabies and influenza. A doctor who diagnoses one of these conditions must report the case to the relevant state health authority. Outbreaks or cases of unusual diseases can then be investigated. However, there are limitations to data collected this way. Infections can be under-reported because not all infected patients seek health care and those who do will not all receive a diagnosis. Delays between the onset of symptoms, diagnosis and reporting can also limit the ability of public health authorities to respond quickly to epidemics.

Quarantine is a highly effective way to stop individuals exposed to infectious diseases from carrying disease into healthy populations. Exposed individuals are prevented from entering a healthy population until the incubation period of that disease has passed, proving that they are not infected. Crew members from all Apollo space missions (1963–72) were quarantined on return from the Moon because of the potential risk of contamination by unknown lunar pathogens (Figure 16.4.1, page 268).

contact tracing
a process for identifying potential cases; recent contacts of an infected individual are contacted and screened for the infection

notifiable disease
a disease that, if diagnosed, is required to be reported to public health authorities

quarantine
the enforced isolation of individuals at risk of carrying disease to prevent the spread of that disease into healthy populations

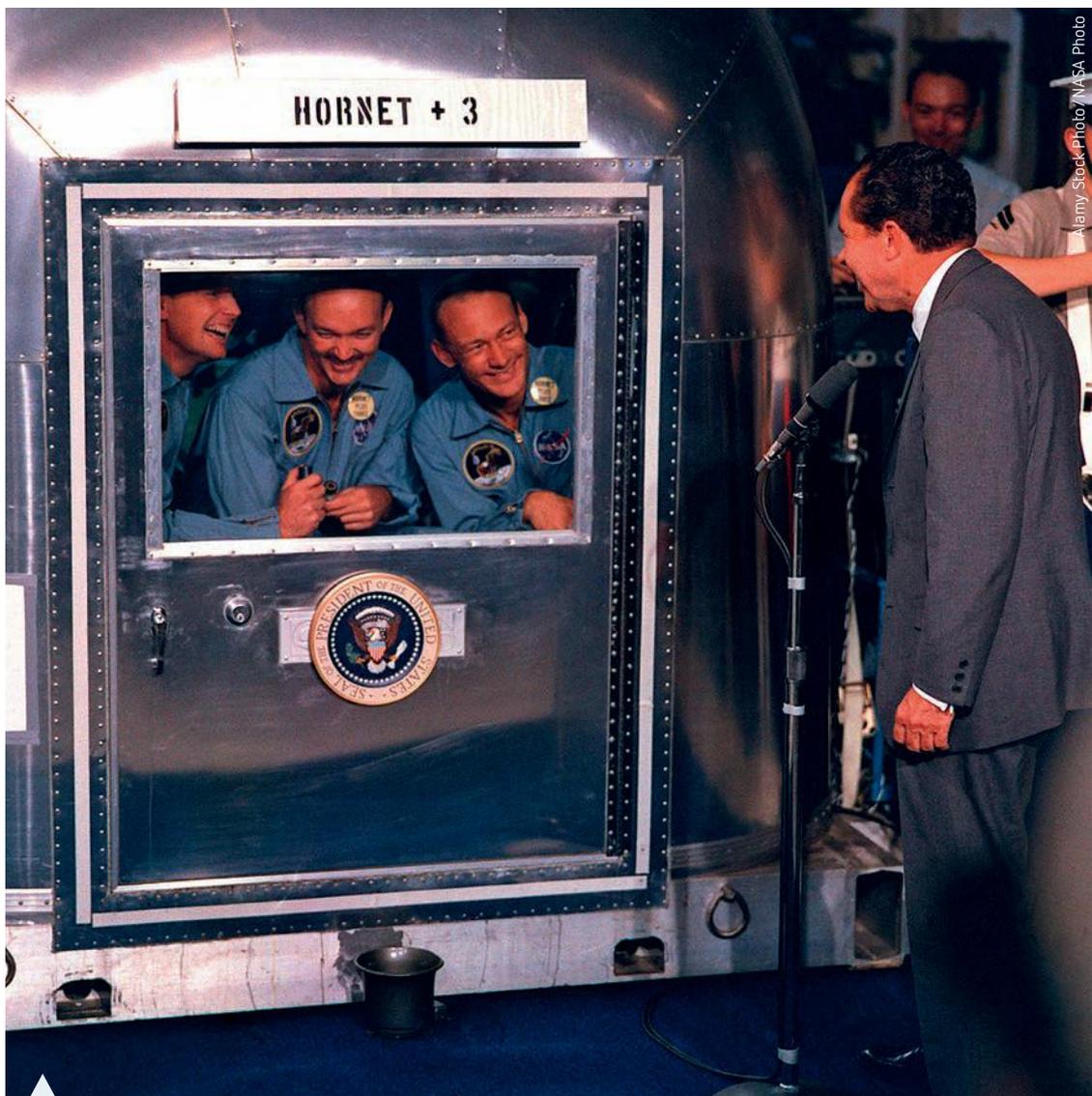


FIGURE 16.4.1 US President Richard Nixon visits the Apollo 11 crew housed in a sealed, mobile quarantine facility following their return from the Moon in 1969.

Quarantine is currently used in this way to prevent the spread of animal pathogens. When people import pet cats or dogs into Australia from overseas, the animal is held at a quarantine facility for at least 30 days. Quarantine measures to protect human health can still occur. Captains of aeroplanes and ships are required to report passengers displaying symptoms of certain infections. In exceptional circumstances, intensified quarantine measures may be implemented at airports to try to prevent the spread of disease by air travel.

Goods brought into Australia on passenger planes and commercial shipments are also inspected for high-risk items such as meat or plant products. These products can then be stopped from entering the country. Australia has particularly strict quarantine laws because of the potentially devastating impact of imported pathogens on our unique flora and fauna. As an island, protecting our borders from imported pathogens and pests is easier than in many other parts of the world.



School and workplace closures

It is often suggested that the closure of schools and workplaces could be an effective strategy to control the spread of disease during an epidemic. These social centres play an important role when disease transmission is by social contact. However, the closure of school and childcare facilities would need to be done early in the outbreak because closure in response to high absenteeism is often too late to be effective in reducing transmission. Past experience shows that many students visit public areas during school closure and that a high degree of cooperation from the public would be required to keep children and teenagers from congregating in other community settings.

It is also important that the community accepts and supports school and workplace closure because it can be more disruptive in large urbanised populations than in small rural communities. The cost of workplace closure may outweigh the benefit of preventing the spread of disease if it causes great economic disruption.

Reduction of mass gatherings

Mass gatherings, including concerts, religious observances, sports matches and festivals, are characterised by a concentration of people in close contact with each other. As such, they potentially increase the risk of the spread of infectious diseases. Reducing mass gatherings in an area where an outbreak already exists could be one way to control the spread of a disease.

Scientific evidence from epidemiological research suggests that mass events do not increase the spread of disease in either the host nation or among visitors. Instead, it is suggested that well known strategies are likely to be more effective. For example, covering coughs and sneezes, washing hands often and cleaning frequently touched surfaces such as door knobs and hand rails are recommended for people attending mass gatherings.

Temperature screening

Infrared thermal image scanners (ITIS) are the most common form of mass temperature screening. They work by detecting infrared radiation and forming an image in which different colours indicate different body temperatures. Screening programs are labour- and cost-intensive; nurses need to be stationed at airports 24 hours a day. Research using data from both the SARS and influenza A pandemics has concluded that thermal screening is not as effective as informing travellers about the risks of a disease and what to do if symptoms start after arrival in a country.

Thomas Duncan was the first person to be diagnosed with the Ebola virus in the United States, yet his temperature had been taken three times at the airport, with all readings considered to be within normal levels. During the 2009 influenza A pandemic, temperature screening detected few cases, ranging from 5.8 to 12.9%. This is because patients may not develop symptoms for many days after infection and asymptomatic cases can be very infectious. In addition, passengers can use common drugs to reduce the signs of fever, including a high temperature. Modelling studies have also concluded that entry screening would play a minimal role in reducing the number of imported cases during a pandemic.

Travel restrictions

The United States has had a public health Do Not Board (DNB) list in operation since mid-2007. People on this list are not allowed to board commercial aircraft because they have diseases, such as TB, that would pose a serious health threat to fellow domestic and international air travellers. Critics are concerned with how medical privacy is maintained for the named person, the possibility of passengers changing their names to evade the ban, whether healthy people with similar names will be mistaken for sick ones and how easily people get off the list once they are no longer infectious.

After the outbreak of the Ebola virus in Guinea in March 2014 and its subsequent spread to nearby countries in West Africa, there were calls to impose travel restrictions to the United States from affected countries. Critics judged a ban to be a poor way of containing the threat of a pandemic because it was thought that it could drive infected patients underground, lead to prejudice and stigma, render communities less likely to cooperate and make it more difficult to address the outbreak. Besides, commercial flights were needed to provide medical relief to the affected countries. It was decided that screening for Ebola symptoms before people boarded an aeroplane was more effective and far preferable to a blanket travel ban.

SECTION REVIEW

16.4

REMEMBERING

- 1 List three personal hygiene measures that could prevent the spread of disease.
- 2 Define 'contact tracing'.
- 3 Describe what is meant by a notifiable disease, giving an example.

UNDERSTANDING

- 4 Compare and contrast quarantine and medical isolation.
- 5 Choose two factors that can reduce the effectiveness of school closures and explain their limitations.
- 6 Explain the limitations of temperature screening as a way of preventing the spread of disease.

APPLYING

- 7 Imagine you are the organiser of a pop concert and the government wants you to cancel the event because of an influenza outbreak. Decide whether or not you would cancel, giving reasons for your decision.

16.5 Best practice in disease prevention

Public health authorities use all available information to develop strategies for the prevention of disease outbreaks. An excellent example of this methodology is provided by the detective-like way in which John Snow came to understand and track down the source of a cholera epidemic near his home in London, in the middle of the 19th century.

In September 1854, a deadly outbreak of cholera struck Soho in London. At the time, cholera was commonly believed to be spread by a miasma, a noxious vapour thought to cause diseases. John Snow, a physician working in London, spent time talking to local residents and observed that almost all of the cases of cholera occurred in people who lived close to and used a particular water pump. Importantly, he also showed that people who lived close to the pump and who did not contract the disease used different water sources. Snow's convincing data was his map (Figure 16.5.1) that showed cholera cases (in red) clustered around a water pump on Broad Street. He used this evidence to persuade the local authorities that the best way to curtail the outbreak was to disable that particular pump. His theory was confirmed when this action prevented the further spread of disease.

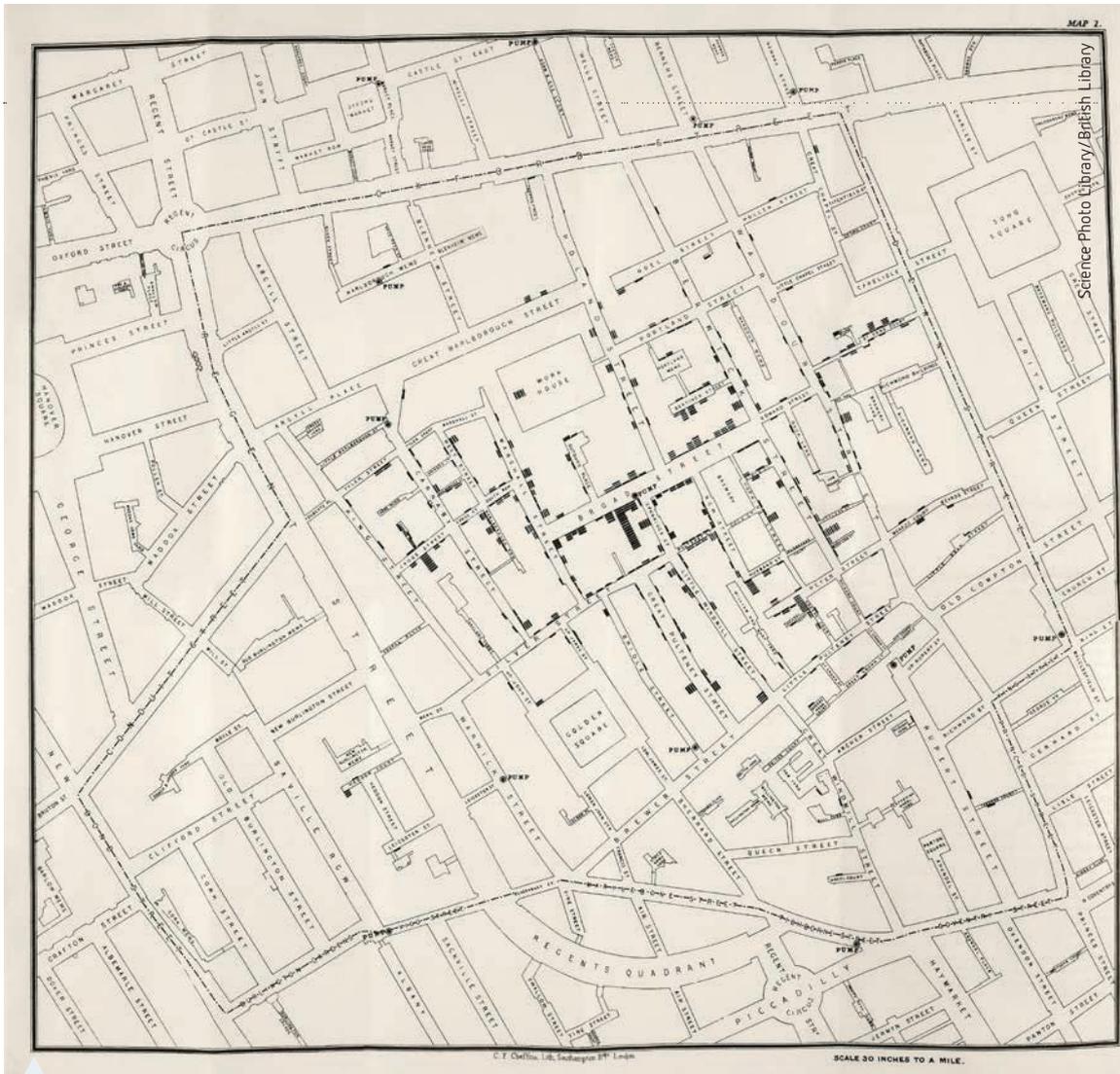


FIGURE 16.5.1 A reproduction of John Snow's map showing cases of cholera in red and pumps marked as Xs. The cluster of cholera cases around the Broad Street pump strongly suggests a link between the water and the disease.

John Snow became renowned as the father of modern epidemiology. It was not until almost 30 years later that the bacterium *Vibrio cholerae* was found to be the causative agent of cholera. Cholera is spread via the faecal–oral route and is often transmitted in water that has been contaminated with sewage. Snow identified that the outbreak probably started with a baby, Frances Lewis, whose soiled nappies were washed in water that leaked into the pump's water supply.

SECTION REVIEW

16.5

REMEMBERING

- 1 Describe the belief regarding disease transmission in the middle of the 19th century.
- 2 State the causative agent of cholera.

UNDERSTANDING

- 3 Describe the information that John Snow used to decide the source of the cholera infection.



▶ APPLYING

4 Legionnaire's disease is a bacterial lung infection caused by *Legionella* bacteria. The bacteria breed in aquatic environments and are transmitted to humans when they inhale contaminated water vapour. Outbreaks of legionnaire's disease are usually linked to a particular source, such as a spa, a hot water system or an air conditioner.

Suppose that the local health department has received reports of four cases of legionnaire's disease occurring in the same suburb over 3 days. The epidemiologist leading the investigation used detailed interviews to produce the data in Table 16.5.1.

TABLE 16.5.1 Epidemiological evidence gathered from legionnaire's outbreak investigation

	CASE			
	1	2	3	4
Lives	Apartment block A	Apartment block B	Apartment block A	Private home
Occupation	Store manager at local shopping centre	Builder working on carpark extension at shopping centre	School teacher	Retired
Other places visited in previous week	<ul style="list-style-type: none"> • Bank • Swimming pool • Movie cinema 	<ul style="list-style-type: none"> • Apartment block A • Shopping centre 	<ul style="list-style-type: none"> • Shopping centre • Zoo • Hospital 	<ul style="list-style-type: none"> • Hospital • Swimming pool • Shopping centre

- a Predict where these individuals may have contracted the infection. Justify your response.
- b Suggest a way to confirm this.

16.6 Interpreting data: modelling the spread of disease

Models have an important role in preventing disease outbreaks. They can use a vast array of data and are very useful for informing decision makers.

Using models to predict the spread of disease

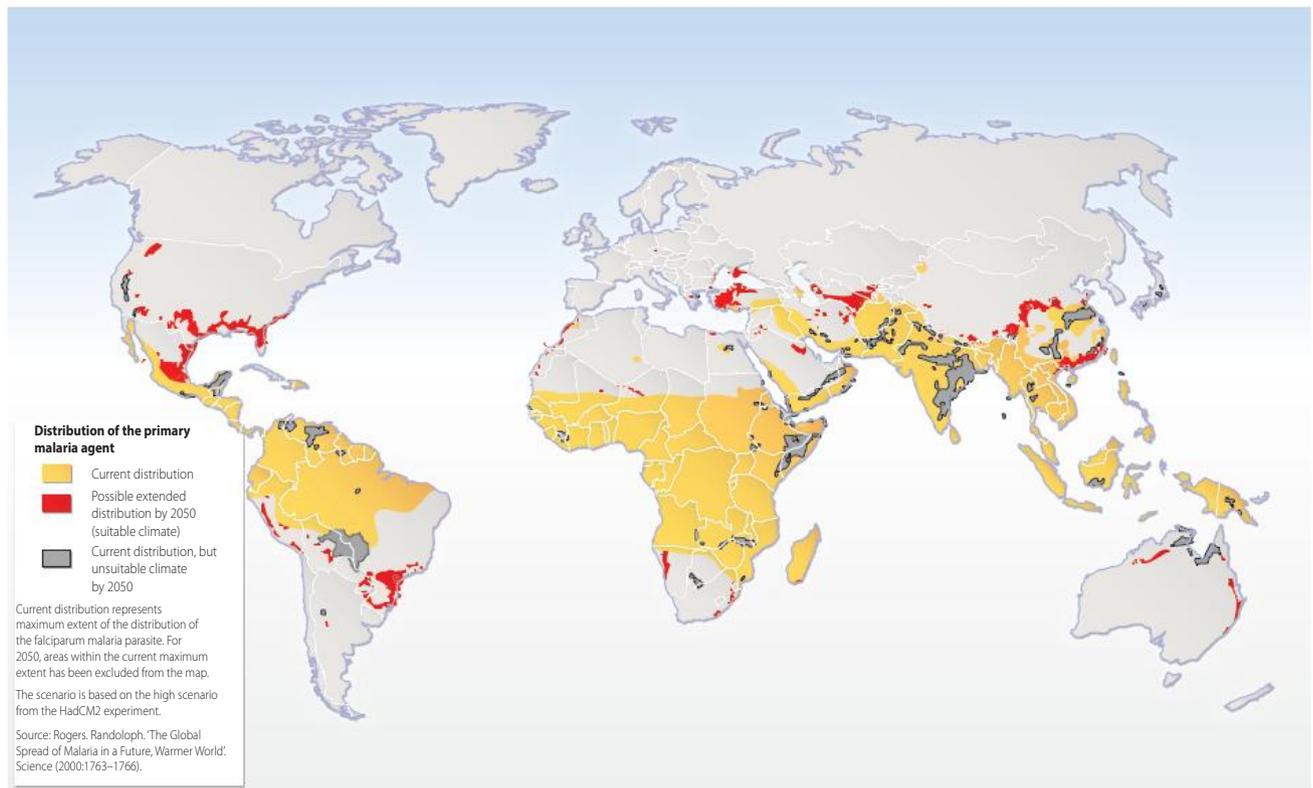
Models that can predict the spread of disease are important tools in the control of outbreaks. Such models can be used to explore the likely effects of newly emerging pathogens and to predict the possible spread of disease under changed environmental conditions. Models help predict changes within the already complex set of factors that influence disease transmission. Models can also be used to design and predict the effects of potential public health interventions.

Modelling is being used to predict the effect of climate change on the geographic distribution of vectors and the pathogens they carry; for example, malaria-harboured mosquitoes. Mathematical modelling has long been applied to many aspects of malaria research, such as control and prevention strategies. Models have the potential to determine the optimal strategies for eliminating malaria from different epidemiological settings.



Chapter 14 discusses the life cycle of the malaria parasite *Plasmodium*.

Models suggest that increases in temperature and changes in rainfall are likely to cause the spread of *Anopheles*, and hence malaria, into areas that were previously uninhabitable for the mosquitoes. Figure 16.6.1 shows the predicted changes in the distribution of malaria modelled as a result of climate change. By 2050, large areas in the United States, Brazil, Mexico and the Mediterranean, that are not currently affected by malaria, will develop a climate suitable for the vector.



UNEP / GRI D-Arendal http://www.grida.no/graphicslib/detail/climate-change-andmalaria-scenario-for-2050_bffe#

FIGURE 16.6.1 Climate change and malaria. A map showing the predicted change in distribution by 2050 of *Plasmodium falciparum*, based on modelling data

In order to make predictions like these, models include several assumptions about the way that different variables behave. The accuracy of these models depends on these assumptions being met. The spread of disease is a very complex process, and is affected by many factors. A good model is one that takes this complexity into consideration.

Digital disease surveillance

One emerging way of monitoring disease activity and frequency is people's use of the Internet and social media. Web-search company Google has developed a program that tracks how frequently people use their search engine to look up influenza-like illnesses. Figure 16.6.2 (page 274) compares data obtained by this method, called digital disease surveillance, with traditional reporting data. Spikes in Google search activity correspond with the peak influenza season.

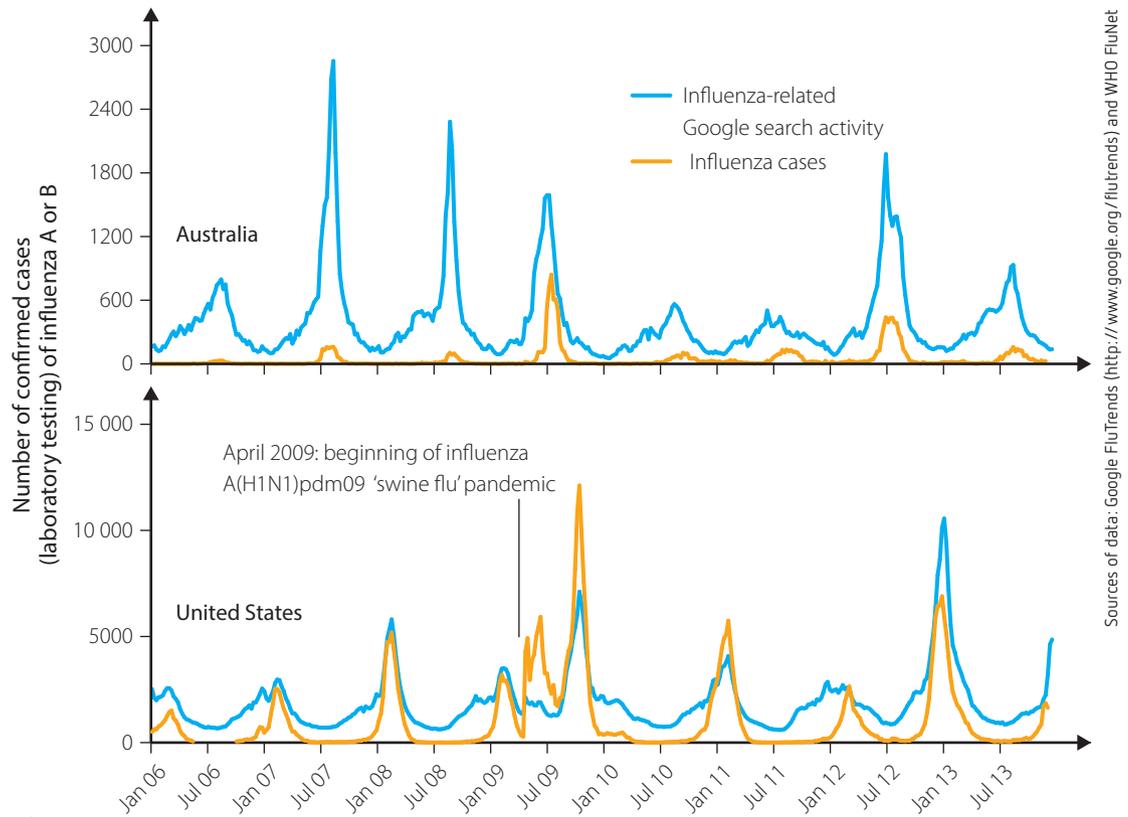


FIGURE 16.6.2 Patterns of influenza infection and Google search activity related to flu-like illness in the United States and Australia

Digital disease surveillance mechanisms have the advantage of providing information to public health authorities in real time. However, the quality of the information is limited by the effectiveness of the algorithms that determine whether a tweet or search is actually about an illness. Furthermore, high Internet activity about an illness does not always correspond to high disease activity because it can be skewed by other events, such as the illness of a celebrity.

Its limitations mean that digital disease surveillance is not likely to replace traditional reporting methods. However, it does provide epidemiologists with an additional source of data for modelling disease.

PRACTICAL ACTIVITY 16.6.1

Outbreak management in Australia

AIM

To learn about the control of disease outbreaks in Australia by examining a recent case

MATERIALS

- computer with Internet access
- large sheet of poster paper
- markers and pens

PROCEDURE

- 1 Choose one of the following outbreaks from recent Australian history.
 - 2000 legionnaire's disease outbreak in Melbourne
 - 2012–13 listeria outbreak
 - 2008–09 dengue fever outbreak in Cairns
 - 2011 hendra virus outbreak
- 2 Perform an Internet search about the disease and outbreak, aiming to find the following information.
 - Characteristics of the disease (for example, the type of pathogen, symptoms, mortality, incubation period and mode of transmission)
 - Size and impact of the outbreak
 - Outcomes of the epidemiological investigation (for example, was a source found?)
 - Control measures used by public health authorities
- 3 Summarise the information on the poster paper. You could use a flowchart or timeline to show how events unfolded.
- 4 Using your poster, explain to a classmate what you have found.
- 5 What sources of information did you choose to use? Explain why you chose these sources and how you know that they are reliable.

DISCUSSION

- 1 Outline the process of investigating an outbreak, using your case as an example.
- 2 Explain, using your case as an example, how the mode of transmission of a disease can direct an outbreak investigation.

SECTION REVIEW

16.6

REMEMBERING

- 1 Name the pathogen and vector of malaria.
- 2 Describe the way in which digital disease surveillance is carried out.
- 3 State two limitations of using digital disease surveillance mechanisms.

UNDERSTANDING

- 4 Explain how mathematical modelling can help epidemiologists control the spread of disease.

APPLYING

- 5 Use the map in Figure 16.6.1 (page 273) to describe the predicted change in distribution of malaria in Australia by 2050. Suggest two likely responses of Australian health officials to this change in distribution.

CHAPTER REVIEW QUESTIONS

DETAIL QUESTIONS

- 1 What health consequences are associated with the movement of individuals?
- 2 What process is associated with the prevention of disease outbreaks?
- 3 What dangers are associated with a disease outbreak?

CATEGORY QUESTIONS

- 4 What process is associated with the spread of an infectious disease?
- 5 What consequences are associated with the spread of disease?
- 6 What process is associated with the prevention of infectious disease outbreaks?

ELABORATION QUESTIONS

- 7 What effect would be seen on the transmission of malaria if the vector were wiped out?
- 8 Describe the effect of immunisation on the spread of disease.
- 9 Explain why people are more likely to catch influenza in cold, wet weather.

EVIDENCE QUESTIONS

- 10 Explain the reasoning behind your answer to Question 7.
- 11 Describe the effect of wiping out the vector of malaria on the pathogen itself.
- 12 Does the observation that people can catch colds in summer negate your answer in Question 9?

END-OF-CHAPTER EXAM



End-of-chapter test

- 1 The ability of a pathogen to spread from one host to another host is called its:
 - A virulence
 - B infectivity
 - C pathogenicity
 - D susceptibility.
- 2 A living organism that transmits pathogens from one host to another is a:
 - A carrier
 - B definitive host
 - C vector
 - D fomite.
- 3 Which of the following is not true about immunisation? It is:
 - A still an important way to prevent the spread of disease
 - B a way to cure infectious diseases
 - C a useful method of improving community health
 - D one way to eradicate an infectious disease.
- 4 What is the name for when a person suffering a disease is kept away from healthy individuals?
- 5 What is the name for a disease that is required to be reported?
- 6 What is the name for an infection that is spread in a healthcare setting?
- 7 Compare and contrast the meanings of morbidity and mortality.
- 8 Explain what it means to say that until 1981 malaria was endemic in Australia.
- 9 Describe herd immunity.

UNITS 1 & 2 PRACTICE EXAM

MULTIPLE-CHOICE QUESTIONS

QUESTION 1

The endosymbiotic theory predicts that both mitochondria and chloroplasts evolved when once-independent prokaryotic organisms came to live symbiotically inside larger prokaryotic cells. Which of the following is evidence for this theory?

- A** Chloroplasts are not found in all eukaryotic cells.
- B** DNA is present in both mitochondria and chloroplasts.
- C** The cell wall is found in both eukaryotes and prokaryotes.
- D** Eukaryotic cells and prokaryotic cells are approximately the same size.

QUESTION 2

Select the best description from the following.

- A** Photosynthesis is a series of reactions that occurs in the stroma and thylakoid membrane system of the mitochondria.
- B** The internal membranes of a chloroplast are folded to provide more surface area for chemical reactions to occur.
- C** Mitochondria have their own ribosomes and ribonucleic acid (RNA), but not their own genetic material (DNA).
- D** Chloroplasts consist of an outer smooth membrane and an inner membrane where the enzymes of cellular respiration are located.

QUESTION 3

A biochemical pathway:

- A** consists of a series of steps regulated by a single enzyme.
- B** is a single step regulated by enzyme cofactors.
- C** must provide enough energy to maintain the process.
- D** has the products of the first step as the reactants of the next.

QUESTION 4

Glycolysis occurs:

- A** in the cytosol of plants and animals.
- B** in the cytosol of animals, but not plants.
- C** in the mitochondria of plants and animals.
- D** in the mitochondria of animals, but not plants.

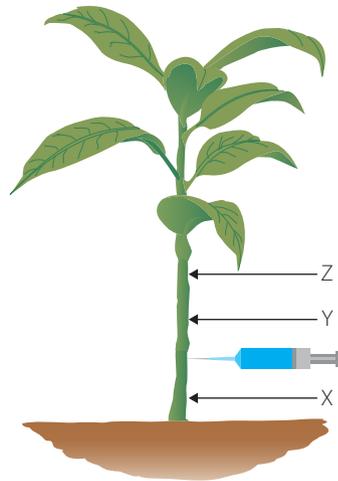
QUESTION 5

Stem cells:

- A** cannot differentiate.
- B** are totipotent.
- C** are specialised.
- D** cannot divide.

QUESTION 6

Refer to the following experimental diagram, which shows a small quantity of radioactive water being injected into the phloem of a plant in bright light.



Radioactive ions would be detected at:

- A W before Y.
- B Y before X.
- C Y before Z.
- D X and Y at the same time.

QUESTION 7

Plant adaptations to deal with a hot, dry climate *do not* include:

- A a thick cuticle to reduce water loss from the epidermal cells.
- B hairs to reduce evaporation of water from the leaf.
- C extra stomata to allow more carbon dioxide into the leaf for photosynthesis.
- D less spongy mesophyll to reduce water loss from the leaf tissue.

QUESTION 8

Animals that live in the desert must minimise the water they lose from their bodies. In these organisms, which part of the kidney is elongated in order to absorb more water by producing concentrated urine?

- A The loop of Henle
- B The proximal tubule
- C The collecting duct
- D All of the above

QUESTION 9

Which of the following factors is likely to reduce disease transmission?

- A Mobility of individuals and pathogens
- B Low population density
- C Poor health and sanitation
- D Predominance of high-risk groups

QUESTION 10

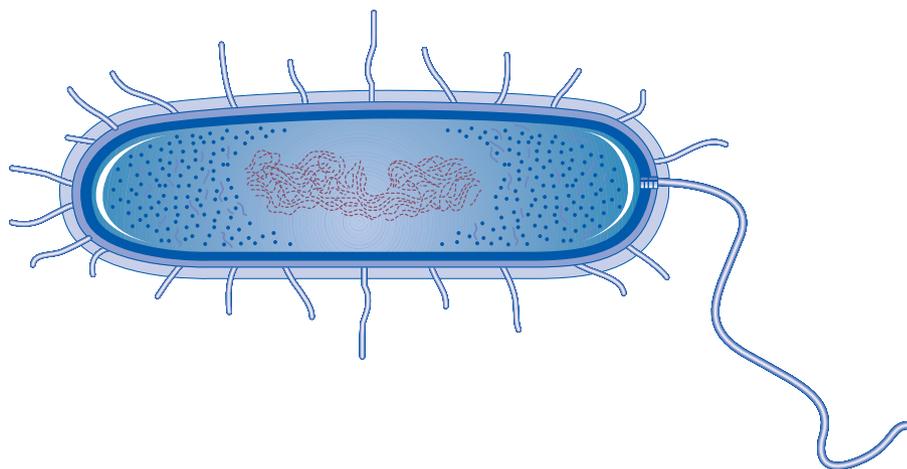
How does a plant respond when invaded by a pathogen?

- A** By producing antibodies at the site of the infection
- B** By growing more leaves and branches
- C** By becoming inflamed around the infection
- D** By producing defensins

SHORT-ANSWER QUESTIONS

QUESTION 1

A drawing of a cell is shown. It is approximately 3-5 μm in length.



- a** Identify the cell as either prokaryotic or eukaryotic.
- b** Describe three features of the cell that were used to identify it.
- c** Describe the structure of the cell membrane in this cell.

QUESTION 2

- a** Organisms require oxygen from their environment. Name a cellular reaction involving the use of oxygen and explain the significance of this reaction to cell survival.
- b** List two environmental factors that can change the activity of an enzyme.
- c** Advertisements for washing powder sometimes promote the product's inclusion of enzymes, which are reported to boost its power. Suggest why enzymes are added to washing powder.
- d** The instructions for using these washing powders recommend a wash of approximately 40°C. Suggest what would happen to the enzymes if you used a hot wash of approximately 85°C.

QUESTION 3

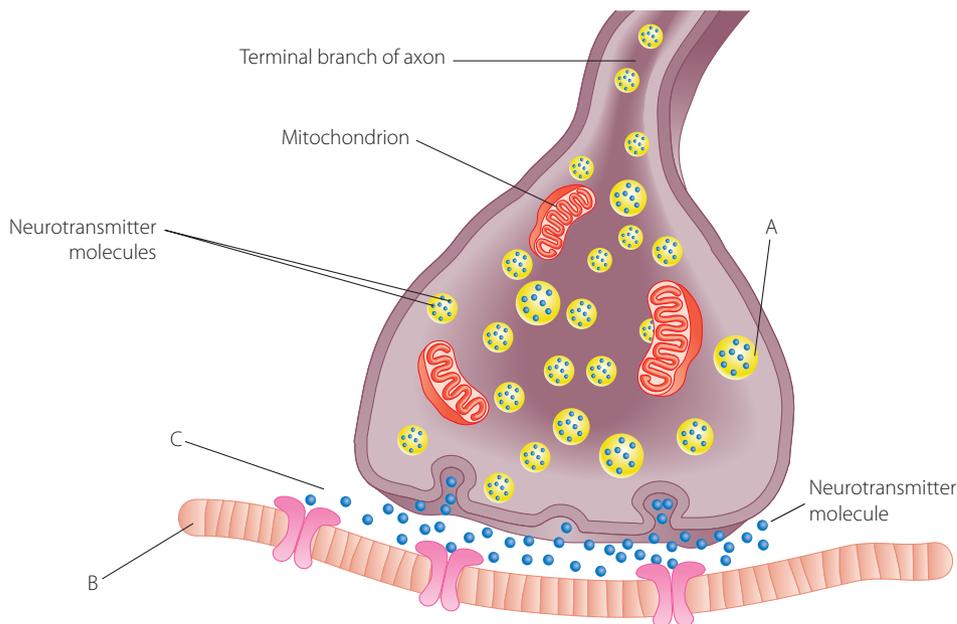
- The kidney is responsible for the excretion of nitrogenous waste in mammals. Name the main nitrogenous waste for mammals.
- There are about one million functional units in the kidney, where the processes of filtration, absorption and secretion take place. Name the functional unit of a kidney.
- Describe the processes of filtration, including the site where filtration occurs.
- The following table shows the composition of various substances within a mammalian kidney. Estimate the filtrate and urine values for glucose and protein in a properly functioning kidney.

Substance (g/100 mL)	Plasma (g/100 mL)	Filtrate (g/100 mL)	Urine (g/100 mL)
Glucose	0.15		
Protein	7.00		
Salts	0.65	0.65	1.2
Nitrogenous waste	0.03	0.03	2.5

- Explain your values for glucose and for proteins.

QUESTION 4

The following diagram represents a synapse.



- Name the function of structure A in the diagram of a synapse.
- Name and describe the function of structure B.
- Explain the role of exocytosis in transmission between neurons.
- Neurotransmitters are hydrophilic molecules. This property determines the type of signal transduction. Describe the steps involved in the signal transduction of neurotransmitters.

QUESTION 5

Data collected from seals living in Antarctic waters was compared to human data. The mass and average body temperature of seals and humans was equivalent.

Feature	Seals	Humans
Oxygen consumption/kg/h	0.19	0.76
Body fat (%)	60	27

- a** Explain how the difference in oxygen consumption and body fat assist seals to live in the cold waters of the Antarctic.
- b** The temperature of skin close to the seal's extremities has been measured at 20°C when the seal is near freezing water. Predict the arrangement of blood vessels in the extremities. Describe how this is an advantage.

QUESTION 6

- a** Diseases can be grouped according to their cause. Many diseases are caused by pathogens. Define a pathogen.
- b** Describe one similarity and one difference between a virus and a prion.
- c** Explain the difference between an antigen and an antibody.
- d** Name the cells that produce antibodies.
- e** When a person is given an organ transplant, the recipient's body recognises the new tissue as 'non-self' and will reject the tissue unless anti-rejection drugs are administered. Identify the cells of the immune system that recognise the transplanted organ tissue as 'non-self'.
- f** Explain how these cells determine whether a particular cell is 'self' or 'non-self' (when considering transplanted tissue).

ANSWERS

CHAPTER 1: CELL MEMBRANE

1.1 SECTION REVIEW

- 1 A differentially permeable membrane allows some substances to pass across it, but not others.
- 2 **a** Membrane receptor proteins
b Cholesterol
c Protein channels in cell
- 3 Channel proteins in cell membranes form channels within membranes to allow the passage of some substances across the membrane.
- 4 **a** The phospholipid bilayer of the cell membrane is described as fluid and membrane proteins form the mosaic part.
b The lipid bilayer is described as fluid because it has the ability to flow and change shape, like a two-dimensional fluid, and membrane proteins are referred to as a mosaic because they are embedded in the lipid in various patterns like a mosaic.

1.2 SECTION REVIEW

- 1 Water is the solvent; salt is the solute.
- 2 Increasing the concentration gradient or temperature will increase the rate of diffusion.
- 3 Facilitated diffusion occurs when charged particles or relatively large molecules are helped to across the membrane, e.g. glucose, amino acids, sodium ions and chloride ions.
- 4 Plant cells do not burst when placed in a hypotonic solution because they have cell walls.
- 5 The pathway of a water molecule would be from external environment into cytoplasm, into contractile vacuole and then out to external environment. The contents of the contractile vacuole would be hypertonic to cytoplasm.
- 6 Chemicals from the cooking food move by diffusion, from high concentration in the kitchen to a lower concentration outside the kitchen.
- 7 If red blood cells were kept in pure water, the water would diffuse into the cells (from high to low concentration of water) and they would burst.
- 8 To restore the crispness of limp salad greens, soak lettuce in cool water. This is because water diffuses from outside the lettuce into the cytoplasm of the cells from a high to low concentration of water. Water then diffuses into the vacuole, pressing outwards and making the cells turgid.
- 9 Isotonic sports drinks have a similar concentration of dissolved substances to blood.
- 10 **a** Solution Z was hypertonic to the animal cell.
b Cells in solution Y were isotonic with the solution.
c In solution X, plant cells would be turgid and swollen, in solution Y they would not change size and in solution Z plant cells would become flaccid and plasmolysed, meaning the cell membrane would pull away from the cell wall.

1.3 SECTION REVIEW

- 1 Membrane carrier proteins
- 2 ATP
- 3 (1) In active transport, moves substances up their concentration gradient, across a cell membrane, using energy, but in simple diffusion substances move down their concentration gradient without energy being used.
(2) Diffusion is not necessarily movement across a cell membrane.
- 4 Intestinal cells actively transport glucose into the body from digested food to ensure it is not excreted and seaweeds actively uptake essential minerals such as iodine that are in low concentrations in the sea.
- 5 Passive and active cellular uptake of glucose molecules are similar because both actions require a membrane carrier protein. They are different because active uptake requires energy and moves glucose from a low to a high concentration, whereas passive transport moves glucose from a high to a low concentration and requires no energy.

1.4 SECTION REVIEW

- 1 Substances taken into cells by endocytosis are usually large and/or polar molecules.
- 2 During endocytosis, the cell membrane flows around the substance and when projections of the membrane meet, membrane fusion occurs, resulting in formation of a vesicle inside cytoplasm.
- 3 Certain white blood cells are known as phagocytes because they engulf invading bacteria by phagocytosis.
- 4 Phagocytosis is said to be a selective process because macrophages use recognition proteins in the plasma membrane of the cells they encounter to discriminate between invading bacteria and body cells.
- 5 Phagocytosis is a type of endocytosis. Endocytosis includes taking in both solid and liquid material in vesicles, while phagocytosis refers only to the uptake of solid material.
- 6 Endocytosis should decrease the area of the cell membrane because vesicles bud off the membrane and enter the cytoplasm.

1.5 SECTION REVIEW

- 1 Size and shape of the substance
- 2 Ions and ethanol cannot enter cells in the same way because they are chemically different. Ethanol is an uncharged molecule so it crosses membranes by dissolving in the phospholipid bilayer, whereas ions are charged particles that are hydrophilic and so cannot pass through the hydrophobic interior of membrane.

- 3 A high concentration gradient of oxygen between the inside and outside of a cell causes high rate of diffusion of oxygen, while a low concentration gradient causes low rate of diffusion.
- 4 a If an *Amoeba* is washed into the sea during a storm, water diffuses out of cytoplasm of *Amoeba*, from a high concentration of water inside the cell, out into the sea where the water is in a lower concentration because of the presence of salt in the sea.
- b Respiration will increase the concentration of carbon dioxide inside working muscle cells therefore it will diffuse out of cells towards a lower concentration.
- c Chloroform moves into cells (low concentration) from a high concentration in lungs.
- d Sodium and chloride ions cannot diffuse across membranes because they are hydrophilic.
- 5 During dialysis, for the wastes to continue diffusing out of the dialysis tube, the surrounding solution must be replaced with fresh solution that does not contain wastes. If this is not done, the wastes in the blood would be at the same concentration (isotonic) at the solution and they would stop diffusing out of the blood.

1.6 SECTION REVIEW

- 1 Surface area of a cube = $6 \times (\text{length of side})^2$
 $= 6 \times 2 \times 2 = 24 \text{ cm}^2$
 Volume of a cube = length \times width \times height
 $= 2 \times 2 \times 2 = 8 \text{ cm}^3$
 Surface area : volume = 24:8
 $= 3:1$
- 2 Surface-area-to-volume ratio reduces as cells enlarge.
- 3 Cells can increase the rate of diffusion of substances across their cell membrane by removing it from inside the cell, by either using the substance or by converting it to another substance.
- 4 Being long, thin or flat increases a cell's surface-area-to-volume ratio.
- 5 As a cell increases in size, both surface area and volume increase, but volume grows faster than surface area, causing a reduction in surface-area-to-volume ratio. The actual rate of diffusion does not change, but the cell reaches a point where exchange of essential substances and wastes across the membrane are not fast enough to service the increased volume of the cell.
- 6 Table 1.6.1 shows that with a diameter of 1 cm, the object would have a SA:V ratio of 6:1. This drops significantly (halves) to 3:1 with an increase of diameter to 2 cm, and with another increase in

diameter to 3 cm, the SA:V ratio drops to 2:1. This data shows there is not a linear relationship between size and surface-area-to-volume ratio.

CHAPTER REVIEW QUESTIONS

- 1 Osmosis only occurs across a differentially permeable membrane.
- 2 Osmosis is caused by a difference in the concentration of water across a differentially permeable membrane.
- 3 Water diffuses from a high concentration of water across a membrane to a low concentration of water.
- 4 Cells may swell or shrink as a result of osmosis. Animal cells may burst as a result of swelling during osmosis.
- 5 Solutions that contain a high concentration of solutes have a low concentration of water. This means that water will diffuse by osmosis from a solution of low solute concentration to a solution of high solute concentration.
- 6 Osmosis occurs across cell membranes and artificial differentially permeable membranes.
- 7 The random movement of particles in liquids results in osmosis.
- 8 Water diffuses from a high concentration of water outside the cubes to a lower concentration of water inside the potato cells, increasing the mass of the tissue.
- 9 The smaller the potato cube, the faster it will gain mass by osmosis when submerged in water.
- 10 Boiled potato cubes would not change mass in water.
- 11 Boiling would destroy the cell membrane, meaning that osmosis could not occur.
- 12 Yes, cubes of other vegetables would also gain mass in water.
- 13 Boiling for a short period of time would probably still destroy the membrane and boiling for longer would not do further damage. Quickly dipping the potato cube into hot water would probably not heat the tissue enough to destroy the membrane.

END-OF-CHAPTER EXAM

- 1 D
- 2 B
- 3 D
- 4 D
- 5 Phagocytosis
- 6 Plasmolysis
- 7 The contractile vacuole removes excess water from the cytoplasm.

- 8 If red blood cells are stored in water, the water would diffuse into the cells by osmosis and the cells would burst.

9 a

	CUBE A	CUBE B	CUBE C	CUBE D
Dimensions (cm)	$1 \times 1 \times 1$	$2 \times 2 \times 2$	$3 \times 3 \times 3$	$4 \times 4 \times 4$
Surface area (cm ²)	6	24	54	96
Volume (cm ³)	1	8	27	64
Surface-area-to-volume ratio	6:1	3:1	2:1	3:2

- b Surface-area-to-volume ratio decreases as cube size increases, but not in a linear way.
- c The larger organism would need to have a very large surface area. This could be achieved by a change in shape. It could be very long, thin and/or flat, or could have many projections.

CHAPTER 2: PROKARYOTIC AND EUKARYOTIC CELLS

2.1 SECTION REVIEW

- Carbohydrates, proteins, lipids and nucleic acids
- Starch, cellulose, glycogen, protein and nucleic acid
- Carbohydrates contain carbon, hydrogen and oxygen atoms in the ratio of 1:2:1, with the general formula for carbohydrates being $n\text{CH}_2\text{O}$.
- Both autotrophs and heterotrophs use glucose for respiration; autotrophs make this glucose in photosynthesis, heterotrophs consume other organisms to obtain their glucose.
- Lipids are called triglycerides because they have three fatty acids attached to a glycerol molecule.
- a Heterotrophic nutrition is when heterotrophs consume others for food, autotrophic nutrition is when autotrophs make their own food.
b Respiration is when glucose is broken down to release energy, whereas photosynthesis uses light energy to synthesise glucose.
c DNA carries the genetic code for production of proteins. RNA is a messenger that takes instructions from nucleus to ribosomes in cytoplasm.
d A monomer is a single subunit. A polymer contains many subunits joined together.

2.2 SECTION REVIEW

- Prokaryotic DNA forms a single circular chromosome in the cytoplasm.
- The following are structures in prokaryotes: ribosomes, cell wall, plasmid, cell membrane, capsule, pili and flagellum (only one is required).
- Plasmids are small circular rings of DNA found in addition to a chromosome in prokaryotes.
- Lack of membrane-bound organelles limits versatility of prokaryotes because they cannot perform several different functions at the same time.

2.3 SECTION REVIEW

- a Nucleus; iv control centre of the cell
b Endoplasmic reticulum; iii synthesis and transport
c Lysosome; i breakdown of materials
d Mitochondria; v aerobic respiration which releases energy to the cell
e Chloroplast; ii photosynthesis and storage
- Carbohydrates, lipids and steroids
- Orange carotene and yellow xanthophylls
- Lysosomes contain digestive enzymes, enabling them to break down worn out organelles.
- a Chlorophyll is the green pigment found inside the chloroplast, which is an organelle that carries out photosynthesis.
b Rough endoplasmic reticulum is covered with ribosomes and is the site of protein synthesis. Smooth endoplasmic reticulum carries out the synthesis of carbohydrates, steroids and lipids.
c Chloroplasts are green coloured plastids and leucoplasts are colourless plastids.
- Although plant cells synthesise glucose in photosynthesis, they still need to respire the glucose in mitochondria to release energy from it.
- Muscle cells contain more mitochondria than a cell in a big toe because muscle cells need to carry out a great deal of respiration to provide energy for muscle contraction. This respiration occurs in the mitochondria.

2.4 SECTION REVIEW

- DNA, cytoplasm, organelles, cytosol and cell membranes
- The cytoplasm is made up of cytosol together with cell organelles. The cytosol is the fluid part of the cytoplasm that contains many dissolved substances and is where many chemical reactions occur.

- 3 Mitochondria and chloroplasts are thought to have a common evolutionary past because:
- both make copies of themselves and split in two, just like bacteria
 - they can only arise from pre-existing mitochondria and chloroplasts; they cannot be formed in a cell that lacks them
 - they are similar in size to small bacteria, have their own genetic material, which, like that in bacteria, is contained on a circular DNA molecule
 - they contain ribosomes and RNA molecules so that they can make their own proteins, and they have two membranes: the outer one was probably derived from the host membrane when it engulfed the bacteria and the inner one is probably the membrane of the ingested bacteria.
- 4 Chloroplasts arose from primitive cyanobacteria that were engulfed by eukaryotic cells already containing mitochondria, around 1 billion years ago.
- 5 Prokaryotic cells contain a single circular chromosome located in cytoplasm, while eukaryotic cells have many linear chromosomes inside their nucleus, which is separate from the cytoplasm.
- 6 Being independent organelles, separated from the cytoplasm by a double membrane, mitochondria are a very efficient way to obtain energy from glucose.

2.5 SECTION REVIEW

- 1 Chloroplasts are surrounded by double membrane; inside this is the stroma, a semi-gel-like fluid that makes up much of volume. The thylakoid membrane system floats suspended in the stroma. Thylakoids

are arranged in stacks called grana and long interconnecting thylakoid membranes link these stacks.

- 2 Similarities: both chloroplasts and mitochondria are surrounded by double membranes; both contain DNA and ribosomes. Differences: chloroplasts contain chlorophyll on thylakoid membranes and enzymes in liquid stroma, but in mitochondria enzymes are fixed to membranes.
- 3 a Figure 2.5.10 shows a eukaryotic cell, because membrane-bound organelles and a nucleus are visible.
- b Figure 2.5.10 was taken with a transmission EM because it shows a high degree of detail and is therefore taken at high resolution.
- c The cell has been cut into thin sections for viewing, therefore some organelles were not sliced through in that particular thin section.
- d Organelle i is a chloroplast (containing a large starch grain) and organelle ii is the nucleus.
- 4 a Light microscope: advantage – cheap, easy to use, readily available, can view living cells; disadvantage – magnification only up to $\times 1000$, poor resolution.
- b SEM: advantage – detailed 3D surface view; disadvantage – medium resolution, cannot see inside cells and organisms.
- c TEM: advantage – very high resolution, very high magnification; disadvantage – can only view very thin sections of preserved material.

2.6 SECTION REVIEW

1

FEATURE	PROKARYOTES	EUKARYOTES
SIMILARITIES		
Outer boundary	Phospholipid membrane	Phospholipid membrane
Ribosomes	Present	Present
Genetic material	DNA	DNA
Site of chemical reactions	Cytosol	Cytosol
DIFFERENCES		
Size	Length: 1–10 μm	Length: 10–100 μm
Chromosomes	Single, circular	Multiple, linear
Unicellular/multicellular	Only unicellular	Unicellular and multicellular
Nucleus	Absent	Present
Date observed in fossil record	3.5 billion years ago	1.8 billion years ago
Cellular organisation	Cytoplasm not compartmentalised	Cytoplasm has compartments formed by membrane-bound organelles

- 2 a Prokaryotic cells: no nucleus, circular chromosome
- b Eukaryotic cells: membrane-bound nucleus and organelles, linear chromosomes
- 3 Because of its large size, it is likely to be a eukaryotic cell. This would be confirmed if further light and electron micrographs showed membrane-bound organelles or a nucleus.

CHAPTER REVIEW QUESTIONS

- 1 Chloroplasts are associated with photosynthesis.
- 2 Usage of carbon dioxide and water, and production of glucose are associated with photosynthesis.
- 3 The purpose of photosynthesis is to produce glucose molecules that can be used to synthesise other molecules or for energy production.
- 4 Organisms use carbohydrates both as an energy source and as a starting point for the synthesis of important macromolecules. The carbohydrates starch and glycogen are macromolecules used as storage molecules and cellulose is used for structural support because it forms plant cell walls. Glucose provides energy for virtually all cellular and physiological processes.
- 5 Three fatty acids and a glycerol molecule can be combined to form a triglyceride which is an important storage molecule.
- 6 The nucleic acids RNA and DNA are involved in protein synthesis and DNA is involved in transmitting genetic information during cell division.
- 7 If cyanobacteria had not been engulfed by primitive eukaryotes, there would be no land plants. This means that cyanobacteria would be the only autotrophs on Earth available for consumption. Given how small and difficult to catch these cyanobacteria would be, heterotrophs are likely to have been much smaller.
- 8 Cells would become clogged up with old and non-functioning organelles and there would not be enough materials to build new organelles. This is because recycling would stop and cells would run out of building blocks such as amino acids.
- 9 It can be shown that plants photosynthesise at a greater rate than they respire, because plants make more oxygen in photosynthesis than they use in respiration, resulting in a net production of oxygen on Earth.
- 10 Evidence that supports the endosymbiotic theory includes observations that:
 - mitochondria and chloroplasts are able to make copies of themselves and split in two, just like bacteria
 - they can only arise from pre-existing mitochondria and chloroplasts

- they cannot be formed in a cell that lacks them
- they are similar in size to small bacteria, have their own genetic material, which, like that in bacteria, is contained on a circular DNA molecule
- they contain ribosomes and RNA molecules allowing them to make their own proteins
- they have two membranes; the outer one was probably derived from the host membrane when it engulfed the bacteria and the inner one is probably the membrane of the ingested bacteria.

END-OF-CHAPTER EXAM

- 1 C
- 2 D
- 3 C
- 4 D
- 5 A
- 6 Smooth endoplasmic reticulum
- 7 Endosymbiotic theory
- 8 If ribosomes failed to work, the cell would be unable to make proteins so could not carry out any chemical reactions because it would have no enzymes.
- 9 Animals store excess glucose in the liver as the macromolecule glycogen; when needed it can be converted back to glucose.
- 10 An unknown cell could be identified as eukaryotic under the microscope if a membrane-bound nucleus or membrane-bound organelles could be identified.

CHAPTER 3: INTERNAL MEMBRANES AND ENZYMES

3.1 SECTION REVIEW

- 1 a Organelle: a specialised structure or compartment within a cell that has a specific function.
- b Cell membrane: the boundary of cells that maintains the contents and regulates movement of substances in and out of the cell.
- c Cristae: the folding of the inner membrane into the matrix of the mitochondria, thus increasing the total surface area of the inner membrane.
- d Mitochondrial matrix: the gel-like substance enclosed by the inner membrane of a mitochondrion.
- 2 Membrane-bound organelles in a cell enable:
 - a large number of activities to occur at the same time in a very limited space and under different conditions
 - specific chemical reactions to occur using a low number of enzymes that can be concentrated and recycled
 - concentration of reactants and storage of products.

- 3 A mitochondrion increases its internal surface area by the folding and stacking of internal membranes. These are studded with enzymes. This increases the number of enzymes available for chemical reactions.

3.2 SECTION REVIEW

- 1 a Cellular metabolism: a term that describes all of the chemical processes occurring in a living cell.
b Biochemical pathway: ordered, enzyme-regulated reaction sequences.
- 2 Intracellular enzymes occur inside cells, speeding up metabolic reactions. Extracellular enzymes are produced by cells, but achieve their effects outside the cell.
- 3 a This stepwise progression allows for the regulation of each reaction and the management of the energy requirements (or energy release) of the reaction.
b As all reactions are reversible, any build-up of product would reverse the reaction or produce a feedback effect in which the forward reaction would be slowed down.

3.3 SECTION REVIEW

- 1 Enzymes are proteins with a specific shape. Substrates bind to an enzyme's active site. As a result of these stresses on the substrate, the activation energy required to create a reaction is lowered. Enzyme activity is affected by temperature and pH.
- 2 Enzymes are not destroyed or altered by the reactions they catalyse, so they can be used again.
- 3 Enzymes act on substrates by lowering the activation energy required for a substrate to react.
- 4 Enzymes:
- act very rapidly. The lock-and-key mechanism explains this because the enzyme-substrate complex causes the substrate to change, producing the end product
 - are not destroyed or altered by the reactions they catalyse; they can be used again. The lock-and-key mechanism explains this because the substrate fits into the enzyme active site, then leaves it. The active site remains intact after the substrate leaves
 - can work in either direction. The lock-and-key mechanism explains this because the substrate molecule attaches to the enzyme
 - are affected by temperature and have an optimal range in which they operate. The lock-and-key mechanism explains this because the active site shape changes when the temperature changes
 - are sensitive to pH. The lock-and-key mechanism explains this because the active site shape changes when the pH changes

- are usually specific to particular reactions. The lock-and-key mechanism explains this because each enzyme has a specific shape that fits closely with the substrate.

- 5 In the induced-fit model of enzyme action, the enzyme's active site can change shape to ensure that the substrate is accommodated by the active site. In the lock-and-key model, the active site is a static structure into which the substrate fits.

3.4.1 PRACTICAL ACTIVITY

Discussion

- 1 The ground liver (tube B) has the highest activity followed by the fresh liver (tube A). The boiled liver (tube C) has the least amount of activity.
- 2 One of the products of hydrogen peroxide breakdown is oxygen gas. This is seen as bubbles, so the more active the enzyme, the more oxygen is formed and the more bubbles are seen.
- 3 Tube A was the control, the variable tested in tube B was exposure to physical forces and the variable tested in tube C was exposure to a temperature of 100°C.
- 4 Enzyme activity increased when the liver in test tube A was ground up. The enzyme was released from the cells and was able to rapidly come into contact with its substrate, the hydrogen peroxide.
- 5 Boiling irreversibly changes the character of proteins. Because the enzyme is a protein its active site would change and it would no longer react with the hydrogen peroxide.

3.4 SECTION REVIEW

- 1 a Psychrophile: an organism that is capable of growth and reproduction in cold temperatures, ranging from -20°C to $+10^{\circ}\text{C}$.
b Denaturation: the process by which the structure of a protein is changed by factors such as pH and temperature; the change in structure often destroys the shape of the active site of the molecule and results in a loss of function.
c Competitive inhibitor: a molecule that binds to an enzyme, which changes the shape of the enzyme so that the substrate can no longer bind to the active site.
d Cofactor: a small inorganic substance that needs to be present in addition to an enzyme to catalyse a certain reaction.
e Non-competitive inhibitor: a molecule that binds to an enzyme at a site other than the active site; this changes the shape of the enzyme so that the substrate can no longer bind to the active site.

- f Coenzyme: a small non-protein organic substance that needs to be present in addition to an enzyme to catalyse a certain reaction.
- 2 The conformation of the active site, and hence the activity of an enzyme, is sensitive to changes in pH and temperature.
- 3 When an enzyme is denatured, the active site loses its functional shape and is no longer able to accommodate the substrate.
- 4 A build-up of product within the cell will act as an inhibitor, binding to a site on the enzyme and slowing down the reaction. If the product is removed, the reaction will speed up again.
- 5 A non-competitive inhibitor may inhibit the activity of the enzyme, but not permanently. Other inhibitors that compete with the substrate are called competitive inhibitors. Their effect can be long lasting.
- 6 If our body temperature increases, enzymes change shape. If they change to such an extent that they are no longer able to function, important reactions in our body may not proceed at a rate fast enough to maintain life.

CHAPTER REVIEW QUESTIONS

- 1 On the surface of an enzyme molecule where substrate molecules attach.
- 2 The folding of an enzyme protein forms a fixed groove or pocket-shaped active site. This groove can accommodate one or more particular substrate molecules. The active site is highly specific for a particular substrate. The substrate must be of a compatible shape for binding to occur.
- 3 When an enzyme-controlled reaction takes place, the enzyme and substrate molecules become joined together for a short time to form an enzyme-substrate complex. The shapes fit together like a lock and key.
- 4 The substrate is converted to the end product by the action of the enzyme.
- 5 Enzymes act very rapidly. They are not destroyed or altered by the reactions they catalyse; they can be used again. Enzymes can work in either direction. They are affected by temperature and are sensitive to pH. They have an optimal range in which they operate. Enzymes are usually specific to particular reactions.
- 6 Enzymes catalyse reactions by lowering the activation energy of the reactions. Specific enzymes control biochemical pathways.
- 7 Temperature, pH, substrate and enzyme concentration, inhibitors, cofactors and coenzymes
- 8 Enzymes speed up reactions because they lower the activation energy of the reaction. The conformational change in the active site prepares the substrate for reaction. Reactions would proceed without enzymes but at a rate that would be so slow they would not be significant.
If the active site changes shape, reaction rates slow down or stop as the substrate is unable to fit into the active site.
- 9 Enzymes are highly specific molecules. A small part of the enzyme, the active site, has the correct shape, or conformation, to bind with a specific reactant (substrate).
- 10 Temperature and pH for instance, alter the shape of the active site. Other factors such as substrate and enzyme concentration, competitors and inhibitors bind to the active site making it unavailable to form more enzyme-substrate complex. This would reduce the reaction rate.
- 11 A similar shaped molecule to a substrate can act as a competitive enzyme inhibitor. This blocks the active site of an enzyme so that the substrate can no longer fit in.

12-16 Student responses will vary.

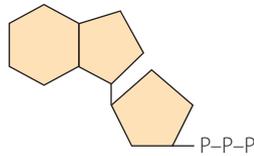
END-OF-CHAPTER EXAM

- 1 A
- 2 C
- 3 C
- 4 B
- 5 D
- 6 Cristae
- 7 Cofactors and coenzymes
- 8 One of: temperature, pH, the presence of inhibitors, the concentrations of reactants and products, and the presence of cofactors and coenzymes.
- 9 The active site is a place on the enzyme's surface. Its precise shape allows substrate molecules to become attached; it is this close contact that causes a reaction.
- 10 Enzymes are highly specific because of the shape of their active site. Only specific substrates of one enzyme will bind to the active site. Each enzyme generally catalyses one specific chemical reaction.
- 11 a At a lower temperature, all chemical reactions proceed at a lower rate.
b At a higher temperature, the enzyme will become denatured.
c A lower temperature does not permanently affect the function of the enzyme's active site. At a higher temperature, the active site will not be preserved.
- 12 Body fluids are normally buffered to maintain the optimum pH for enzyme activity.

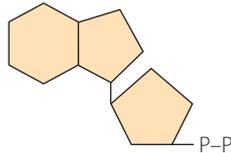
CHAPTER 4: ENERGY AND METABOLISM

4.1 SECTION REVIEW

1 a ATP molecule



b ADP molecule



- ADP is composed of an adenosine molecule with two phosphate groups attached. When another phosphate group is attached to ADP it forms ATP. ATPase is the enzyme that speeds up the reaction of ATP breaking down to ADP + P.
- ATP is made up of adenosine, bound to a chain of three phosphate groups. When a cell requires energy to drive an endergonic reaction, the high-energy chemical bonds attaching the last phosphate group to ATP are broken, thus releasing stored energy.
- A battery stores chemical energy that can be released as electrical energy to power various appliances. In the same way, ATP stores chemical energy in the high-energy chemical bonds attaching the last phosphate group to ATP. This stored energy is released when the bonds are broken and a phosphate group is removed. This energy is now available to fuel a cellular reaction.

4.2 SECTION REVIEW

- ATP molecules and hydrogen ions are the products of light-dependent reactions used as inputs for light-independent reactions.
- Glucose
- $6\text{CO}_2 + 12\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 + 6\text{H}_2\text{O}$
- Only living plant cells that contain chloroplasts carry out photosynthesis. For example, root cells do not.
- In the light-dependent reaction, solar energy is absorbed by pigments within the thylakoid membranes (grana) of the chloroplast. This energy is used to split water molecules into hydrogen ions and oxygen gas. In this process, molecules of ATP are produced. The light-independent reaction occurs in the stroma of the chloroplast. In this reaction, carbon dioxide and hydrogen ions join to produce glucose.

4.3.1 PRACTICAL ACTIVITY

Discussion

- The only difference between the tubes was the presence of the foil. All other factors were the same. If the tubes had been put in the cupboard to keep them away from the light, other factors could vary (e.g. temperature, humidity).
- Tube A was the control for tube B, and tube C was the control for tube D. Tube C was also a control for tube A, and tube D was a control for tube B. Variables being tested were the presence of light and the presence of the plant.
- Photosynthesis:
 $12\text{H}_2\text{O} + 6\text{CO}_2 \rightarrow 6\text{O}_2 + \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{H}_2\text{O}$
 - Cellular respiration:
 $6\text{O}_2 + \text{C}_6\text{H}_{12}\text{O}_6 \rightarrow 6\text{H}_2\text{O} + 6\text{CO}_2 + 36\text{ATP}$
- Plants photosynthesise when all the requirements for photosynthesis are present (i.e. water, carbon dioxide, light, chlorophyll). Plants carry out cellular respiration at all times.
- The experiment is testing the production and use of carbon dioxide in photosynthesis and respiration. If atmospheric carbon dioxide is allowed to enter and leave the test tubes, it makes it extremely difficult to draw the conclusion that the processes being investigated are changing the carbon dioxide levels. Any carbon dioxide produced by the experiment would be lost to the atmosphere.
- Tubes C and D acted as controls to show that the colour of the indicator, and hence the pH, did not change because of any factor other than the presence of the plant.
- Oxygen could also be used to measure the rate of photosynthesis and respiration; however, the concentration of carbon dioxide is easier to measure using an indicator because it dissolves in water to form carbonic acid. Oxygen would not change the pH of the water.
- Water plants are adapted to an aquatic environment and can more easily utilise dissolved carbon dioxide or oxygen. Land plants depend on gases entering through stomata.
- Students will discuss this from their experiences during the experiment.

Conclusion

- The rate of photosynthesis is less than the rate of cellular respiration.
 - The rate of photosynthesis is more than the rate of cellular respiration.
 - The rate of photosynthesis is equal to the rate of cellular respiration.
- Light allows photosynthesis to take place. Without light, the process will not occur. Light has no direct

effect on the rate of cellular respiration; however, in order for cellular respiration to occur within the closed system, as established in this exercise, the amount of glucose present will have an effect on the rate of cellular respiration.

■ 4.3 SECTION REVIEW

- 1 $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 36ATP$
- 2 The initial substrate in the glycolysis pathway is glucose and the final product is the three-carbon compound called pyruvate.
- 3 Glycolysis takes place in the cytosol.
- 4 Aerobic respiration takes place in the mitochondria, whereas fermentation takes place in the cytosol. The final products and the amount of net ATP produced are different in both pathways.
- 5 In animal cells and plant cells, the final products of aerobic respiration are carbon dioxide and water. Products vary in anaerobic respiration; in animals, the final product is lactic acid and in plants, carbon dioxide and ethanol.
- 6 In aerobic cellular respiration, carbon dioxide is the by-product of a reaction that involves pyruvate and oxygen.
- 7 The fermentation process is used to make breads rise. A product of alcohol fermentation is carbon dioxide gas. It is the carbon dioxide bubbles that pass through the dough, causing it to rise. In lactic acid fermentation, there is no liberation of carbon dioxide; therefore, the desired result cannot be obtained.
- 8 This statement is incorrect. Lactic acid fermentation results in the release of a small amount of energy; therefore, muscle cells can contract for a short while without oxygen.

■ CHAPTER REVIEW QUESTIONS

- 1 Through the building up of ATP from ADP and breaking down of ATP to ADP. When chemical bonds are broken down, energy is released.
- 2 Photosynthesis
- 3 Cellular respiration
- 4 When a cell requires energy to drive a reaction, the high-energy chemical bonds attaching the last phosphate group 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 (ADP). This reaction is sped up by the enzyme ATPase. Free energy obtained from a reaction within the cell can also be used to add a phosphate group to ADP, converting it to ATP.

5 Photosynthesis is a series of chemical reactions. There are two distinct stages: the light-dependent stage and the light-independent stage.

6 The light-dependent stage occurs in the thylakoid membranes of the chloroplast. The light-independent stage occurs in the stroma of the chloroplast.

7 The first stage of cellular respiration is called glycolysis.

If oxygen is present in aerobic cellular respiration, reactions involve a cyclic biochemical pathway called the Krebs cycle. The electron transfer chain is the third and final stage of aerobic cellular respiration.

If no oxygen is present in anaerobic cellular respiration, two pathways are used: alcohol fermentation and lactic acid fermentation.

8 Glycolysis, alcohol fermentation and lactic acid fermentation take place in the cytosol. Krebs cycle and electron transport system take place in the mitochondria.

9 The outputs of photosynthesis are the inputs of aerobic cellular respiration. Similarly, the outputs of aerobic cellular respiration are the inputs of photosynthesis.

10 Oxygen produced by photosynthesis is necessary for life. Chemical energy is also necessary to sustain life. This is transformed from light energy from the Sun in the process of photosynthesis.

11 Cellular respiration is necessary to break down and release the energy in chemical bonds in glucose molecules formed in photosynthesis. The chemical energy is used to fuel the build up of ATP molecules. The ATP-ADP cycle is necessary for energy to be transferred within a cell to where it is needed for vital chemical reactions.

12 Both the rates of photosynthesis and cellular respiration would decrease because less light energy is harnessed. Fewer glucose molecules would be available for cellular respiration.

13-17 Student responses will vary.

■ END-OF-CHAPTER EXAM

- 1 C
- 2 C
- 3 B
- 4 A
- 5 D
- 6 A
- 7 B

- 8 a $6\text{CO}_2 + 12\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 + 6\text{H}_2\text{O}$
 b $\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + 36-38\text{ATP}$
- 9 a Oxygen
 b Glucose
- 10 Anaerobic respiration has a much greater yield of ATP.
- 11 Glycolysis occurs in the cytoplasm.
 Krebs cycle occurs in the mitochondria.
 Electron transfer chain occurs in the mitochondria.
- 12 This represents the ATP–ADP cycle. When a cell requires energy to drive a reaction, the high-energy chemical bonds attaching the last phosphate group to ATP are broken, thus releasing stored energy. This energy is now available to fuel a cellular reaction.
- 13 ATP is made up of adenosine, bound to a chain of three phosphate groups. When a cell requires energy to drive an endergonic reaction, the high-energy chemical bonds attaching the last phosphate group to ATP are broken, thus releasing stored energy.
- 14 a 20 minutes
 b The plant was in put in the dark; the carbon dioxide produced in cellular respiration is not being used in photosynthesis.
 c The plant was put in light conditions.
 d The rate of photosynthesis was at its maximum. Limiting factors could be the amount of water, the amount of light, the temperature and the amount of oxygen (if the plant was in a contained environment).
 e Enzymes would denature. Cellular metabolism would slow down to the stage where life could not be sustained.
 f Carbon dioxide is continually produced in cellular respiration but is used in photosynthesis. The lower the carbon dioxide concentration, the greater the rate of photosynthesis.
- 3 • Totipotent stem cells have the ability to develop into any type of human cell at all, including all those in an embryo and in the tissues needed to support embryonic development; they have total potential.
 • Pluripotent stem cells can develop into all of the cells in an embryo, but not the embryonic supporting tissues; they have many potentials.
 • Multipotent stem cells can develop into multiple specialised cell types within a particular tissue or organ; for example, blood stem cells develop into red blood cells, several types of white blood cells and platelets.
 • Embryonic stem cells are pluripotent cells that occur in an embryo, and can be harvested from there.
 • Adult stem cells are multipotent cells that can be harvested from tissues that require constant replenishment in adults.
- 4 The zygote can be considered the primary stem cell because this single cell gives rise to all cells in a mature organism.
- 5 For the reason provided in the answer to Question 4, a zygote must be totipotent.

5.2 SECTION REVIEW

- Less duplication of tasks among cells.
 • Increased efficiency for whole organism, allowing wider variety of biochemical functioning, and thus more complex performance of tasks possible.
- Although all body cells in an organism have the same genetic material, only particular parts of this material are activated in the different cell types
- Various responses may be acceptable. For example, if a particular specialised tissue is not functioning correctly, the functioning of other parts or even of the whole organism can be adversely affected.

5.3 SECTION REVIEW

- Cells → tissues → organs → systems
- Groups of specialised cells work together to perform a similar function, forming a tissue. Collections of different types of tissues together perform a particular function, forming an organ. Collections of organs together carry out particular functions, forming a system.
- All the different specialised cells in multicellular organisms are totally dependent on each other, because each cell type only performs certain functions of the many that are required. Therefore, it is necessary for there to be communication and coordination between cells so that the organism as a whole can function.

CHAPTER 5: CELL DIFFERENTIATION AND SPECIALISATION

5.1 SECTION REVIEW

- a True – differentiation forms specialised cells.
 b False – all cells have the same DNA but different segments (genes) are activated.
 c True – stem cells are the source of all specialised cells.
- (1) Have the potential to divide and replicate for a long period of time. (2) Are unspecialised – have not yet developed into a particular cell type. (3) Have the ability to differentiate into different specialised cells.

CHAPTER REVIEW QUESTIONS

- Stem cells:
 - have the ability to divide and replicate for a long period of time
 - are unspecialised – have not yet developed into a particular cell type
 - have the ability to differentiate into different specialised cells.
- Multipotent stem cell that occurs in an embryo; can be removed from embryo and cultured in the laboratory.
- Cells, tissues, organs, systems
- A previously unspecialised cell develops particular structures to perform particular functions due to certain parts of its genetic makeup becoming activated.
- Digestive system: mouth, pharynx (throat), oesophagus, stomach, small intestine, liver, gall bladder, pancreas, large intestine, anus
Circulatory system: heart, arteries, arterioles, capillaries, venules, veins
Respiratory system: mouth/nose, pharynx (throat), trachea, bronchi, bronchioles, alveoli
Urinary excretory system: kidneys, ureters, bladder, urethra
Musculoskeletal system: bones, muscles, ligaments, tendons, cartilage
Nervous system: brain, spinal cord, nerves (major organs only)
- The zygote is the first cell of the new individual. Being formed by fertilisation of egg cell by sperm cell, it has all the genetic material necessary, from both parents, to form complete individual after a multitude of cell divisions.
- Although all cells have identical genetic material, only a small portion is actively 'switched on'. Therefore, the particular structure and function of a specialised cell depends on which parts of genetic material are actively expressed.
- Each of the different body systems has its own particular roles to play in the overall functioning of the organism. Therefore, all specialised cells in every system must be functioning well to supply materials necessary for all other specialised cells in other systems, so that the whole organism can function.
- Numerous examples are possible.
For example: our teeth 'chatter' when we are cold:
A part of the brain in the nervous system is able to detect a lower temperature in the blood, and sends signals via nerves to jaw muscles to alternately contract and relax automatically, to generate heat.
For muscles of the musculoskeletal system to contract, individual muscle cells require oxygen

and glucose to provide energy via the reactions of cellular respiration. The oxygen and glucose are delivered by the circulatory system, in various blood vessels leading from the heart. The oxygen attaches to red blood cells, and the glucose dissolves in the blood plasma, and then diffuse across the walls of capillaries, composed of a single layer of epithelial cells, and then into individual jaw muscle cells.

The oxygen was absorbed by the lungs of the respiratory system, where oxygen molecules diffused across single cell thickness of alveolus walls into capillaries to be transported in various blood vessels to the heart.

The glucose was absorbed by the small intestine of the digestive system, where glucose molecules diffused across the single cell thickness of the villi walls into capillaries to be transported to the heart.

END-OF-CHAPTER EXAM

- A
- B
- A
- A
- Stem cells are able to continue dividing by mitosis for very long periods of time.
Stem cells are unspecialised cells, but are able to differentiate into many different types with different structures and functions.
- Totipotent – can develop into any type of cell in the human body, including those necessary to support the developing embryo.
Pluripotent – can develop into any type of cell in the human body but not those that support the developing embryo.
Multipotent – can develop into multiple specialised cell types but only within a particular tissue or organ
- Although all cells have identical genetic material, only a small portion is actively 'switched on'. Therefore, the particular structure and function of a specialised cell depends on which parts of the genetic material are actively expressed.
- The digestive system is the site of exchange of nutrients between the external environment and the internal environment: it breaks down ingested food into small enough molecules to diffuse across into the circulatory system, and excretes undigested and unabsorbed substances.
The respiratory system is the site of exchange of gases between the external and internal environments: oxygen gas diffuses into circulatory system and carbon dioxide gas diffuses out into lungs to be expelled.
The circulatory system transports inputs and outputs of cells around to all other cells of the body

that then carry out their particular functions, using inputs and producing their own outputs.

The kidney organs in the excretory system contain the main site of exchange between internal and external environments of waste and excess substances, removing them from the blood and excreting them.

The nervous system senses and responds to the external and internal environments, by sending signals via nerves to organs to carry out appropriate responses.

The endocrine system also functions in communication between different parts of the body by synthesising and releasing hormones into the circulatory system. These hormones also cause responses in particular specialised cells in organs.

The specialised cells in each of the above organ systems only carry out their particular described function, the products/results of which are used by all other specialised cells in other organ systems.

CHAPTER 6: GAS EXCHANGE AND TRANSPORT

6.1 SECTION REVIEW

1 Gas exchange surface must:

- be moist, because 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

6

	MOIST EXCHANGE SURFACE	THIN PERMEABLE EXCHANGE SURFACE	LARGE SURFACE AREA	CONCENTRATION GRADIENT ACROSS EXCHANGE SURFACE
Mammal	Alveolar inner surface lined with film of water	Alveolar and capillary walls one cell thick	Bunches of alveoli at end of bronchioles	Air in alveolus higher O ₂ and lower CO ₂ concentration than blood in capillary
Bony fish	Gills immersed in water	Gill covering wall one cell thick	Multiple layers of filaments on gill arches	Surrounding water has higher O ₂ and lower CO ₂ concentration than blood in capillaries gill arches

6.2 SECTION REVIEW

1 Blood, blood vessels, heart

2 Blood remains within the blood vessels, and is pumped all around the body within these vessels by the heart.

3 Capillary diameters are approximately 6–8 µm, that is, less than one hundredth of 1 mm, being equal to or even less than the diameter of a red blood cell. Capillary diameters are much smaller than those of both arteries and veins which can vary greatly, depending on their location in the body.

- have a large surface area in relation to volume of the organism, to adequately supply the gaseous requirements and efficiently remove gaseous waste
- have a greater concentration of gas to be transported on one side of the membrane than on the other, so that the concentration gradient is maintained.

2 a Oxygen

b Carbon dioxide

3 a From outside to inside: mouth/nose, throat, trachea, bronchus, bronchiole, alveolar air space, one cell thick alveolar wall and one cell thick capillary wall

b From outside to inside: mouth, throat, one cell thick gill surface and one cell thick capillary wall

4 Unlike water and food, oxygen gas required for cellular respiration cannot be stored, so must be constantly taken in, and the waste gas, carbon dioxide, resulting from cellular respiration must be constantly removed.

5 • Layer of water lining inside surfaces of alveoli.

• Walls of alveoli are only one cell thick, the cell type being epithelium, which are flattened in shape, providing absolute minimal distance across which gas molecules must diffuse.

• Multiple bunches of alveoli at ends of bronchioles provide very large surface area.

• Air in alveoli has higher concentration of oxygen and lower concentration of carbon dioxide than blood in capillaries in close proximity.

Vein diameters may range from approximately 1–15 mm, and arteries from approximately 0.5–25 mm, though arteries have much thicker walls than veins.

4 Tubular shaped organ with very thin walls composed of one layer of flattened endothelial cells, joined like a jigsaw puzzle to form the surface

5 Suited to exchange function:

- inner and outer surfaces bathed in fluid
- walls just one cell thick
- very small diameter, so minimal distance for molecules to travel for exchange.

- 7 Substances must be dissolved in water to diffuse across membranes.
- 8 Air containing oxygen (O_2) and carbon dioxide (CO_2) gases is inhaled into the alveoli of the human lung. The concentration of O_2 is higher in the air in each alveolus compared to that in the blood in the capillary surrounding it, so O_2 gas diffuses across the one cell thick alveolar and capillary walls to enter the blood inside the capillary. Conversely, the CO_2 concentration in the blood in the capillary is higher than that in the air in the alveolus, so CO_2 gas diffuses out through capillary wall and into alveolus through its wall.

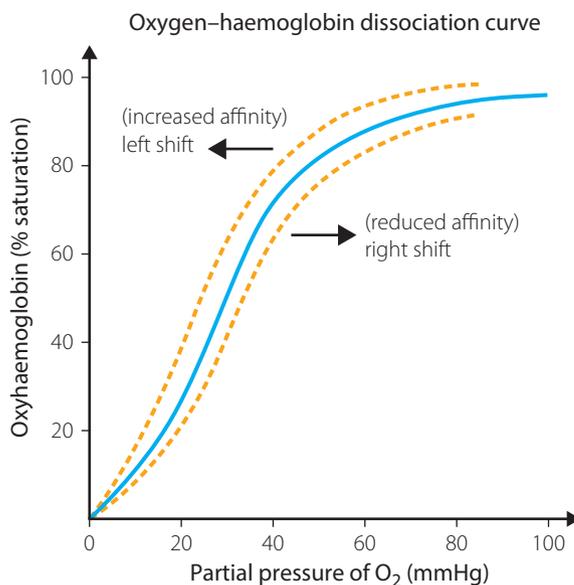
Refer to Figure 6.2.2 (page 97) for an illustration of this process.

- 9 Oxygen gas (O_2) bonds to haemoglobin (Hb) molecules in red blood cells to form oxyhaemoglobin. The Hb molecule can bond with a limited number of O_2 molecules. When maximum amount of O_2 is bonded, that's 100% O_2 saturation. If Hb is bonded at half capacity, O_2 saturation is 50% and so on.

O_2 saturation, shown on y axis of graph in the following graph, is related in part to partial pressure of O_2 , (P_{O_2}), shown on x axis of graph.

In the alveoli, P_{O_2} is high, so O_2 readily bonds with Hb – Hb has high affinity for O_2 . Blood circulates to body cells, where P_{O_2} is less – Hb has low affinity for O_2 , so O_2 is released to cells.

Various factors can reduce affinity, or cause a right shift, as shown in the following graph, such as increased temperature; or they can increase affinity, causing a left shift, such as a decrease in temperature.



7.1 SECTION REVIEW

- 1 Mouth → pharynx (throat) → oesophagus → stomach → small intestine

2

Structure	Function
Mouth	Mechanical digestion: food chewed into smaller pieces with larger surface area for chemical breakdown, food mixed with saliva by tongue to distribute chemical digestive enzymes and to moisten for swallowing Tongue pushes food to back of mouth to be swallowed Chemical digestion: of carbohydrate begins
Pharynx	Also involved in swallowing and is passage to opening of oesophagus
Oesophagus	Tube carrying food to stomach, rhythmic contractions move food along tube
Stomach	Mechanical digestion: food is churned to mix it with digestive enzymes Chemical digestion: of protein begins
Small intestine	Chemical digestion of all types of organic molecules; digestive enzymes from pancreas, intestinal wall; bile from liver/gall bladder to emulsify fats

- 3 Capillaries, lymph vessels

- 4 • Moist outer and inner surface

- Very thin permeable surface
- Very large surface area
- In close proximity to capillaries

- 5 External environment – digestive tube is continuous with external environment through the mouth and anus

- 6 Large surface area – greatly increases rate at which digested food molecules can diffuse; convolutions of outer membranes of individual cells forming villus wall, called microvilli, increase diffusion rate even further.

Single cell wall thickness – minimises distance that molecules have to diffuse.

Elongated shape – with capillary network and lacteals protruding inside, minimises distance that molecules have to diffuse to enter circulatory system.

7.2 SECTION REVIEW

- 1 a Breakdown of carbohydrates
b Breakdown of proteins
c Breakdown of lipids

- 2 a Simple sugars
- b Amino acids
- c Fatty acids and glycerol

7.3 SECTION REVIEW

- 1 Ammonia is extremely toxic even in very small quantities; it is converted to urea.
- 2 Ammonia, urea and uric acid are the three forms of nitrogenous waste excreted.
- 3 Different animals have different habitats and lifestyles; the different forms of nitrogenous waste excretion must offer advantages to certain animals in their particular habitats and with their particular lifestyles; for example: fish can excrete the extremely toxic ammonia immediately and continuously into their aquatic surroundings, and don't have to expend energy converting it into a less harmful substance, or lose water to dilute it.

7.4 SECTION REVIEW

- 1 Renal artery → capillary → glomerulus → Bowman's capsule → proximal tubule → loop of Henle → distal tubule → collecting duct → renal pelvis of kidney → ureter → bladder → urethra
- 2 a Glomerulus: internal environment because substances are dissolved in blood within the closed circulatory system.
b Bowman's capsule: external environment because substances have passed out of circulatory system through glomerulus wall into Bowman's capsule which is continuous with nephron tubules, collecting ducts and following structures emptying outside body.
c Tubules of the nephron: external environment (refer to explanation in part b),
d Capillary network surrounding nephron tubules: internal environment because it is part of closed circulatory system containing blood,
e Renal vein: internal environment because it is part of closed circulatory system containing blood
f Ureter: external environment because it leads to bladder and then to urethra, which leads to exterior of body.
- 3 Refer to Figure 7.4.2.

7.5 SECTION REVIEW

- 1 a i Filtration: about one-fifth of the blood plasma and all substances dissolved in it, except the large proteins and blood cells and platelets, are forced out of the glomerulus and through the Bowman's capsule membrane into the cavity in the capsule.
ii Reabsorption: water and many essential molecules dissolved in it are transferred back

into the capillaries surrounding the nephron tubules leading from the Bowman's capsule.

- iii Secretion: additional nitrogenous wastes and minerals or any other chemicals in excess of requirements are transferred out of the capillary blood and interstitial fluid and into the fluid of tubules/collecting ducts to be excreted.
- b Filtration occurs out through glomerulus wall and into Bowman's capsule through wall. Reabsorption occurs from proximal tubule, loop of Henle, distal tubule and collecting ducts. Secretion occurs from capillary network into collecting ducts.
- 2 Reabsorption of useful substances occurs from nephron tubules back into capillary network. Secretion of wastes and non-required substances occurs from capillary network into nephron tubules for excretion.
- 3 Many functions are constantly performed by kidneys, not only waste removal, but regulation of water and mineral levels in the blood and pH levels in the blood. The body's blood plasma is filtered and processed 60 times a day. Reabsorption requires a lot of energy, because active transport of substances is necessary. Active transport also occurs initially in the concentrating of the urine to prevent excess water loss. Reabsorption and secretion are constantly occurring to adjust substance levels in the blood because conditions change constantly in the body according to activities carried out, and changing inputs to the body.

7.6 MANDATORY PRACTICAL

Results

MIXTURE	COLOUR EXPECTED
Iodine + amylase	Iodine remains yellow-brown
Iodine + starch	Iodine changes colour to blue-black
Iodine + water	Iodine remains yellow-brown

Discussion

- 1 If any starch is present, added iodine will change colour to blue-black/purple. If no starch is present, added iodine will not change colour; that is, the colour will remain yellow-brown. Therefore, no colour change when iodine is added indicates that amylase has been active in the breakdown of all starch to glucose.
- 2 To show that iodine only changes colour when starch is present, and not when water and/or amylase are/is present without starch
- 3 To validate resulting observations, and indicate possible variation in results
- 4 Water is present in all solutions, including amylase and starch solutions, so had to 'rule out' the

possibility that iodine colour change is due to presence of water.

5 Student responses will vary, although expectations are that there:

- a *will be* an iodine colour change in test tubes 1–3 that contain starch + water, but this may depend on temperature
- b *will not be* an iodine colour change in test tubes of A–C at temperatures where amylase has

been active in breaking down all starch present; however, activity of amylase and thus iodine colour change *will* depend on temperature.

6 Student responses will vary, but could be of the form:

At ___°C, the time at which all starch is broken down by amylase activity is ...

At ___°C, starch is not broken down by amylase activity after 20 minutes.

7 For example:

TEST TUBE	COLOUR DESCRIPTION				
	AFTER MIXING WITH STARCH AT INDICATED TIME (MIN)				
	0	5	10	15	20
A at 0°					
B at 0°					
C at 0°					
A at 20°					
B at 20°					
C at 20°					
A at 40°					
B at 40°					
C at 40°					
A at 60°					
B at 60°					
C at 60°					
A at 80°					
B at 80°					
C at 80°					

8 Activity level of amylase is affected by temperature.

9 Depending on success of experimental procedure, responses could be of the form:

Amylase does not appear to function at _____°C.

Explanation: enzymes are proteins, which are denatured and become non-functional above certain temperatures because of breakage of bonds holding them in shape.

Conclusion

10 Depending on success of experimental procedure, responses could be of the form:

Temperature *is* an important factor in determining the activity and reaction rate of amylase.

11 Depending on success of experimental procedure, responses could be of the form:

Amylase is active between temperatures of _____°C and _____°C.

12 Depending on success of experimental procedure, responses could be of the form:

The optimum temperature at which amylase functions is _____°C.

CHAPTER REVIEW QUESTIONS

1 Mechanical digestion and chemical digestion to break down food particles into individual molecules small enough to diffuse across exchange surface of small intestines

2 a Nutrients enter the internal environment of the body through the villi lining the surface of the small intestine, and then move in through the walls of the capillaries and lacteals up inside the villi.

b Nutrient molecules are dissolved in the blood of capillaries. The blood is returned via veins to the heart to be pumped around the entire body within the vessels of the circulatory system, which branch into fine capillaries reaching to within a very short distance of every body cell.

- 3 Nephrons
- 4 Excretory system
- 5 Urine drains out of the kidneys via ureters into the bladder where it is stored until it is consciously excreted under muscular control through the urethra to the outside of the body.
- 6 a Amylases
b Proteins
c Lipases
- 7 Excess carbohydrate breakdown products simple sugars which are converted into glycogen and stored in the liver. Excess lipid breakdown products are stored for later use or converted into other substances.
- 8 a Blood plasma and dissolved molecules, except for large proteins, blood cells and platelets, are forced out of glomerulus and through into Bowman's capsule.
b Water and useful substances dissolved in it are transferred back out of nephron tubules and into the capillaries surrounding them.
c Additional nitrogenous wastes and other substances not required by the body at that time are transferred into nephron tubules/collecting ducts for excretion.
d Glomerulus and Bowman's capsule
e From nephron tubules and collecting ducts into capillaries
f From capillaries/interstitial fluid into nephron tubules/collecting ducts
- 9 a Many organic compounds are progressively broken down from very large molecules into smaller but still large molecules and eventually into the smallest breakdown products.
b Different chemical environments may be necessary for the different digestive enzymes to function; for example, proteases in the stomach require an acid environment, but this is not suitable for the action of other types of enzymes.
- 10 • Moist outer and inner surface
• Very thin permeable surface
• Very large surface area
- 11 The particular proteases that are released in the stomach for the digestion of some types of proteins only function in acidic conditions. The stomach produces hydrochloric acid and this provides the appropriate chemical environment. Digestion of other protein types in the small intestine, and of carbohydrates and lipids, is carried out by enzymes that do not require the acidic environment created in the stomach.
- 12 a Amylase, suitable for digestion of carbohydrate, is released by salivary glands into the mouth of humans. This type of enzyme is not likely to be released into the whale mouth because the predominant organic compounds present in the whale diet do not include carbohydrates.
b It is likely that the overall range of enzymes produced by whales is smaller than that produced by humans because whales have a much less varied diet. More specifically, there would be less amylase produced by the whale due to the much lower proportion of carbohydrates included in their diet.
- 13 The evolution of the loop of Henle as an adaptation in mammals and birds suits them to living on land where there is often a struggle to obtain enough water for survival, particularly in arid environments. Therefore, the production of concentrated urine, made possible by the loop of Henle, can reduce water loss associated with the excretion of waste materials removed from the blood.

■ END-OF-CHAPTER EXAM

- 1 D
- 2 B
- 3 C
- 4 A
- 5 D
- 6 B
- 7 Glucose molecules would pass out through cells in wall of glomerulus, across cells in wall of Bowman's capsule, out across cells in wall of nephron tubule, in across wall of capillary surrounding nephron tubule.
- 8 The digestive tract is part of the external environment because it is continuous with mouth, where food is ingested from outside the body, and with anus, through which wastes are excreted from body.
- 9 The capillaries are part of the closed circulatory system, but the circulatory system is intimately involved with the excretory system in eliminating wastes from cells, and its capillaries are located close to the tissues comprising the excretory system, as they are for other body systems.
- 10 Freshwater fish: no need for concentrating urine to conserve water because fish is surrounded by watery environment, thus no loop of Henle structure in nephron
Terrestrial mammal: needs to conserve water, so has loop of Henle, but of moderate length
Spinifex hopping mouse: needs to conserve as much water as possible in extreme arid environment, so has very long loop of Henle so urine can be made increasingly concentrated as it moves along the length of loop

- 11 Necessary features of exchange surfaces include: external and internal surfaces bathed in fluid; thin membranes; large surface area; and close proximity to capillaries for transporting substances.

All these characteristics are present in the surfaces through which digested food particles pass from the small intestine into blood of the internal environment, and the surfaces through which waste particles in blood pass to the external environment.

The covering of villi on the intestinal wall provides a massive surface area through which molecules move. Both villi and capillary walls are only one cell thick, and both have surfaces bathed in fluid. Capillaries of the circulatory system extend right up inside villi to minimise distance absorbed molecules must travel to enter blood.

Glomeruli are specialised extensions of capillaries that deliver waste products to kidney nephrons for excretion. They also have moist walls only one cell thick. The large glomeruli surface area is due to thousands of glomeruli each entering a kidney nephron. A Bowman's capsule closely surrounds each glomerulus, minimising the distance waste particles travel as they cross through into the moisture-lined, one-cell-thick wall of the capsule, just as the distance between villi walls and circulatory vessels inside them is minimised. Once inside the Bowman's capsule tubule, waste materials are already in the external environment because capsule tubule is continuous with all other nephron tubules, then collecting ducts out of the kidney, and the ureter tube leading to the bladder, which empties body wastes through the urethra.

CHAPTER 8: PLANT SYSTEMS: GAS EXCHANGE AND TRANSPORT SYSTEMS

8.1 SECTION REVIEW

- 1 Lenticels are open pores in the dead bark where the parenchyma tissue pushes through the epidermis, whereas stomata are gaps in the living epidermal layer itself and are surrounded by living guard cells that open and close the stomata.
- 2 Oxygen, carbon dioxide and water vapour
- 3 Daylight, temperature, rate of water vapour loss, water availability, concentration of CO_2 in the leaf and humidity
- 4 At high temperatures, plants tend to close their stomata to reduce water loss.
- 5 Student responses should be similar to Figure 8.2.1, page 124.

8.2 SECTION REVIEW

- 1 The leaf is the main photosynthetic organ of the plant.
- 2 Carbon dioxide and sunlight. Water enters the plant via the roots rather than the leaves.
- 3 The spongy mesophyll is a thick layer of irregularly spaced and shaped cells with some chloroplasts, while the palisade mesophyll is a thin layer of densely packed, elongated cells with lots of chloroplasts.
- 4 Chlorophyll captures the energy from sunlight and releases it for the other molecules in the chloroplast to use for photosynthesis.
- 5 Student responses should show CO_2 entering the leaf through the stomata and diffusing into the mesophyll cells, O_2 diffusing out of the mesophyll cells and leaving the leaf through the stomata, and light entering the mesophyll cells through the upper epidermis.
- 6
 - a Provides leaf with protection and is the location of stomata
 - b Main site of photosynthesis
 - c Pores through which the movement of gases such as CO_2 can be controlled
 - d Provide spaces within the leaf to allow movement of gases
 - e Provide support and control to stomata, opening and closing the pores as required
- 7 If the whole leaf were as densely packed as the palisade mesophyll, there would be problems accessing CO_2 . The leaf would also be extremely thin and much more fragile, because the light would not penetrate to the bottom of a thick palisade mesophyll.

8.3 SECTION REVIEW

- 1 The xylem is made of tracheids (thin dead cells with pores that overlap each other) and vessel elements (dead cells that stack directly on top of one another). Both types of cell act as tubes for the movement of water.
- 2 The phloem is made of sieve tube cells (living cells without a nucleus or vacuole that are connected to, and share cytoplasm with, each other through sieve plates) and companion cells (living cells with all organelles that are connected to sieve tube cells through plasmodesmata). Sieve tube cells allow the flow of sugary cytoplasm (sap), while companion cells keep the sieve tube cells alive.

XYLEM	BOTH	PHLOEM
Dead cells	Movement of substances in plants	Living cells
Does not require companion cells	Form vascular bundles in most areas of the plant	Requires companion cells
Cells only contain water (with dissolved minerals)	Made of specialised plant cells	Cells contain cytoplasm and several organelles
Moves water from roots to leaves		Moves sucrose from leaves to high growth or storage areas
Driven by root pressure and transpiration		Driven by water pressure and the concentration gradient

- 4 Plants don't have skeletons, so dead cells can be useful just to provide structural support. They can also be useful as an outer lining to insulate the living cells of the plant and protect them from predators. Hollow cells can also form pathways for bulk movement of substances.
- 5 Vessels such as xylem and phloem need to be intact to transport substances around the plant. If the bark that is removed contained the phloem, the tree would no longer be able to get sucrose to the roots, and they would die. If the bark contained the xylem, the tree wouldn't be able to get water to the leaves, and they would die. Students may also propose that ringbarking wouldn't work if the tree had functional xylem and phloem in the interior of the tree, so it would only work on trees that had their vessels in a ring around the trunk.

8.4 SECTION REVIEW

- Xylem and phloem
- Vascular tissue is arranged in bundles in most plants, with a ring of phloem forming a ring around the xylem.
- Roots absorb water and minerals and transport them to the stem. Stems transport water, minerals and sap between the roots and leaves.
 - Both roots and stems transport water and minerals.
 - Roots almost exclusively absorb water and minerals.
- Root hairs drastically increase the surface area of the roots.
- Xylem vessels are extremely thin and made of lignin, which is very polar. These make adhesion particularly strong in the xylem, which helps the water to be lifted through the plant.
- Student responses could include: hot air temperature, low humidity, strong wind, intense sunlight, large leaves, no cuticle or dense stomata.
- Student responses could include: cool air temperature, high humidity, no wind, weak sunlight,

small or modified leaves, thick cuticle or limited stomata.

- Cohesion is the attraction of water molecules to other water molecules. Adhesion is the attraction between water molecules and the container, in this case the walls of the xylem.
- All energy originates from the sun.
- Xylem: dead cells form a vessel for water and minerals to move via transpiration. Phloem: living cells form a vessel for sap and sucrose to move via a concentration gradient.
- No. The water moves through dead cells, but this doesn't mean there are no living cells left.

8.5 SECTION REVIEW

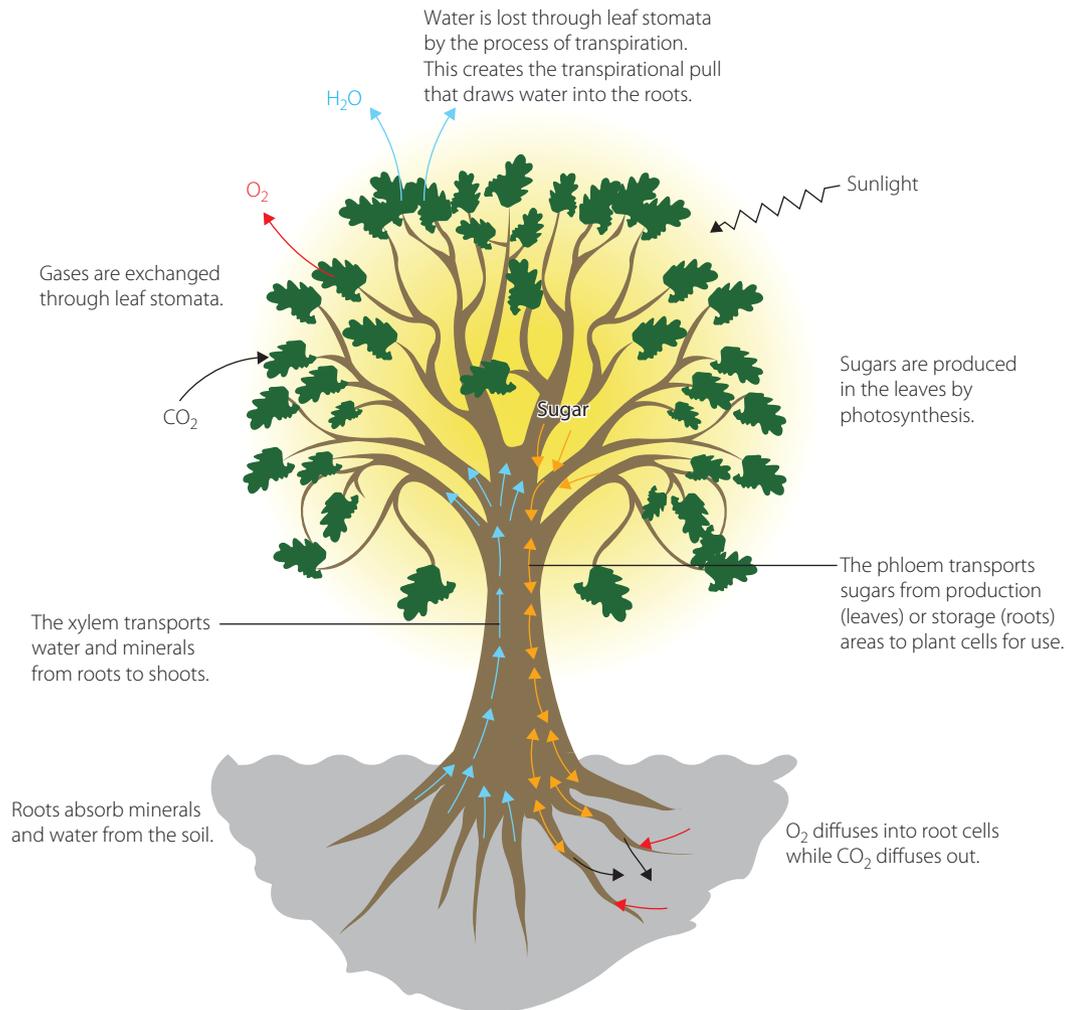
- A plasmodesmata is a tiny channel through plant cell walls that allows communication between cells by sharing cytoplasm.
 - A concentration gradient is the difference in concentration of a substance between two different regions
 - Sap is the thick, sugary cytoplasm that fills the phloem of plants.
- Student responses will vary. Examples include potassium, nitrates and iron.
- Sucrose enters the phloem by active transport from the mesophyll cells. It leaves the phloem by passive diffusion into cells that have lower sucrose concentration than the phloem.
- Areas of high growth have strong demand for energy. They use up sucrose very quickly and are continually absorbing it from the phloem. This leaves this area of the phloem with a low concentration of sucrose, which draws the sucrose from other areas of the phloem. Since the flow of sap in the phloem is not direction-dependent, it could flow up or down the plant equally easily.
- Water from the xylem must cross into the phloem as it collects sucrose from the leaves, so that the sap in the phloem is able to flow. As the sucrose is taken into cells, the water returns to the xylem.

6 The concentration of sucrose in the phloem must be higher than in most cells to allow it to diffuse into the rest of the plant cells. Mesophyll cells produce sucrose, giving them a high sucrose concentration. To maintain this concentration gradient between the phloem and body cells, the mesophyll cells must actively transport sucrose into the phloem, against the concentration gradient between the phloem and mesophyll cells.

7 The sap transports bulk quantities of sugar, so it is very highly concentrated. A high solute concentration lowers the freezing point of the sap solution to well below zero. The water that could potentially freeze is transported in the xylem, rather than with the sap in the phloem, further reducing the likelihood of the sap freezing.

CHAPTER REVIEW QUESTIONS

1



2 The epidermis acts as a barrier between the leaf and the external environment. The stomata regulate access to carbon dioxide and the loss of oxygen and water vapour from the leaf. The palisade mesophyll carries out most of the photosynthesis. The spongy mesophyll does some photosynthesis and creates air spaces for the movement of gases. The phloem transports sucrose away from the mesophyll cells. The xylem transports water and nutrients to the mesophyll cells.

3 Air temperature, humidity, wind, strength and duration of sunlight, leaf size, shape and number and the density of stomata.

4 Student responses should refer to vertical stability and long-term water access (via the water table) as benefits of taproots for plants that have tall trunks, many branches and leaves or live in semi-arid areas where rainfall is inadequate. They should refer to growth rate and access to rainfall as benefits of fibrous roots for plants that are low to the ground,

fast-growing, short-lived or in areas where rainfall is reliable.

- 5 Xylem would be larger, clearer (because it doesn't have any cell contents) and the boundaries between elements would be slanted (because they overlap). Phloem would be towards the outside of the plant (away from the large empty cells of the interior), smaller, darker (due to cell contents) and perpendicular boundaries (because they have sieve plates). Companion cells may also be visible with the phloem, while the xylem would not have companion cells.
- 6 Student responses should identify that the plant will draw water from the equipment and lose it to transpiration, moving the air bubble along the capillary tube. They should indicate that the lamp and fan would be used to investigate the effects of light and wind on the rate of transpiration.
- 7 Australian native trees have adapted to Australia's climate, which is generally hot and dry. Even in winter, the trees are usually at no risk of freezing, since snow is confined to high altitudes in the southern states. Winter sunlight is also considerably stronger for most of Australia than for most of the northern hemisphere. This means that trees don't need to drop their leaves to reduce their risk of freezing or to save on energy when sunlight is particularly weak.
- 8 Student responses may include that if the leafy shoot is still living, it will use the water for photosynthesis rather than only transpiration (minimised by ensuring the shoot is dead), and that the lamp will provide both light and heat, so these two factors cannot be tested separately (minimised by comparing the results of a living shoot with a dead shoot that would only react to the heat, not the light).
- 9 Student responses will vary widely but should be concisely summarised and clearly support their response.

■ END-OF-CHAPTER EXAM

- 1 B
- 2 D
- 3 C
- 4 Xylem cells are dead, overlap each other and are used to transport water. Phloem cells are living but the sieve tube cells have no nuclei and are kept alive by the companion cells, they are stacked on top of one another with sieve plates between them and are used to transport sucrose.
- 5 Student responses may include: air temperature, humidity, wind, strength and duration of sunlight, leaf size, shape and number and the density of stomata.

- 6
 - a Stomata open by absorbing water from surrounding epidermal cells and becoming rigid. They close by releasing the water.
 - b Stomata should open when water is abundant and light is shining on the leaves. Stomata should close when water is scarce and when light is not shining on the leaves.
- 7 Student responses should explain the movement of water by osmosis through the root hairs into the xylem, creating root pressure, the dual action of adhesion and cohesion to pull the column of water up the stem and the role of transpiration in removing water from the tops of the xylem to draw the water the rest of the way up the plant.
- 8 Student responses should include active transport from the mesophyll cell to the phloem, the influx of water from the xylem to counteract the concentration increase, the flow of sap away from the area where water influxed and the diffusion of sucrose into a cell that has a low sucrose concentration.

CHAPTER 9: HOMEOSTASIS

■ 9.1 SECTION REVIEW

- 1
 - a Stimulus: a signal that causes a response
 - b Receptor: a structure that detects or receives stimuli
 - c Effector: an organ, cell or protein that acts in response to a stimulus
 - d Response: the action resulting from a stimulus
- 2 See Figure 9.1.2, page 146
- 3 Negative feedback is a biological process where a response counteracts a stimulus. For example, increased blood glucose is detected by a receptor, which send the detected signal to the CNS. The CNS assesses the blood glucose level against the set point and determines that it is too high. The CNS then sends the response signal to the effector (in this case, the pancreas), which produces insulin to remove glucose from the blood. In this way, negative feedback keeps the internal environment within specific tolerance limits.
- 4 Unlike negative feedback, which counteracts a disturbance, positive feedback reinforces a stimulus. This means that if the blood glucose level was too high, negative feedback would lower it while if positive feedback were involved, it would raise it further! Positive feedback amplifies and encourages extreme conditions, which is the opposite of what homeostasis strives for. Homeostasis requires stability and conditions kept within strictly defined limits, and the extremes that positive feedback brings about destroys that.

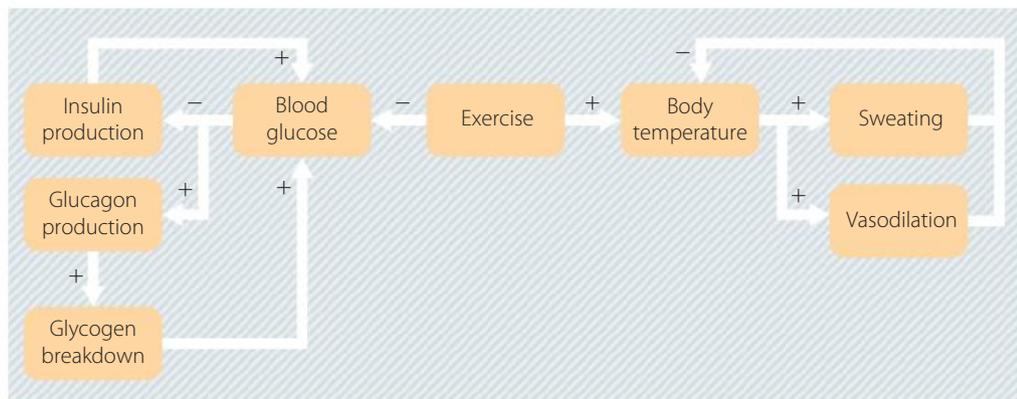
9.2 SECTION REVIEW

- 1 Chemoreceptors (e.g. tastebuds), mechanoreceptors (e.g. skin pressure), photoreceptors (e.g. retina), thermoreceptors (e.g. skin temperature), nociceptors (e.g. skin pain)
- 2 The interstitial fluid and the blood plasma
- 3 Exteroreceptors detect stimuli that are external to the body, such as air temperature and smells, while interoceptors detect stimuli that are inside the body, such as body temperature and blood glucose level.
- 4 External signals: light intensity, touch, air temperature. Internal signals: blood glucose, temperature, pH.
- 5 Nociceptors detect the same things that the other four categories detect, but only register intense levels as pain. For example, thermoreceptors in the skin detect the warm water of the shower, but nociceptors provide the pain signal when you scald yourself while cooking. The existence of a receptor designed specifically for pain may have contributed to our evolutionary survival by notifying the body immediately of dangerous external conditions. The pain feedback loop does not involve the brain and is therefore faster in responding; you pull your hand away from the scalding steam before you register that it is hot.

9.3 SECTION REVIEW

- 1 a Effector: an organ, cell or protein that acts in response to a stimulus
b Muscle: tissue made up of long, thin fibres that contract when stimulated

- c Gland: an organ that secretes chemicals or proteins within the body or externally
- 2 A motor neuron relays a signal from the spinal cord to an effector (both muscles and glands).
- 3 In feedback control diagrams, arrows show the progression of the system, plus-signs show that the initial factor increases the effect and minus-signs show that the initial factor decreases the effect.
- 4 Motor neuron signal → ATP binds to myosin → myosin pushes actin forward using ATP energy → myosin relaxes while ADP unbinds
- 5 Endocrine glands secrete substances (usually hormones) into the internal environment, such as the pancreas secreting insulin or the adrenal glands secreting adrenaline. Exocrine glands also secrete substances, but these are usually enzymes in a fluid rather than hormones, because instead of secreting into the blood, exocrine glands secrete onto the external surface. This means they also need to secrete the fluid. Exocrine glands include those that secrete saliva, sweat and stomach acid.
- 6 Stimuli that would trigger muscles include a range of brain-based signals, such as balance and coordination for skeletal muscles and steady, continual contractions such as the heartbeat and digestive peristalsis for smooth muscle. Stimuli that would trigger glands, however, include brain-based signals such as hunger, as well as direct chemical stimuli.
- 7 Student responses should contain some of the detail shown in the figure below.



9.4 SECTION REVIEW

- 1 a Metabolism: the sum of chemical reactions that maintain life within an organism
b Anabolic reaction: a reaction that builds up complex molecules from simple molecules
c Catabolic reaction: a reaction, such as cellular respiration, that involves the breakdown of complex molecules to simpler products
- 2 Student responses will vary. Examples are body temperature, pH and blood glucose.
- 3 Student responses will vary. Examples include injury and death.
- 4 Anabolism: chemical reactions that build large molecules. For example: gluconeogenesis and protein production.

Catabolism: chemical reactions that break down large molecules into smaller ones. For example, glycolysis and fat digestion.

- 5 a Anabolic reactions require energy to proceed and are therefore endergonic reactions.
- b Catabolic reactions release energy from chemical bonds and are therefore exergonic reactions.
- 6 a Anabolic – creates large molecules
- b Catabolic – breaks down large molecules
- c Anabolic – creates large molecules
- d Anabolic – creates large molecules
- e Catabolic – breaks down large molecules
- 7 When metabolism increases, so does temperature, which alters the effectiveness of enzymes.

CHAPTER REVIEW QUESTIONS

- 1 a Stimulus: a signal that causes a response
- b Receptor: a structure that detects or receives stimuli

4 Student responses should include:

NEGATIVE FEEDBACK	BOTH	POSITIVE FEEDBACK
Supports homeostasis by counteracting change	Responses to stimuli	Destroys homeostasis by reinforcing change
Necessary for continual maintenance of the body	Feedback control mechanisms	Only useful during times of major development in the body
Examples include maintaining blood glucose levels and body temperature	Consist of receptor, processing centre and effector	Examples include childbirth, puberty and metamorphosis (e.g. in insects)

- 5 Catabolic reactions generally produce net ATP and heat, and their pathways end with smaller molecules than they began with.
- 6 Enzymes are long chains of amino acids that have been folded into a specific shape. They are held in this shape by the bonding and electrostatic attractions between the strands. pH is the concentration of H^+ and this would interfere with the electrostatic attractions between the strands, causing the enzyme to lose its shape and therefore, be ineffective. Temperature affects how kinetically active the molecule is. Too much random movement may disrupt the shape of the enzyme as well as make enzyme–substrate binding more difficult. This is why enzymes require specific pH and temperature levels to function correctly.
- 7 Student responses should encompass all of his injuries and show a clear understanding that lack of water would have stopped his ability to sweat and that raised body temperature would have disrupted the enzymes that run all other processes in his body.

- c Processing centre: the organ or organ system, usually the central nervous system, that receives signals from receptors and sends appropriate responses to effectors
- d Effector: an organ, cell or protein that acts in response to a stimulus
- e Response: the action resulting from a stimulus
- f Metabolism: the sum of chemical reactions that maintain life within an organism
- 2 The stimulus–response model has three phases. First, a stimulus is detected by a receptor. Second, the receptor sends the signal to the processing centre, which interprets the signal and organises a response. Third, the processing centre sends the response signal to an effector, which carries out the response.
- 3 Negative feedback is where the response that the processing centre organises counteracts or cancels the stimulus. It usually works by having a gland turn on or off production of a substance, or having a muscle contract or release.

- 8 Student responses will vary widely, but the articles you choose should be clearly linked to Question 6 and of a reliable nature.
- 9 Limitations of the model can include oversimplification, where the pathway from receptor to processing centre to effector is not linear or incorporates many different steps, as well as the fact that it is missing the neural and/or hormonal pathways that transfer the signals between the three components of the model. Feedback control diagrams address the oversimplification somewhat by including non-linear pathways and multiple steps.

END-OF-CHAPTER EXAM

- 1 B
- 2 D
- 3 A
- 4 A
- 5 The stimulus–response model explains the mechanism of homeostasis – the maintenance of a relatively stable internal environment. It involves

detection of a change in conditions, processing of the stimulus and the initiation of a response.

- 6 Chemoreceptors (chemicals), mechanoreceptors (pressure), photoreceptors (light), thermoreceptors (heat) and nociceptors (pain).
- 7 Effectors are either muscles such as skeletal muscles, which contract in response to neural stimuli, or glands such as salivary glands, which produce secretions in response to either neural or chemical stimuli.
- 8 Student responses should reference a lack of detection of stimuli. Failing to detect external stimuli would result in the individual being unresponsive to their environment, similar to coma. Failing to detect internal stimuli would result in the individual failing to respond to changes in the body chemistry, leading to a loss of homeostasis and death.
- 9 Student responses should state that Robert's blood glucose level was under homeostatic control due to its maintenance within a narrow range.
- 10 Student responses should reference the need for stable and specific conditions for optimal enzyme activity. Conditions should include at least pH and temperature, which are both altered by increasing or decreasing metabolism.

CHAPTER 10: NEURAL HOMEOSTATIC CONTROL PATHWAYS

10.1 SECTION REVIEW

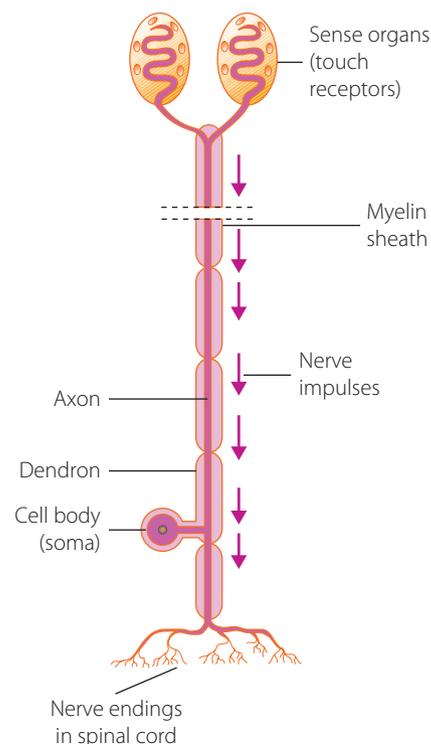
- 1
 - a Soma: the main cell body of a neuron
 - b Axon: the tubular extension of a neuron cell body that conducts the nerve impulse
 - c Myelin sheath: the fatty layers of insulation surrounding the axon of a neuron; made of Schwann cells
 - d Schwann cells: cells that wrap tightly around the axons of neurons to form the myelin sheath
 - e Nodes of Ranvier: small spaces between the Schwann cells along the axon of a neuron
- 2 Sensory neurons, interneurons (or interconnecting neurons) and motor neurons.
- 3 A neuron is an individual cell, a nerve fibre is a bundle of axons, and a bundle of interconnecting nerve fibres makes a nerve.
- 4 The myelin sheath is composed of Schwann cells that grow wrapped around the axon. Myelin has two main functions: to make the nerve impulse jump from node to node, thus increasing the speed of transmission and to insulate the axon against picking up nerve impulses from neighbouring neurons.
- 5 Lack of myelin leads to a degradation in the two purposes of myelin. When the nerve impulse does not jump from node to node, signal transmission

slows down. This would result in slow responses to stimuli, which would inhibit the ability to think quickly, or make the quick muscle changes required for motor skills like handwriting and balance. When the axon is not insulated against accidentally picking up nearby impulses, the pathway of a signal would be impossible to control. Signals intended for hands and fingers may end up moving eyelids or toes and thought processes may become confused.

- 6 Neurons have a very elongated structure, unlike most body cells. Those that do have elongated structures are generally completely elongated rather than neurons, which have a distinct, round cell body and elongated appendages. Neurons are also myelinated and are generally bundled together in nerve fibres.
- 7 Student diagrams should include soma, axon, dendrites, axon terminals, myelin sheath and nodes of Ranvier.

10.2 SECTION REVIEW

1



- 2 Sensory neurons have a side-bulge soma along the length of the axon, dendritic terminals that branch off the axon and terminate in sensory receptors, axon terminals that terminate in synapses and the impulse is directed towards the CNS. Motor neurons have a soma that is inline at one end of the axon, dendritic terminals that branch directly off the soma and terminate in synapses, axon terminals that

terminate in end plates that interface with effectors and the impulse is directed away from the CNS.

- Interneurons have many dendrites and axon terminals that connect in vast, complicated webs. These webs cannot be made with sensory or motor neurons because both of them have specialised ends that cannot interconnect the way that interneurons can. The webs are required for thought patterns and decision-making, even non-conscious decision-making such as homeostasis, which is vital to the maintenance of a multicellular organism.

10.3 SECTION REVIEW

- The axon terminal is filled with secretory vesicles of neurotransmitters and embedded in the cell

- Student responses should include:

SIGNAL TRANSMISSION	BOTH	SIGNAL TRANSDUCTION
Inside a single neuron	Nerve impulses	In the synapse between two neurons
Electrical signalling	Triggered by ions	Chemical signalling
Triggered by influx of sodium ions		Triggered by influx of calcium ions

- Initial resting potential → Impulse triggers membrane to become permeable to sodium → Sodium influx triggers action potential (ie. makes inside the axon more positive than outside) → Potassium ions diffuse out → Membrane becomes impermeable again → Sodium is pumped out and potassium in to restore resting potential
 - Impulse triggers the opening of calcium ion channels in the presynaptic membrane → Calcium influx triggers exocytosis of vesicles containing neurotransmitters → Released neurotransmitters diffuse across the synapse → Neurotransmitters dock with ion channel receptors in postsynaptic membrane → Postsynaptic ion channels open allowing influx of sodium ions → Sodium influx triggers impulse in postsynaptic neuron → Enzymes deactivate neurotransmitters → Neurotransmitters are recycled back into the presynaptic neuron
- Sodium deficiency would result in a lack of sodium ions outside the axon membrane. This would mean that the outside is not as positive as the inside, making the neuron in action potential all the time rather than resting potential. Without proper functioning neurons, the internal and external environment cannot be monitored and responses cannot be reliably sent. This would result in a breakdown of homeostasis and metabolism, causing death.

CHAPTER REVIEW QUESTIONS

- Sensory neuron, then interneuron, then motor neuron

membrane are ion channels and receptors for neurotransmitter uptake.

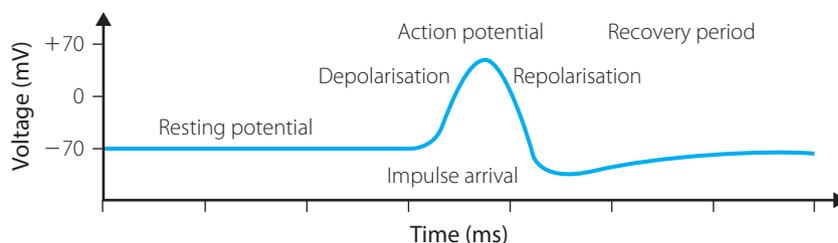
- Myelin has two main functions: to make the nerve impulse jump from node to node, thus increasing the speed of transmission, and to insulate the axon against picking up nerve impulses from neighbouring neurons.
- Rising: sodium ions diffuse rapidly into the axon, potassium ions are trapped inside. Falling: potassium ions begin to diffuse out of the axon, sodium-potassium pumps move sodium out to restore balance.

- Student responses should be similar to Figure 10.3.1.
 - Student responses should be similar to Figure 10.3.2.
- Student responses should include: the cell body looks distinct from the appendages, the thin axons are bundled into nerve fibres and the Schwann cells wrap tightly around the axon.
- Differentiating features for sensory neurons include sensory receptors in the dendrites and a side-bulge soma. Those for interneurons include the axon, axon terminals and dendrites looking extremely similar, radiating from the cell body. Differentiating features for motor neurons include end-plates on the axon terminals.
- Conscious and non-conscious actions would both involve sensory and motor neurons in similar patterns, such as choosing to remove your hand from a warm surface and reflexively removing it from a hot surface. However, the interneurons that process the stimulus and send the appropriate response to the effector would be different. Conscious actions would require many interneurons in complex webs such as in the brain to think and make a decision, while non-conscious actions require extremely short reaction times and no thought. They are likely to be processed by a single interneuron in the spinal cord rather than travelling through the webs of the brain.
- Student responses will vary, but should include reference to neurotransmitters stimulating the postsynaptic neuron, triggering the continuation of the signal and enzymes removing them from the synapse. Possible malfunctions could include not enough

dopamine production to trigger the postsynaptic neuron, too many removal enzymes, too many dopamine channels so that the neurotransmitter is removed too quickly, and a limited number of postsynaptic receptors so the dopamine must stimulate the neuron for longer to be effective.

- 7 Student responses will vary but should include references to triggering impulses in neurons within the chest that overcome the impulses they are receiving in abnormal heart functioning.
- 8 Student responses will vary but could include situations where quick responses and attention to multiple stimuli is required.
- 9 Student responses will vary widely, but the articles chosen should be clearly linked to Question 7 and of a reliable nature.

8



- 9 Student responses will vary but should include reference to reducing the number of successful signal transductions to the facial muscles, effectively cutting them off from nervous input.
- 10 Student responses will vary but could include disruption of any of the key components of signal transmission within the neuron such as the sodium-potassium pumps, nodes of Ranvier, myelin sheath, or the concentrations of sodium or potassium.
- 11 Student responses should argue that stimulatory nerves would be more active in the brain to keep it well-nourished and warm, while inhibitory nerves would be more active in the fingers to constrict the blood flow to unnecessary extremities.

CHAPTER 11: HORMONAL HOMEOSTATIC CONTROL PATHWAYS

11.1 SECTION REVIEW

- 1 **a** Hormones: chemicals produced by the body to prompt responses from specific cells
b Glands: organs that secrete chemicals or proteins within the body or externally
c Receptors: structure that detect or receive stimuli
- 2 See Table 11.1.1, page 172.
- 3 Possible responses include solubility, polarity, binding location, what they are made from and how they travel in the blood.

END-OF-CHAPTER EXAM

- 1 D
- 2 B
- 3 A
- 4 C
- 5 D
- 6 Sodium-potassium pumps are located in the cell membrane of the axon of a neuron and actively pump three sodium ions out of the cell for every two potassium ions it pumps into the cell.
- 7 Student responses should include explanations of the signal jumping between nodes of Ranvier and the insulation of the axon against neighbouring signals as well as references to the characteristic symptoms of multiple sclerosis and Parkinson's disease.

- 4 The effect of a signalling molecule is triggered only by the specific receptor that it can bind to. Only cells that express this specific receptor will be affected.
- 5 Water-soluble hormones will be filtered by the kidneys into the urine, so overdoses are less likely. Fat-soluble hormones tend to accumulate in stored fat and are not easily filtered out of the blood.

11.2 SECTION REVIEW

- 1 The first pathway is upregulation of its own receptor so that the cell becomes more sensitive to it. The second pathway is the one that triggers the cellular response.
- 2 Cell sensitivity is how well the cell responds to a hormone. Cells with more receptors have larger responses and, therefore, are more sensitive.
- 3 Upregulation is when the cell is prompted to produce more of a particular component (or make a process faster), while downregulation is when the cell is prompted to produce less or makes a process slower.
- 4 Mitosis is generally upregulated in high-turnover tissues such as the gut and mouth linings and the skin, while it is generally downregulated in low-turnover tissues such as the liver and bone.

INQUIRING FURTHER

- 1 Student responses will vary but should refer to IGF-1 surviving pasteurisation and digestion and the implication of raised IGF-1 levels in humans as possibly promoting the growth of cancers.

- 2 BST is denatured in the pasteurisation process and, thus, is entirely inert. It is misleading because BST is not the cause of the concerns surrounding rBST use; it is IGF-1.

3

	DAIRY CATTLE	CONSUMERS	ECONOMICS	ENVIRONMENT
Risks	Mastitis, injection-site reactions, lameness and reproductive problems	IGF-1 concerns, moral concerns with cattle risks	Reproductive problems for injected cattle leading to no milk from them, mastitis is expensive to fix	Poor animal welfare
Benefits	Fewer calves need to be born and lost to produce the same amount of milk for the humans	Potentially cheaper milk due to lower production costs	Fewer cattle required for milk production, lower production costs	Potentially lower methane emissions, potentially fewer cattle requiring less arable land

Student responses may vary but should be logically and scientifically defended.

11.3 SECTION REVIEW

- 1 Hormone binds to extracellular receptor, receptor changes conformation and activates secondary messenger inside the cell, secondary messenger activates other secondary messengers in a cascade, messenger cascade amplifies the signal and activates effector proteins, which produce the cellular response.
- 2 Ion channels open hydrophilic passages through the membrane to allow charged molecules through. G protein-coupled receptors activate the G protein as the first of their secondary messengers. Tyrosine kinase receptors are membrane-embedded enzymes that are the first of the secondary messengers themselves.
- 3 Fat-soluble hormones can pass through the cell membrane to bind to receptors inside the cell, so they don't need a cascade of secondary messengers to carry their signal to effector proteins.
- 4 A single hormone molecule binds to a single receptor, which usually activates a single molecule of the first secondary messenger in the cascade but can activate more than one. This messenger can activate more than one of the second messenger, each of which can activate more than one of the third messenger. In this way, the single hormone molecule can eventually cause a large number of effector proteins to be activated.
- 5 Hormones need to bind to receptors to begin their effect, so if each type of cell produces a slightly

different receptor, the hormone will still bind to it but the effect will be different. This is because a slightly different receptor will activate a different signal transduction pathway and therefore, cause a different cellular response.

- 6 Cortisol plays a role in the healthy maintenance of blood pressure, blood glucose levels, fat storage and immune responses. These would be disrupted by continued exposure to highly stressful situations and may result in high blood pressure, diabetes, obesity and lowered immunity, even if the individual has an otherwise healthy lifestyle.

CHAPTER REVIEW QUESTIONS

- 1 Hypothalamus, pineal gland, pituitary gland, thyroid gland, parathyroid glands, adrenal glands, pancreas and ovaries/testes
- 2 Glands produce hormones, which bind to receptors that are expressed on the surface of target cells.
- 3
 - a Upregulation: when a cell is prompted to produce more of a particular cellular component, such as enzymes or receptors
 - b Downregulation: when a cell is prompted to produce less of a particular cellular component, such as enzymes or receptors
 - c Signal transduction: the process by which a cell converts one kind of signal into another; occurs when an extracellular signal binds to and activates a receptor, which, in turn, alters intracellular molecules to bring about a cell response

WATER-SOLUBLE	BOTH	FAT-SOLUBLE
Hydrophilic	Target all types of body tissue	Hydrophobic
Polar or charged	Affect all types of cellular processes	Non-polar
Derived from amino acids	Travel via the bloodstream	Most derived from cholesterol
Structured like amino acids		Heavily ring-structured
Can't pass through membranes		Can pass through membranes
Travels independently in blood		Require companion molecule to travel in blood
Binds to external receptors and initiates signal transduction		Binds to internal receptors

- 5 Student responses will vary widely. Cortisol is given as an example in the text. The second example will need to be researched but most human hormones have different effects in different tissues.
- 6 Student responses will vary but should explain signal amplification as well as different receptors causing different effects.
- 7 Student responses will vary but should mention several of testosterone's effects, such as pubic and facial hair growth, increased muscle mass and aggression. Responses should clearly link these effects with negative outcomes for the individual both inside and outside of the sport.
- 8 Student responses will vary widely but the studies chosen should be from credible sources and clearly support their argument.
- 9 Student responses will vary widely but could refer to artificial enhancement as getting the very best performance possible from the human body and thus, if everyone used them, the playing field would not only be level, but at the very limits of physical capability. Responses to this person will depend on the argument chosen.

8 Student responses may be similar to the following.

ARGUMENTS FOR:	ARGUMENTS AGAINST:
Every cell will be acutely sensitive to the required hormones	Maintaining so many receptors is resource intensive for the cell
Signalling will occur faster	Many of the receptors will be crowding the cell surface without being used regularly
Signalling will be less taxing for the cell since it only needs to produce the cellular response instead of also upregulating the receptor to become more sensitive	Increased risk of a hormone incorrectly binding to the wrong receptor and activating unwanted cellular responses

- 9 Student responses will vary but should refer to the function of the nervous system as a fast-acting response to stimuli that tends to coordinate movements and small-scale body processes, as opposed to the function of the endocrine system as a slow response to stimuli that tends to regulate

■ END-OF-CHAPTER EXAM

- 1 D
- 2 C
- 3 B
- 4 The effects of signalling molecules are triggered only by the specific receptor that it can bind to. Only cells that express this specific receptor will be affected.
- 5 Water-soluble hormones are hydrophilic, derived from amino acids and cannot pass through membranes. Fat-soluble hormones are hydrophobic, usually derived from cholesterol and can pass through cell membranes.
- 6 Externally binding hormones effect change in the cell through signal transduction, where a cascade of secondary messengers carry the signal from the membrane-bound receptor to the effector proteins.
- 7 Signal amplification means that a single hormone molecule binding to a single receptor can activate many effector proteins within the cell and thus, elicit a strong cellular response. This makes the process much more efficient and less expensive for the body because it doesn't have to produce large quantities of hormone to get a strong response.

processes that take a long time such as growth and development.

- 10 1. Stimulus detected: ADH binds to receptor.
2. Signal processed: signal transduction using ATP and cAMP as initial secondary messengers.

3. Effector produces response: aquaporin storage vesicle exocytosis.
4. Response: aquaporin channels merge with cell membrane allowing reabsorption of water from collecting duct.

CHAPTER 12: THERMOREGULATION

12.1 SECTION REVIEW

- 1 **a** Thermoregulation: the regulation of body temperature
- b** Endotherm: an animal that retains heat generated by metabolic activity
- c** Hypothermia: a state in which the internal temperature drops below the set point
- d** Hyperthermia: a state in which the internal temperature rises above the set point
- 2 For endotherms living in low-temperature environments, the problem is how to increase heat gain and reduce heat loss. In high-temperature environments, the problem is how to reduce heat gain and increase heat loss.
- 3 **a** Incorrect. Enzymes do not function at their optimum rate when the temperature rises.
- b** Correct. Active sites in enzymes lose their shape permanently and denature.
- c** Correct. Enzyme function slows significantly if body temperatures fall and the individual suffers from hypothermia.

12.2 SECTION REVIEW

- 1 Insulation, brown adipose tissue, shape and size
- 2 The shape of an organism affects the surface-area-to-volume ratio. The greater the ratio, the more heat is lost to or gained from the environment. Larger, more rounded animals have a lower surface area to volume ratio and so lose less heat to the environment. They are often found in cold places.
- 3 Cells in brown adipose tissue have more mitochondria than white adipose tissue cells. Because mitochondria generate heat, the more mitochondria, the more heat generation.
- 4 The surface area of the ears varies between the examples given in Figure 12.2.3. It can be explained by the different conditions under which the foxes live. In hot conditions, a relatively large total surface area increases the surface from which radiation can take place. Heat loss is increased in hot conditions. The Arctic fox, in cooler conditions, reduces heat loss by the fact that the ears have a smaller surface area.

12.3 SECTION REVIEW

- 1 An endotherm has a temperature tolerance range within which the rate of heat production is in

equilibrium with the rate of heat loss to the external environment. An endotherm does not have to use large amounts of energy to control its temperature within this range. The lower critical temperature is the lowest temperature of the tolerance range whereas the upper critical temperature is the highest temperature of the tolerance range. Below the lower critical temperature and above the upper critical temperatures, the metabolic rate increases. Hibernation is an example of a response when the external temperature is lower than the lower critical temperature.

- 2 Huddling reduces a group's overall surface-area-to-volume ratio. This reduces how much of the group's bodies are exposed to the colder open air, reducing heat loss overall.
- 3 Torpor is a state of decreased physiological activity. Both hibernation and aestivation are forms of torpor and are characterised by periods of dormancy. Hibernation occurs over long periods of cold conditions, whereas aestivation occurs over long periods of dry conditions.
- 4 **a** Incorrect. Kleptothermy is an example of huddling. Metabolic rate and body temperature do not vary.
- b** Correct. When conditions are very cold, metabolic rate may be insufficient to maintain body temperature within tolerance limits. The metabolic rate falls to a level that just sustains life during hibernation.

12.4 SECTION REVIEW

- 1 Arterioles in the skin constrict, counter-current heat exchange operates, and shivering occurs. Students may also mention that sweating and/or panting decreases.
- 2 Arterioles in the skin dilate and sweating and/or panting increases.
- 3 Vasodilation occurs when blood vessels dilate or widen. This increases blood flowing through the skin, thereby increasing the amount of heat radiated and lost by the skin via the blood.
- 4 Blood travelling in the arteries to an area of the body exposed to cold conditions, such as in the extremities, warms the blood returning to the body in the adjacent veins. The outgoing blood to the extremity is cooled in the process but not enough to affect cell activities. Because the temperature gradient between the area and the surroundings is reduced, heat loss is minimised.
- 5 On hot days, skin becomes covered with sweat secreted from sweat glands. When water evaporates from the skin, heat energy is taken away from the internal surface and the blood flowing close to it. This lowers the body temperature. In windy

conditions the water is removed quickly, taking heat away more rapidly and making the person feel cooler. In humid conditions the water concentration in the air is high, reducing evaporation rates and hence limiting the heat loss.

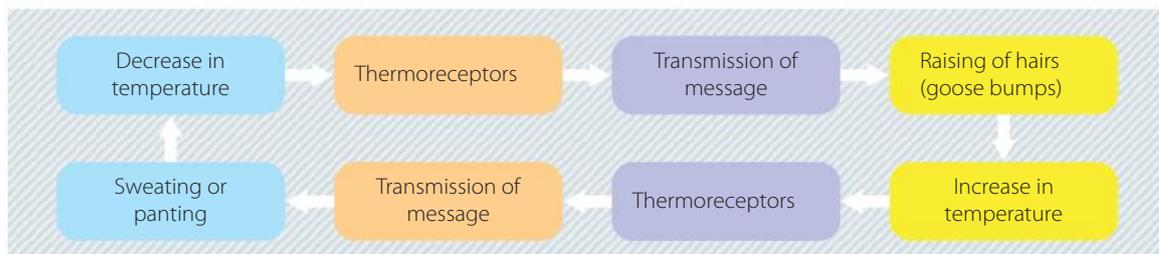
6 Diagram should be similar to Figure 12.4.1, page 188.

12.5.1 PRACTICAL ACTIVITY

Discussion

- 1 Cotton wool simulates hairs lying flat on the surface of the skin.
- 2 An insulating layer of air can be achieved in mammals by the contraction of erector muscles at the base of hairs. These muscles contract under cold conditions, resulting in hairs standing up and trapping a layer of air between them and the skin.
- 3 In cold weather, the erector muscles at the base of the cat's fur contract, raising the fur to trap an air layer that makes the cat look bigger. On hot days, the erector muscles at the base of hairs relax and consequently hairs are flattened, increasing heat loss.
- 4 From their results, students should be able to make a similar explanation to the following. On hot days, skin becomes covered with sweat secreted from sweat glands. Water evaporates from the skin, taking

3



- 4 When body temperature in mammals starts to drop, the hairs on the skin are raised (goose bumps) and vasoconstriction of blood vessels occurs to conserve heat. Shivering and an increase in metabolic rate create heat to raise the body temperature and many behaviours change to conserve and create heat (e.g. increase in the amount of activity/exercise). For example, in this activity the role of insulation on heat loss from body surfaces was investigated.
- 5 When body temperature of mammals starts to increase, hair on the skin is lowered and vasodilation causes blood to flow closer to the skin. Sweating or panting will help to lower the body temperature. Many behaviours that reduce body temperature will also occur (e.g. a decrease in the amount of activity/exercise). For example, in this

away heat energy from the internal surface and the blood flowing close to it. This lowers the body temperature. Under windy conditions, the water is removed quickly, taking heat away more rapidly and making you feel cooler.

- 5 Animals such as dogs do not have many sweat glands and cool themselves mainly by panting. This evaporates water from inside the dog's mouth and removes heat from the surface of the tongue and the blood flowing close to it.
- 6 Frogs are more susceptible to water loss from body surfaces on a windy hot day. They do not have any insulating layers or other effective means of stopping water loss through their body surface. So under these conditions, as shown by experimental results, these animals are very susceptible to water loss.

Taking it further

- 1 Part B. Test tubes 1 and 3 are sprayed with water (simulating perspiration on the skin) to test if warm water (perspiration) leaving a surface carries heat away with it (as would be the case when perspiration evaporates from the skin surface).
- 2 Test tube C in Part A is used as a control for test tubes A and B. Test tube 4 in Part B is used as a control for test tubes 1, 2 and 3.

activity the role of water loss from body surfaces in losing heat was investigated.

12.5 SECTION REVIEW

- 1 The hypothalamus 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.
- 2 The hypothalamus releases thyrotropin-releasing hormone (TRH), which activates the anterior pituitary gland to release thyroid-stimulating hormone (TSH). TSH stimulates the thyroid gland to secrete the thyroxine into the blood.
- 3 When the core temperature drops, the metabolic rate increases, requiring more glucose to supply the increased rate of cellular respiration. Insulin levels increase to release more glucose to cells. When the

core temperature increases, the metabolic rate does not increase, requiring no increase in insulin levels.

- 4 Thyroxine levels increase to a certain amount. When levels are high, thyroxine has an inhibitory effect on the anterior pituitary gland, which responds by secreting less TSH, in turn reducing the amount of thyroxine. This is an example of negative feedback because the high level of thyroxine in the blood inhibits further secretion of thyroxine.

Insulin levels increase to a certain amount, reducing blood glucose. When blood glucose levels are low, insulin production decreases. This is an example of negative feedback because the response to high levels of insulin inhibits further secretion of insulin.

CHAPTER REVIEW QUESTIONS

- Heat exchange and metabolic activity affect the internal core temperature. Endotherms have internal temperatures set to where their enzymes work efficiently. If internal temperatures rise above the set point, enzyme efficiency decreases. If body temperatures fall, enzyme function slows significantly.
 - Structural features, behavioural responses, physiological mechanisms and homeostatic mechanisms
 - Insulation, brown adipose tissue, shape and size
 - Moving locations, huddling and torpor
 - Vasomotor control, evaporative heat loss, counter-current heat exchange and thermogenesis
 - Hormone negative feedback
 - When temperatures vary beyond the set point, thermoregulatory mechanisms respond. Responses include increasing or decreasing heat gain; increasing or decreasing heat loss; increasing or decreasing metabolic activity in response to temperature variations.
 - Structural features: insulation decreased, e.g. thinner coat; amount of brown adipose tissue decreased; smaller body size and more exposed surface area to increase heat loss
Behavioural responses: moving into the shade; reduced huddling, aestivation
Physiological mechanisms: vasodilation; increased sweating or licking; reduced thermogenesis
Homeostatic mechanism: reduced production of thyroxine and insulin
 - Structural features: insulation increased, e.g. thicker coat; amount of brown adipose tissue increased; larger size and less exposed surface area to decrease heat loss
Behavioural responses: moving into the sun; increased huddling, hibernation
- Physiological mechanisms: vasoconstriction; decreased sweating or licking; increased thermogenesis, including shivering
Homeostatic mechanism: increased production of thyroxine and insulin

10–14 Student responses will vary.

END-OF-CHAPTER EXAM

- D
- B
- C
- C
- A
- B
- D
- Structural features: any two of insulation, brown adipose tissue, shape and size.
Behavioural responses: any two of moving locations, huddling, torpor
Physiological mechanisms: any two of vasomotor control, evaporative heat loss, counter-current heat exchange, thermogenesis
Homeostatic mechanisms: thyroxine and insulin negative feedback
- A small mammal has a greater surface-area-to-volume ratio and loses more heat than a large mammal. Shivering is a form of thermogenesis that produces more heat.
- The set point is the temperature at which metabolic activities function best for that organism.
 - Eskimo pup: -24°C
 - Sloth: $+28^{\circ}\text{C}$
 - Polar bear pup
 - Ground squirrel
 - Species living in Arctic conditions have a lower critical temperature than species living in tropical conditions. When lower critical temperatures are reached, metabolism increases at a higher rate in tropical than in Arctic species.
 - Torpor, hibernation, dormancy, aestivation.

CHAPTER 13: OSMOREGULATION

13.1 SECTION REVIEW

- The function of osmoregulation is to control solute concentration in cells.
- Osmoregulators regulate their osmotic concentration to be either higher or lower than their external environment. Osmoconformers allow their osmotic concentration to be equal to the concentration of the external environment.

- 3 Ammonia, urea and uric acid. It is essential to remove these wastes because they are toxic.
- 4 Osmoconformers can tolerate fluctuations in salinity in their surroundings better than osmoregulators. Osmoconformers reduce the need to move water into and out of their bodies and need to spend less energy regulating their internal osmotic concentration.

- 5 Rise in osmotic pressure → detected by osmoreceptors → hypothalamus → message to pituitary gland → secretion of ADH → detected in kidney → increased permeability of cells lining collecting ducts → increased water movement to blood → reduction in osmotic pressure.

6

STRUCTURAL FEATURES	BEHAVIOURAL RESPONSES	PHYSIOLOGICAL MECHANISMS	HOMEOSTATIC MECHANISMS
Waterproof or impermeable outer layer	Aestivation	Urine concentration	Antidiuretic hormone (ADH)
Kidney	Burrowing	Tissue fluid concentration	

13.2 SECTION REVIEW

- 1 Any three of:
 - thick waxy cuticle on the leaf surface
 - reduced numbers of stomata on the top of the leaf and increased numbers on the bottom of the leaf
 - sunken stomata
 - cylindrical or rolled leaves
 - reduced leaf numbers or no leaves
 - hairs on leaves.
- 2 The cuticle is a translucent, waxy, water-impermeable layer secreted by epidermal cells in the leaf. The cuticle restricts water loss but allows light rays to pass through into photosynthetic parts of the plant.
- 3 The leaf hairs help create a humid microclimate, reducing transpiration through the stomata because the concentration gradient has been reduced, making it harder for water evaporation out of the stomata.
- 4 Halophytes live in salty environments. The habitat is physiologically dry due to a high solute concentration. The habitat of xerophytes is physically dry. Consequently, similar structural adaptations for a dry habitat are commonly found in both halophytes and xerophytes.
- 5 a Student responses will vary but could include: in a seasonally dry riverbed, around a desert water hole or an area with a source of water deep underground.
 b Student responses will vary but could include: in a desert area subject to infrequent heavy rain. Ephemeral plants are examples of plants with a superficial root system. They are short-lived plants appearing when there is abundant moisture following good rains.
- 6 Plants living in dry or salty environments (xerophytes and halophytes) typically have fewer

stomata, located on the underside of the leaf in sunken grooves or pits. Plants that grow in or on water (hydrophytes) only have stomata on the upper surfaces of the leaves. Plants that are exposed to an environment where it is neither too dry nor too wet have a larger number of stomata on the undersides of the leaves.

13.4 MANDATORY PRACTICAL

- 1 Stomata may not be evenly distributed throughout the leaf surface. By counting stomata in three separate fields of view, a more accurate estimation of stomata number can be made.
- 2 Water is lost through open stomata. The undersides of leaves are not exposed to direct sunlight, which reduces water loss.
- 3 Stomata are expected to be on the upper leaf surface in aquatic plants (hydrophytes). Hydrophytes do not need adaptations for water retention. Because water contains much less oxygen than air, the problem for hydrophytes is lack of oxygen, so stomata are on the upper surfaces in contact with air.

CHAPTER REVIEW QUESTIONS

- 1 If the supply of water does not meet what is lost, the relative concentrations of solute and solvent in tissue fluids become difficult to regulate. Physiological functions are therefore affected. In endotherms, a loss in blood volume results in a blood pressure drop; toxic wastes cannot be excreted effectively and enzyme function is affected. Severe dehydration can lead to death.
- 2 Structural features, behavioural responses, physiological mechanisms and homeostatic mechanisms
- 3 Structural features and homeostatic mechanisms
- 4 Waterproof or impermeable outer layer and organs of the excretory system, including kidneys
- 5 Burrowing

- 6 Reabsorption of water affecting concentration of nitrogenous waste excreted
- 7 Osmotic pressure of the blood is maintained by antidiuretic hormone (ADH) in a negative feedback loop.
- 8 Leaf structure and shape including waxy cuticle, number and distribution of stomata, sunken stomata, rolled leaves, hairs on leaves and reduced leaf numbers or no leaves. Root system shape and position.
- 9 Abscisic acid (ABA) is a key hormone that regulates water status and stomatal movement.
- 10 Shape and size of organisms and parts of organisms, such as a waterproof layer, act to maintain water balance in animals and plants. Both animals and plants have hormone negative feedback loops that regulate the water balance.
- 11 Osmoregulation controls solute concentration in cells. To do this, the body makes compensatory adjustments to the extracellular fluid to maintain its volume and composition. This is achieved through structural features, behavioural responses, physiological mechanisms and homeostatic mechanisms.
- 12 Animals would drink more water. There would be an increased output of ADH, which would cause an increase in water reabsorption in the kidneys, resulting in more concentrated urine. Desert animals would spend more time in burrows.
- 13 Animals would drink less water. There would be a decreased output of ADH, which would cause a decrease in water reabsorption in the kidneys resulting in more frequent, dilute urine production. Desert animals would be able to spend more time in the open.
- 14 There would be an increased output of ABA, which would accumulate in guard cells. This would cause guard cells to lose turgidity and induce stomatal closure. Transpiration would be reduced.
- 15 There would be a decreased output of ABA. This would cause guard cells to gain turgidity and stomata would open. Transpiration would be increased.

16–20 Student responses will vary.

■ END-OF-CHAPTER EXAM

- 1 A
- 2 A
- 3 C
- 4 D
- 5 B

- 6 Possible answers include producing highly concentrated urine; burrowing in the desert sands; having a waterproof or impermeable outer layer.
- 7 Marine fish drink copious amounts of sea water, thereby creating a problem due to the additional salt intake. High levels of urea in their body tissues increases the internal solute concentration of their tissues which become slightly higher in concentration, or hypertonic, compared to the surrounding water. The water that consequently moves in by osmosis is easily removed by the kidneys.
- 8
 - a Hypothalamus
 - b Pituitary gland
 - c Urine output and sweating will decrease because reabsorption of water has increased. Blood pressure will increase.
 - d ADH levels would decrease because reabsorption of water needs to decrease.
- 9 The Sun's rays are strongest on the upper side of a leaf. The cuticle reduces water loss due to the evaporative effect of the Sun.
- 10 Moist air is trapped around the stomata, thereby decreasing the rate of transpiration.
- 11
 - a Abscisic acid (ABA)
 - b When ABA accumulates in the guard cells there is a rapid alteration of their osmotic potential, causing them to lose turgidity and induce stomatal closure. Transpiration is reduced, conserving water.

CHAPTER 14: INFECTIOUS DISEASE

■ 14.1 SECTION REVIEW

- 1
 - a Disease: a condition that interferes with how an organism functions
 - b Pathogen: a disease-causing agent
 - c Communicable: a disease transmitted from one individual to another
- 2 Pathogens include prions, viruses, bacteria, fungi, protists and parasites.
- 3
 - a Susceptibility: resistance of an organism to a pathogen
 - b Incubation period: time between infection and the onset of symptoms
- 4 The pathogen infects its host, lives on or in it and derives nourishment from it.
- 5 Infectious diseases are caused by an infectious agent, called a pathogen, which can be transmitted to new hosts. Non-infectious diseases are not caused by pathogens, nor can they be transmitted from one host to another; they may be caused by genetic, environmental or lifestyle factors.

- 6 Symptoms can be used by doctors to diagnose the cause of a patient's disease, ensuring appropriate treatment is provided.

14.2 SECTION REVIEW

- 1 Bovine spongiform encephalopathy (in cattle) and variant Creutzfeldt–Jakob disease (in humans)
- 2 Prion proteins convert normal proteins to harmful prion form. When these then convert other normal forms to harmful forms, large numbers of prion proteins aggregate into filaments that kill brain cells.
- 3 Binary fission is the division of a bacterial cell in two identical cells.
- 4 When fungi feed, their hyphae penetrate the host where they secrete enzymes. This allows them to digest their food external to their cells and absorb nutrients directly through their cell walls and membranes.
- 5 Cinnamon fungus growing on jarrah forests and rusts that infect wheat and barley are two fungal diseases of plants.
- 6 The symptoms of *Giardia* include nausea and diarrhoea. Infection occurs when this waterborne pathogen produces resistant cyst stages that are passed in the faeces of a host and transmitted to a new host in drinking water.
- 7 Ectoparasites live on the surface of the body. Examples are ticks and fleas. Endoparasites live within the host's body. Examples are nematode worms, tapeworms and flukes.
- 8 All viruses are parasites because they must live and reproduce inside a living cell, relying on their host cell for all their needs.
- 9 Prions are unique because they have no genetic material, neither DNA nor RNA. They are different

from other non-cellular infectious agents because the normal prion protein cellular form exists naturally in our bodies.

- 10 Virus specificity occurs because a virus recognises and binds to its host cell by surface receptors specific for that cell.
- 11 Different strains of bacteria can be identified by the colour they become in the Gram stain, their shape and the shape and colour of their colonies when cultured on agar plates.
- 12 *Plasmodium* is the pathogen that causes the disease, whereas malaria is the disease.

14.3 SECTION REVIEW

- 1 The pathogenicity of an organism is determined by its ability to stick to or invade a particular cell type, produce toxins, and evade a host's immune system.
- 2 Virulence factors are characteristics that help bacteria to invade the host, cause disease, and evade host defences, e.g. adherence factors, invasion factors, capsules, toxins and lifestyle changes.
- 3 Adherence factors are characteristics that help bacteria to bind to host cell surfaces.
- 4 Pathogenicity is the capacity to cause disease and virulence is the measure of the pathogenicity.
- 5 Because they enable a pathogen to enter into the tissues and cells of their host to grow and reproduce, invasion factors help to make an organism pathogenic.
- 6 Endotoxins and exotoxins are similar because they are both poisonous substances and virulence factors. They are different because endotoxins are lipopolysaccharides released on lysis of a cell, whereas exotoxins are proteins secreted by bacteria.

14.4 SECTION REVIEW

1

MODE OF TRANSMISSION	PATHOGEN ADAPTATIONS	EXAMPLE OF PATHOGEN
Direct contact	Reproduction in skin causing itchy skin lesions. Asymptomatic virus shedding Forms itchy lesions full of pathogen	<i>Varicella zoster virus</i> <i>Herpes simplex virus</i> <i>Herpes</i> , chicken pox, scabies
Body fluids	Causes nasal secretions and irritation. May survive well outside host	Common cold, glandular fever, HIV-AIDS
Foodborne	Induce messy diarrhoea and vomiting, can reproduce in food	<i>Salmonella</i> , <i>Staphylococcus</i> , <i>E. coli</i>
Waterborne	May have intermediate host, forms resistant spores, produces large numbers of eggs	<i>Giardia</i> , <i>Entamoeba</i> , cholera
Vectors	May reproduce in vector, resistant to damage by vector, does not kill vector before transmission	Malaria, plague, African sleeping sickness

- 2 a Contagious: able to be transferred by direct contact
- b Asymptomatic: without signs or symptoms
- 3 Bacteria can be prevented from growing on food by keeping food out of the temperature danger zone of between 5°C and 60°C, where most bacteria grow and reproduce. Cooked food should be cooled quickly to 5°C.
- 4 Body fluids are any liquids that come from inside the body, including sweat, tears, vomit, nasal secretions, blood, saliva and urine.
- 5 Zoonotic diseases such as ringworm can be transmitted between animals and humans. This benefits the pathogen because even though it may be killed in one host, the reservoir in the other host can be used to reinfect the first host.
- 6 A vector transfers a pathogen from one host to another. An intermediate host does not usually deliver the pathogen, but provides a site for pathogen to spend some of its life cycle and it often multiplies there.
- 7 A lack of running water, sanitation and garbage collection will reduce people's ability to wash themselves, keep their homes clean and keep their food and water uncontaminated, and it may enable vectors and intermediate hosts to grow and breed. All of these will increase the spread of disease.
- 8 Reproduction may occur in vector, increasing the chance of transmission, and the vector can help the pathogen to penetrate host defences, e.g. mosquitos pierce skin and inject malaria pathogen into host blood. Without a vector, some pathogens may never come into contact with their host.
- 9 a Mode of transmission: mosquito vector; benefit: relatively easy way for the roundworm to get from one person's blood to another's.
- b The advantage of the juveniles moving near the skin of the host at night is that they are more likely to be taken up by a mosquito vector.
- c The juveniles migrating to the mosquito's proboscis makes it more likely for them to be injected into new host when mosquito bites another person.
- 10 Adaptations of this species are that a mate is readily available as the male and female travel around together; attached to each other; asexual reproduction in the snail increases the likelihood of transmission; and larvae would survive well in pond water, until they are able to find a new host.

■ CHAPTER REVIEW QUESTIONS

- 1 Pathogens can be transmitted in a huge variety of places and situations.
- 2 During transmission of a pathogen, the first step requires the pathogen to escape from the body of its current host. It must then gain transport to a suitable new host, enter their body, establish itself in their tissues and finally ensure it reproduces so it can once again be passed to a new host.
- 3 Intermediate hosts and vectors are other organisms that are associated with transmission of pathogens.
- 4 Pathogens can be located anywhere inside or on the surface of a living organism. Even bacteria are attacked by pathogens (bacteriophages).
- 5 Pathogens have a huge array of adaptations that enable them to endure adverse conditions, as well as extract nutrients from their host. These include the hooks and suckers of intestinal parasites that help them hold on to their host, and resistant cysts produced to withstand dry conditions.
- 6 Virulence factors are characteristics that promote the establishment and maintenance of disease. They include the ability to stick to and invade a particular cell type, produce toxins, or cope with or avoid the host immune system. Virulence factors bring about the disturbances in body function that are known as disease.
- 7 A drought is likely to reduce the waterborne transmission of pathogens.
- 8 One benefit of using a vector for transmission would be that the pathogen can be enclosed inside another organism's body at all times. Another benefit is that the vector may deposit the pathogen in an otherwise inaccessible place, e.g. in the blood or tissues of the host.
- 9 Waterborne pathogens rely on free water in the environment such as rivers and lakes. These may be too small or non-existent in times of drought, causing the death of the pathogen.
- 10 If a pathogen is inside another organism's body, it would not be subject to variations in environmental conditions. Also, insect vectors can inject pathogens into the bloodstream of animals or through the cell walls of plants, places the pathogen would be unable to access alone.

■ END-OF-CHAPTER EXAM

- 1 D
- 2 B
- 3 C
- 4 Incubation period
- 5 Body fluids
- 6 Non-infectious disease: a disease not caused by a pathogen
- 7 The vector of *Plasmodium* is the *Anopheles* mosquito. Its role in the life cycle is to take up the pathogen from one host and transfer it into the blood of another and to provide nutrients for the reproduction of developmental stages.

- 8 a The infection rate was initially very low, then rose fairly consistently from 1986, reaching a maximum in 1992, then fell quickly down to a fairly low level in 1996.
- b When they cause disease, prion proteins convert normal proteins to the harmful prion form, which convert other normal forms to more harmful forms, then large numbers of prion proteins aggregate into filaments that kill brain cells.
- c The incidence of disease dropped rapidly after 1992 because sheep offal, the likely source of infection, was banned as a cattle food in 1992.

CHAPTER 15: IMMUNE RESPONSE AND DEFENCE AGAINST DISEASE

15.1 SECTION REVIEW

- 1 Antigen: a large molecule, usually a protein or polysaccharide, that generates an immune response
- 2 Pattern recognition receptors recognise specific substances and molecular patterns that are characteristic of a wide variety of pathogens, but not found on host cells. Materials that bind to these receptors include lipopolysaccharides, peptidoglycans, chitin, some glycoproteins, flagellin, viral RNA and DNA.
- 3 a PAMP: pathogen-associated molecular pattern; a molecular pattern that is characteristic of a wide variety of pathogens, but not found on host cells
 - b An organism can detect an invasion by recognising a variety of different pathogens, because of their PAMPs.
- 4 Any substance that triggers an immune response is called an antigen, whereas an epitope is a small part of a larger molecule that binds to a receptor site and is antigenic.
- 5 An organism must be able to distinguish between 'self' and 'non-self' to be able to defend itself from invasion by pathogens.

15.2 SECTION REVIEW

- 1 Innate immune responses are non-specific because they respond to any invader, regardless of its type, and without prior exposure.
- 2 a Adaptive responses to infection: responses that target pathogens only after they have been specifically identified by particular components of the immune system
 - b Adaptive responses occur only in vertebrates.
- 3 A difference between innate and adaptive immune responses is that adaptive responses are highly specific because they attack only the pathogen that stimulated that particular response. Innate responses are non-specific because they respond to

any invader, regardless of its type, and without prior exposure. A similarity is that both are very effective in defending body against pathogens.

- 4 The value of immunological memory is that it protects from a second invasion by the same pathogen.

15.3 SECTION REVIEW

- 1 It is important for us to understand plant disease and defence because plants supply us with food, wood, textiles, medicines, dyes, inks and industrial chemicals.
- 2 Plants physically prevent the entry and growth of pathogens by having thick outer bark containing waxy, water-resistant materials on stems and roots, strong cell walls, callose deposits between the cell wall and cell membrane, and by shedding infected parts such as leaves and branches and plugging wounds with resin.

NAME OF CHEMICAL DEFENCE	WAY IN WHICH IT WORKS
Defensins	Antimicrobial, antiviral and antitoxic properties
Tannins	Bitter taste that deters herbivores and toxic to insects
Toxins	Secreted into soil to deter nematodes
Pyrethrins	Insect neurotoxins that kill invading insects

- 4 Companion plants release substances such as toxins into the environment that are toxic to pathogens of their neighbouring crop plant.
- 5 Defensins kill invading micro-organisms by reducing membrane permeability and inhibiting the action of enzymes and ribosomes.
- 6 The structural features of leaves that are barriers to infection by pathogens include:
 - a thick waxy cuticle that prevents entry of pathogens
 - waxy cuticles and vertically hanging leaves that prevent moisture films inhibiting bacterial growth, roundworms and fungal spore germination
 - hairs and thorns that deter vectors of pathogens
 - stomatal openings guarded by hairs and sunken stomata that make access by pathogens very difficult.

15.4 SECTION REVIEW

- 1 Surface barriers, inflammation and the complement system
- 2 Secretions from sweat and oil glands in the skin give the skin a pH ranging from 3 to 5, which is acidic

enough to prevent colonisation by many pathogenic species.

- 3 The skin has chemical, physical and biological barriers to invasion by pathogens.
- 4 Mucous membranes produce thick, sticky mucus that traps invaders. It also contains the antimicrobial agents lysozyme and defensins that can destroy invaders.
- 5 Keratin in the skin forms a hard outer layer that is impervious to water and pathogens.
- 6 In blood clotting, platelets trigger the formation of a web-like mesh of fibrin protein that stabilises the aggregation of platelets and traps red blood cells to form a clot.
- 7 The body can flush out micro-organisms by passing urine, producing tears, coughing, sneezing and the movement of mucus by cilia.
- 8 Symbiotic micro-organisms live on skin but do not cause disease. By taking up space and using nutrients, they prevent colonisation by other pathogenic micro-organisms. Excessive washing could remove them, allowing the growth of pathogens.

15.5 SECTION REVIEW

- 1 Following the activation of complement, complement proteins bind to the surface of pathogens, acting as a tag to facilitate their detection and uptake by phagocytes, induce chemotaxis to the damaged or infected site, activate phagocytes and stimulate mast cells to release histamine.
- 2 Redness, swelling, pain and heat
- 3 In inflammation, mast cells release histamine and prostaglandins. The histamine induces vasodilation and increases the permeability of capillaries and the prostaglandins cause vasodilation, fever and pain.
- 4 Chemotaxis is directed migration and provides a way for immune cells in blood to be recruited to sites of infection or tissue damage. White blood cells move towards increasing concentrations of molecules that induce chemotaxis called chemokines. Chemokines include molecules released by micro-organisms, activated macrophages and other immune cells.
- 5 The protein cytokines secreted by macrophages require ribosomes for their synthesis and lysosomes play a role in breaking down phagocytosed invaders.
- 6 Vasodilation is the widening of blood vessels to an area. The resulting increased blood flow to the affected area carries leucocytes and defensive chemicals to the site of invasion.
- 7
 - Macrophage recognises bacterial surface molecules as 'non-self'.
 - Macrophage envelops bacterium with its cell membrane.
 - Vacuole forms around bacterium.
 - Lysosome fuses with vacuole.
 - Powerful enzymes digest bacterium.

15.6 SECTION REVIEW

- 1 A protein
- 2 An antigen is a substance that stimulates an immune response, whereas an antibody, which binds to and destroys an invader, is part of that response.
- 3 Antibodies can:
 - bind to antigens activating the complement cascade and attracting phagocytes
 - tag pathogens for phagocytosis and destruction (opsonisation)
 - neutralise toxins preventing them from binding to their target
 - cause pathogens to clump together (agglutination).
- 4 Plasma cells synthesise and secrete antibodies. Rough endoplasmic reticulum is where proteins for export from the cell are produced and this process uses energy, which is supplied by the mitochondria.
- 5 Activated killer T cells divide to form effector and memory cells; memory cells can be activated quickly upon a second encounter with the same pathogen, rapidly destroying the infected body cells or tumour cells.
- 6 Antibodies bind to complementary (matching) antigens with a lock and key specificity in a similar way to enzymes binding with their substrate.

15.7 SECTION REVIEW

- 1 Immunodeficiency: a state in which the immune system does not function properly, leaving a person susceptible to infections that the immune system could normally fight off
- 2 People develop symptoms of chickenpox when first exposed to the virus because it takes some time for them to mount an immune response. On the second exposure memory cells are activated, making the response much quicker and more powerful.
- 3 As antibodies are secreted into the blood, they are unable to reach intracellular pathogens.
- 4 Individuals in both Categories A and B may show some symptoms and virus numbers can be similar in both categories, making the stages hard to distinguish.

15.8 SECTION REVIEW

- 1 Passive immunity can occur from antibodies being transferred via the placenta or by antibody

serum injection. Active immunity can come from vaccination with a weakened antigen or when a person recovers from infection by a pathogen.

- 2 A vaccine may contain a dead version of the pathogen or a weakened (attenuated) strain of the pathogen.
- 3 Passive immunity results from antibodies being introduced into the organism, whereas active immunity occurs when antibodies are made by the immune system in response to the presence of an antigen.
- 4 Passive immunity lasts only about 28 days because antibodies only last in the blood for around 28 days.
- 5 **a** Passive immunity
 - b** The benefit of passive immunity is that because a baby's immune system does not develop for a number of months, without passive immunity they would be vulnerable to infection by pathogens.
- 6 Vaccines stimulate antibody and memory cell production. The antibodies usually allow a person to fight off the pathogen before suffering major ill effects of disease. As well, the memory cells produced are capable of a very rapid response should the pathogen be encountered again.

■ CHAPTER REVIEW QUESTIONS

- 1 Innate defence barriers occur in the skin and external openings of the respiratory, digestive, excretory and reproductive systems.
- 2 If innate defence barriers are breached, pathogens can either enter the body and cause disease or live successfully on the body surfaces.
- 3 The innate defence responses of inflammation are caused by mast cells releasing histamine. This leads to vasodilation and plasma leaking from capillaries, which causes the typical symptoms of heat, redness, pain and swelling.
- 4 The actions that are associated with innate defence barriers include flushing by urine and tears and removal of pathogens by coughing and the beating of cilia. As well, the skin secretes sweat and oil and mucous membranes secrete lysozyme and defensins.
- 5 Cuts and abrasions allow pathogens to enter the body. Pathogens may penetrate into the host or live on the skin or in mucous membranes.
- 6 During inflammation, increased blood flow takes leucocytes to the point of invasion and increased permeability of blood vessels allows cells and materials from the blood to enter the tissues. Pain encourages the host to rest so that energy can be directed to fighting the infection.
- 7 The best way to prevent illness is to prevent the entry of pathogens into the body. It requires much less energy and expertise to prevent entry of pathogens by using innate defence barriers than fight pathogens once they are inside the body. Outside the body, pathogens have less food and fewer resources available for growth and reproduction.
- 8 If cilia were unable to beat, the host could develop lung diseases.
- 9 An inability to switch off inflammation once the danger has passed would mean resources would be needlessly directed at fighting an enemy that did not exist. As well, it would be difficult for the part of the body affected, e.g. a leg or foot, to work properly, suggesting the host could be incapacitated.
- 10 Pathogens could secrete enzymes to attack the skin to allow entry. They could make the skin itchy to encourage the host to scratch and so breach the skin.
- 11 Without the action of cilia, mucus that has trapped dust and pathogens would remain in the lungs where it could cause disease.

■ END-OF-CHAPTER EXAM

- 1 B
- 2 D
- 3 B
- 4 Inflammation
- 5 Antibody
- 6 One of: defensins with antimicrobial, antiviral and antitoxic properties; toxins that deter nematodes; bitter tasting tannins that are toxic to insects; pyrethrins that are insect neurotoxins;
- 7 Compared with the primary response, the secondary response shows a greater production of antibody, which occurs faster and remains at higher levels for much longer.
- 8 Complement proteins circulate in blood as inactive precursors. They become activated when they encounter a foreign body, such as an invading bacterium. Activation of one complement protein has a cascading effect, stimulating the activation of other complement proteins, which then activate other proteins in turn.

CHAPTER 16: TRANSMISSION AND SPREAD OF DISEASE

■ 16.1 SECTION REVIEW

- 1 Severe acute respiratory syndrome
- 2 The symptoms of SARS include very high temperatures, a cough and difficulty breathing.
- 3 10%
- 4 The statement 'the rapid transmission of disease by air travel has implications for the control of

infectious diseases' means that a disease may be transmitted very quickly and may infect many people before health officials realise that it has even entered the country.

- 5 Measles killed high numbers during exploration of Central America because local populations had no natural immunity and resistance to measles because they had never encountered it before.

■ 16.2 SECTION REVIEW

- 1 a Endemic
b Pandemic
c Epidemic
- 2 (1) Persistence of pathogens – a pathogen can persist in a host without causing symptoms, e.g. TB, allowing people to unknowingly transmit the disease.
(2) Transmission mechanism – some diseases are not easily spread because of their mode of transmission, e.g. malaria can only be spread by the *Anopheles* mosquito, which has a restricted distribution in the world.
(3) Proportion of population who are immune or immunised – if large numbers of people are immune to a disease, it is less likely to be transmitted.
(4) Mobility of affected individuals – movement is likely to increase the spread of a disease because it brings infected people in contact with uninfected individuals.
- 3 Persisting within a host provides many opportunities for transmission to a new host.
- 4 If transmission uses a vector, such as malaria being spread by a mosquito bite, if mosquitos are in the environment, the disease is more likely to spread quickly because transmission is relatively easy and multiplication of the pathogen can occur in the vector.

■ 16.3 SECTION REVIEW

- 1 Human activity such as building suitable sanitation and providing clean water can reduce the spread of waterborne diseases.
- 2 The mosquito that transmits dengue fever is well adapted to living in urban environments because it breeds in artificial water pools such as water tanks or buckets.
- 3 Floods can increase the spread of disease because water supplies can become easily contaminated with faeces. Droughts can also increase the spread of disease because lack of fresh water can lead to breakdown of hygiene practices.
- 4 Herd immunity can protect an entire population from a serious disease because if a large enough proportion of the population is immune to a disease, then there are too few susceptible individuals to sustain disease spread.

■ 16.4 SECTION REVIEW

- 1 Handwashing, staying home when ill and covering coughs and sneezes
- 2 Contact tracing: a way to locate people with an infectious disease. Recent contacts of an infected individual are contacted and screened for the infection.
- 3 A notifiable disease is a disease that, if diagnosed, is required to be reported to public health authorities. Examples are chickenpox, syphilis, rabies and influenza.
- 4 Quarantine isolates a person who may or may not have contracted the disease, whereas medical isolation is used for people who have already caught the disease.
- 5 School closures will be less effective if students visit other community areas where they may catch the disease. Also, to be effective, closures must be done early in the disease cycle.
- 6 Temperature screening is often not a useful way of preventing the spread of disease because symptoms may not develop for many days after infection and asymptomatic cases can be very infectious.
- 7 Student responses will vary. For example, students may recommend not cancelling because mass gatherings seem not to increase the spread of disease. Education regarding the protection of people from pathogens by handwashing and avoiding contaminated surfaces is more important in controlling the spread of disease.

■ 16.5 SECTION REVIEW

- 1 In the middle of the 19th century, disease was thought to be spread by a miasma, which was a noxious vapour.
- 2 *Vibrio cholera*
- 3 John Snow noticed that almost all of the cases of cholera occurred in people who lived close to and used a single water pump, and that people who lived close to the pump and did not contract the disease used different water sources.
- 4 a These individuals may have contracted the infection at the shopping centre because it was the only place that everyone who contracted the disease had visited.
b This could be confirmed by testing the shopping centre hot water systems and air conditioners for *Legionella* bacteria.

■ 16.6 SECTION REVIEW

- 1 The pathogen of malaria is *Plasmodium falciparum* and the vector is the *Anopheles* mosquito.
- 2 Digital disease surveillance is carried out by Google using a program that tracks how frequently people

use the search engine to look up influenza-like illnesses.

- 3 When using digital disease surveillance mechanisms the quality of data is limited by the effectiveness of algorithms in determining whether or not a tweet or search is actually about an illness. Also, high Internet activity about an illness does not always correspond to high disease activity; it can be skewed by other events, such as the illness of a celebrity.
- 4 Mathematical modelling can help epidemiologists control the spread of disease because it can make predictions about the possible spread of disease under changed environmental conditions.
- 5 It is predicted that malaria will become prevalent along the east coast and Kimberley region of Australia by 2050. Two likely responses of Australian health officials to this change in distribution would be to monitor malaria outbreaks and advise people on ways to avoid being bitten by mosquitoes.

CHAPTER REVIEW QUESTIONS

- 1 The health consequences associated with the movement of individuals is an increased spread of infectious diseases.
- 2 Immunisation is one process associated with the prevention of disease outbreaks.
- 3 The dangers associated with a disease outbreak include death (mortality) and illness (morbidity).
- 4 A process associated with the spread of an infectious disease is entry into the host.
- 5 The consequences associated with the spread of disease are illness and possible death.
- 6 An important process associated with the prevention of infectious disease outbreaks includes stopping the transmission of a pathogen from one host to another.
- 7 If the vector for malaria were wiped out, no new infections would occur and after a period of time malaria would no longer exist.
- 8 Immunisation reduces the spread of disease and may eradicate a disease entirely.
- 9 People are more likely to catch influenza in cold, wet weather because flu is spread by droplets in the air being breathed in by the new host. Virus may live longer in droplets in moist conditions and people are more likely to be crowded close together in cold, wet conditions.
- 10 Without a vector to pass malaria from person to person, no new transmissions would occur. For a period of time, the pathogen would continue to live in its host, causing disease.
- 11 Without a vector to carry it to new hosts, eventually the pathogen in its host would die, or the host itself might die. The pathogen could not be transmitted to a new host.

- 12 The observation that people can catch colds in summer does not negate the answer to Question 9 because droplets can still carry virus particles from the respiratory tract of one individual to another in summer.

END-OF-CHAPTER EXAM

- 1 B
- 2 C
- 3 B
- 4 Isolation
- 5 Notifiable
- 6 Nosocomial
- 7 Morbidity is the impact of a disease within a population, measured by the number of people affected, while mortality is the impact measured by the number of deaths.
- 8 Until 1981, malaria was endemic in Australia because it occurred at a relatively constant rate in Australia, then after that time it was eradicated.
- 9 Herd immunity refers to the phenomenon whereby once a particular proportion of the population is immune to a disease; susceptible individuals are also better protected from that disease.

BIOLOGY UNITS 1 & 2 PRACTICE EXAM

MULTIPLE-CHOICE QUESTIONS

- 1 B
DNA is necessary for self-replication and the arrangement of DNA is similar in mitochondria, chloroplasts and prokaryotes.
- 2 B
Photosynthesis is a series of reactions that occur in the stroma and thylakoid membrane system of chloroplasts. The internal thylakoid membranes are folded to provide more surface area for chemical reactions to occur.
- 3 D
A biochemical pathway consists of a series of steps in which the products or outputs of the first step become the reactants or inputs of the next. Each step is regulated by a specific enzyme.
- 4 A
Glycolysis occurs in the cytosol of plants and animals.
- 5 B
Stem cells differ from other cells in the body in that they are unspecialised, they have the potential to divide and replicate for long periods of time and they can differentiate to form different specialised cells.

- 6 A
Radioactivity would be detected at W before Y because phloem transports sugars, in solution, from the leaves to the roots for storage.
- 7 C
Extra stomata would not help a plant deal with a hot, dry climate, because water loss would be increased.
- 8 A
The loop of Henle is the part of the kidney where water is removed and therefore does not become part of the urine.
- 9 B
Transmission is likely to be reduced by low population density because there would be less close contact between people.
- 10 D
Plants do not have innate or adaptive responses such as the production of antibodies or inflammation. Defensin production is a chemical defence strategy.

■ SHORT-ANSWER QUESTIONS

- 1 a Prokaryotic
b Three of: small size, no internal membranes, single circular chromosome, exist as single cell
c The cell membrane is made up of a lipid bilayer with specialised protein molecules embedded in it.
- 2 a Aerobic cellular respiration is the reaction. This reaction allows transfer of energy to molecules of ATP that is a useable form of energy to maintain cell survival.
b Temperature, pH
c The enzymes help to break down starch (amylases), protein stains (proteases) and fatty or greasy stains (lipases).
d A hot wash would denature the enzymes so they would stop working.
- 3 a Urea
b Nephron
c Filtration occurs inside the Bowman's capsule. Blood inside the capillaries of the glomerulus is under high pressure. The pressure forces out water and all small solutes into the Bowman's capsule.
d Glucose filtrate 0.15; glucose urine 0.0; protein filtrate 0.0; protein urine 0.0.
e Glucose is a small molecule that can pass through the glomerulus and therefore be present in the filtrate. It is not in the urine as it is reabsorbed from the kidney tubules.
Protein is a large molecule that cannot pass through the glomerulus, so should not be present in either the filtrate or the urine.
- 4 a Structure A is a secretory vesicle that stores neurotransmitters in the axon terminal.
b Structure B is a postsynaptic neuron, meaning it is the neuron after the synapse. It has binding sites for neurotransmitters, which open channels for sodium ions to pass through.
c When the impulse arrives at a neuron synapse, it causes calcium ion channels in the cell membrane to open, resulting in an influx of calcium ions. These stimulate exocytosis, in which the vesicles fuse to the presynaptic membrane and release their neurotransmitters into the synapse.
d Neurotransmitters bind to receptor proteins in the postsynaptic neuron. This triggers a cascade of modifications to intracellular proteins within the cell. Effector proteins in the cell are stimulated to elicit a response.
- 5 a Higher oxygen consumption indicates a higher rate of aerobic cellular respiration producing more metabolic heat.
A greater amount of body fat creates more insulation so less heat will be lost to the surroundings.
b This is an example of counter-current heat exchange. Arteries and veins are located close to each other in the extremities. Blood travelling in the arteries to the extremity warms the blood returning to the body in the adjacent veins. The outgoing blood to the extremity is cooled in the process but not enough to affect cell activities. As the temperature gradient between the extremity and the surroundings is reduced, heat loss is minimised. Heat in arteries coming from the body core is transferred directly to the returning blood in the veins rather than being lost to the environment.
- 6 a A pathogen is an infectious agent that causes disease.
b Similarity: they are both non-cellular pathogens; Difference: viruses contain DNA or RNA; prions do not.
c An antigen is a foreign particle/organism that has entered the body and been detected as being 'non-self'. The body responds by producing antibodies that are able to stop the spread of the antigen. An antigen is an antibody generator.
d Plasma cells
e T-helper cells *or* antigen presenting cells *or* macrophages
f Antigen presenting cells engulf the foreign cells and then present fragments of the foreign tissue on the end of MHC II marker molecules. T cell receptors are able to recognise whether these fragments are 'self' or 'non-self'.

GLOSSARY

A

abscisic acid (ABA) a plant hormone produced in response to plant stress involved in stomatal closure

action potential the state of a neural cell membrane in active transmission, when inside the cell is more positive than outside

activation energy the energy required to initiate a reaction

active immunity the immunity formed when the immune system is stimulated by an antigen, and effector and memory cells are generated

active site the place on the surface of an enzyme molecule where substrate molecules attach

active transport the process of using energy to move a substance across a membrane from a region of low concentration to a region of higher concentration

adaptive immune response an acquired immune response; after an initial response to a pathogen, the immune system creates a 'memory' that leads to an enhanced response to subsequent encounters with the same pathogen

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

adenosine triphosphate (ATP) the short-term energy storage molecule of cells

adhesin a characteristic that helps bacteria to bind to host cell surfaces

adhesion the force of attraction between water molecules and the molecules that make up the sides of the tube

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 a metabolic reaction that requires oxygen to produce energy for the cell

aestivation dormancy in some animals during periods of drought

afferent bringing towards, as in blood vessel carrying blood to an organ

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

alveolus a tiny air sac located on the end of a bronchiole

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

ammonia (NH₃) a product of amino acid breakdown that is extremely toxic in humans

anabolic reaction a reaction that builds up complex molecules from simple molecules

anaerobe an organism that does not require oxygen

angiosperm a flowering plant, including many families of tree, shrub and grass

antibody a Y-shaped protein produced by plasma cells that binds to a specific antigen; also called immunoglobulin

antibody serum injection an injection of serum containing antibodies, given to provide immediate protection from a toxin or pathogen

antidiuretic hormone (ADH) a hormone responsible for increased permeability of the distal tubules of the kidney, increasing water reabsorption and reducing urine volume

antigen a large molecule, usually a protein or polysaccharide, that generates an immune response

arteriole a small blood vessel that carries oxygenated blood to the tissues

artery a blood vessel that takes blood away from the heart

asymptomatic without signs or symptoms

autoimmune disease a condition where the immune system attacks the body's own tissues

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

axon the tubular extension of a neuron cell body that conducts the nerve impulse

B

B lymphocyte a class of lymphocytes; once activated, they are characterised by the production of antibodies

bacteriophage a virus that invades bacteria

bilayer a double layer

binary fission the division of a cell into two without mitosis; a prokaryotic cell splits to form two daughter cells

biochemical pathway chemical reactions in cells that occur in a series of enzyme-regulated steps

body fluid a liquid that comes from inside the body

Bowman's capsule the nephron structure in which the glomerulus is positioned, and into which the filtrate from the glomerulus blood is forced

C

callose a polysaccharide formed in plant cell walls in response to injury

capillary a very narrow blood vessel found between arteries and veins; part of a branching network that reaches to within a very small distance of every body cell

capsule a slimy layer sitting outside the cell wall of some species of bacteria

carbohydrate a group of compounds containing carbon, hydrogen and oxygen important as structural components and as energy sources

carotene an orange pigment found in carrots, leaves and flowers

carrier an individual who harbours a pathogen but who does not show symptoms of disease and is capable of transmitting the infection

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

case an individual who is infected with an infectious disease

catabolic reaction a reaction that involves the breakdown of complex molecules to simpler products, e.g. cellular respiration

catalyst a substance that speeds up a chemical reaction without being used up in the reaction

cell 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

cell-mediated immunity when cytotoxic T cells recognise and destroy virally infected and cancerous cells

cellular metabolism all of the chemical processes occurring in a living cell

cellular respiration a series of cellular biochemical reactions and processes using glucose and oxygen and producing carbon dioxide and water

cellulose a polysaccharide made of glucose subunits that is the main component of plant cell walls

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

chemical digestion the break down of large molecules progressively into different smaller molecules in chemical reactions catalysed by digestive enzymes

chemokine a molecule that induces chemotaxis; some cytokines are chemokines

chemoreceptor a detector that detects a chemical stimulus such as oxygen concentration and pH

chemotaxis the movement of an organism or cell along a chemical concentration gradient either towards (positive chemotaxis) or away from (negative chemotaxis) the chemical stimulus

chitin a polysaccharide that is the main component of fungal cell walls and the exoskeletons of insects and other arthropods

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

chloroplast an organelle in mesophyll tissue that utilises light energy to make glucose through photosynthesis

cholesterol a type of lipid found in cell membranes that maintains membrane fluidity

chromoplast a plastid that produces and stores coloured pigments

circulatory system blood, blood vessels and heart working together to ensure all necessary materials are carried around the body to and from cells

closed circulatory system a type of circulatory system in which blood is confined to a series of paths or vessels

coenzyme a small non-protein organic substance that is required in addition to an enzyme to catalyse a certain reaction

cofactor a small inorganic substance that is required in addition to an enzyme to catalyse a certain reaction

cohesion the force of attraction between water molecules

collecting duct a duct in the kidney that collects and transports fluid from several distal tubules to the renal pelvis

communicable can be communicated (transmitted) from one organism to another

companion cell a specialised plant cell situated beside the sieve tubes in the phloem, which provides most of the cell functions for the sieve tube cells

companion plant a plant grown with another plant because one species improves the growth of the other

competitive inhibitor a substance that competes with a substrate for an enzyme's active site

complement system a number of small proteins found in the blood that, when activated, promote chemotaxis, cell lysis and phagocytosis

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

condensation reaction a reaction in which a molecule of water is eliminated when two monomers are bonded together

conformation the shape of a molecule that is determined by the three-dimensional arrangement of its atoms and bonds; important for molecular functioning

connective tissue a type of tissue that supports, strengthens and protects structures of the body

contact tracing a process for identifying potential cases; recent contacts of an infected individual are contacted and screened for the infection

contagious able to be transferred by direct contact

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

counter-current a current that flows in the opposite direction to another current

counter-current exchange the mechanism observed in various systems in living things, and mimicked in engineering, where there is an exchange of particles or energy (heat) between two bodies flowing in opposite directions to each other

counter-current multiplication a system operating between two tubes connected by a hairpin bend and with fluid flowing in opposite directions, where energy is used to transport a material across a membrane of

one tube, enabling the production of a much greater concentration of solutes in the hairpin bend than could otherwise be achieved

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

cuticle a thin, transparent layer of wax on the outside of a leaf's epidermis that reduces water loss

cytokine a small signalling molecule that coordinates inflammation and immune responses, and that leukocytes use to communicate with one another; includes interleukins and interferons

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

cytoplasmic streaming the mixing and movement of the cytoplasm

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

cytotoxic T lymphocyte a class of lymphocytes that destroys virally infected or cancerous cells by secreting proteins that cause cell death

cytotoxin a compound released by cytotoxic T cells that kills infected or cancerous body cells

D

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

defensin a small antimicrobial peptide secreted by virtually all plants and animals

definitive host a host in which the adult phase of a parasite produces gametes

denaturation the process by which the structure of a protein is changed by factors such as pH and temperature; the change in structure often destroys the shape of the active site of the molecule and results in a loss of function

dendrite a fine, thread-like extension of the neuron that converts external signals to nerve impulses within the neuron

depolarisation a change in a cell's membrane potential so that the inside of the membrane is less negative than the outside

dicotyledon (dicot) a flowering plant with a number of characteristics, including a ringed arrangement of vascular bundles in the stem

differentially permeable a quality of a membrane that means only certain kinds of molecules can pass through it

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

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

disaccharide two linked monosaccharide molecules

dissociate to separate; dissociation is the chemical process where oxygen separates from haemoglobin

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

downregulation when a cell is prompted to produce less of a particular cellular component, such as enzymes or receptors

E

ectoparasite a parasite that lives on the surface of another organism

effector an organ, cell or protein that acts in response to a stimulus

efferent taking away from, as in blood vessels carrying blood away from an organ

electron transfer chain the third and final stage of aerobic respiration involving the stepwise transport of electrons

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

encyst when organisms produce a covering around themselves and enter a resting stage

endemic broadly, common to a particular area; specifically, a pathogen that is prevalent at a constant rate within a population

endergonic reaction a chemical reaction that requires energy

endocrine gland a gland that secretes substances directly into the bloodstream

endocrine system the glands of the body that produce hormones

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

endoparasite a parasite that lives inside another organism

endoplasmic reticulum an organelle in eukaryotic cells consisting of an interconnecting system of thin membrane sheets dividing the cytoplasm into compartments and channels

endospore a tough, dormant structure formed by many bacteria to help them resist unfavourable conditions and disperse to new hosts

endosymbiotic theory a theory that suggests that chloroplasts and mitochondria arose from ancient prokaryote cells that were ingested by other prokaryote host cells

endothelial cells a single layer of flattened cells that lines internal surfaces of body structures containing fluid

endotherm an animal that retains heat generated by metabolic activity

endotoxin a poisonous molecule attached to the outer membrane of certain bacteria that is usually released upon lysis of the bacterial cell.

enterotoxin a toxin that disrupts intestinal function

enzyme a protein that catalyses biochemical reactions

enzyme–substrate complex a substance formed when an enzyme and a substrate molecule join

epidemic an increase in the occurrence of a particular disease above the baseline level for that population; tends to refer to larger, more serious events than an outbreak

epidemiologist a scientist who studies the causes and effects of diseases at a population level

epidermis the surface layer of cells in an organism

epithelial cell a cell in a sheet of cells covering any external or internal surface in a multicellular organism

epithelial tissue a type of tissue containing cells that line internal and external surfaces such as blood vessels, digestive organs and airways

epitope a small part of a larger molecule that binds to a receptor site and is antigenic

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

equilibrium reaction a chemical reaction in which the forward and reverse reactions occur at equal rates

eukaryotic cell a complex type of cell with a nucleus and membrane-bound organelles; a member of domain Eukarya

euryhaline an organism that can tolerate a wide change in salinity

exergonic reaction a chemical reaction that releases energy

exocrine gland a gland that secretes substances onto an external surface or body tract

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

exotoxin a protein toxin or enzyme actively secreted by pathogenic bacteria into their surroundings

external environment the environment surrounding a cell outside the cell membrane

exteroceptor a receptor that specifically receives signals from outside the body, such as air temperature, painful pressure or smells

extracellular enzyme an enzyme that is produced by cells but functions outside of the cells

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

F

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

fatty acid a type of organic acid that combines with glycerol to form a fat molecule

feedback mechanism a process that monitors environmental conditions, usually, but not necessarily, in reference to biological systems

fibrin an insoluble, fibrous protein mesh that impedes the flow of blood during clotting

fibrous root a thin, branching root that spreads along the upper layers of soil for rapid colonisation and surface water uptake

filtrate the liquid that has passed through a filter

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

flagellin the material that makes up bacterial flagella

flagellum a whip-like appendage that helps bacteria move

fluid mosaic phospholipid bilayer model the generally accepted model of membranes in which proteins are embedded in a phospholipid bilayer

G

G protein a protein that relays signals from a cell membrane G protein-coupled receptor to other signal transduction proteins inside the cell

genetic disease a disease arising from mutations inherited from parents

gill the gas exchange structure of a fish

gland an organ that secretes chemicals or proteins within the body or externally

glomerulus a network of capillaries, contained within the Bowman's capsule, from which the blood contents are filtered by the structures of the nephron

glucagon a hormone produced in the pancreas that promotes the breakdown of glycogen to glucose in the liver

glycerol a molecule that combines with three fatty acids to form a fat molecule

glycogen an important energy-storing polysaccharide in animals

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

guard cells a pair of crescent-shaped cells that enable the opening and closing of a stoma

H

haemoglobin the iron-containing protein molecule in red blood cells that attracts and binds with oxygen and gives blood its red colour

halophyte a plant that is adapted to salty conditions

herd immunity a form of protection from disease that occurs once a large enough proportion of a population is immune, which means susceptible individuals are better protected from the disease

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

hibernation a period of dormancy over long periods of cold conditions

histamine a chemical released by mast cells that increases blood flow and the permeability of capillaries

homeostasis the maintenance of a relatively constant internal environment within small tolerance limits, despite changes in the external environment

hormone a chemical produced by the body to prompt a response from specific cells

host an organism that is infected by a pathogen

humoral an immune response brought about by antibodies that circulate freely in the bloodstream and can lead to the destruction of pathogens

hydrophilic tending to interact with and dissolve in water

hydrophilic hormone a hormone that is soluble in water and binds to extracellular receptors to initiate a response in that cell; for example, peptide and some amine hormones

hydrophobic avoiding association with water

hydrophobic hormone a hormone that is insoluble in water and binds to intracellular receptors; for example, steroid and thyroid hormones

hydrophytes a plant that is adapted to aquatic conditions

hyperthermia a state in which the internal temperature rises above the set point

hypertonic a solution with a higher solute concentration than another solution

hypothalamus a region of the forebrain that coordinates the endocrine and nervous systems; it secretes hormones and releasing factors that regulate the anterior pituitary gland, controlling body temperature, thirst, hunger and other homeostatic systems

hypothermia a state in which the internal temperature drops below the set point

hypotonic a solution with a lower solute concentration than another solution

I

immune system a complex network of cells, tissues and organs in the body that detects differences between 'self' and foreign organisms, and mounts an immune response

immunodeficiency a state in which the immune system does not function properly, leaving a person susceptible to infections the immune system could normally fight off

immunosuppressant a drug that inhibits the immune system, particularly cell-mediated immunity

incubation period the time between infection and the onset of symptoms

induced-fit model a model to explain that the shape of an enzyme's active site undergoes specific changes, induced by the substrate, to achieve a high degree of specificity with the substrate

infectious disease a disease caused by a pathogen that can be transmitted from one organism to another

infectivity the ability of a pathogen to spread from one host and infect another host

inflammation an innate response to infection or damage that causes swelling, pain and redness

innate immune response a non-specific response to pathogens that is not learned and does not have memory

insulin a hormone produced by the pancreas that regulates the amount of glucose in the blood

interconnecting neuron (interneuron) a cell that transmits nerve impulses within the central nervous system, between sensory and motor neurons

intermediate host an organism in which a pathogen or parasite undergoes development and spends a small portion of its life cycle

internal environment all material contained within the cell membrane

interoceptor a receptor that specifically receives signals from inside the body, such as body temperature, oxygen concentration or pH

interstitial fluid extracellular fluid; fluid in spaces surrounding cells

intracellular enzyme an enzyme that functions inside the cell that produces to speed up and control metabolic reactions

intracellular pathogen an organism that lives inside host cells

invasion factor a characteristic that helps pathogens to invade the host

isotonic a fluid with an equal solute concentration to another fluid

K

keratin a strong, stable structural protein found in skin, hair, horn and nails

keratinised a process by which keratin is deposited in skin cells; the surface becomes tough and waterproof

kidney an organ that excretes the urea dissolved in the blood out of the body

kleptothermy a form of thermoregulation in which an animal shares in the metabolic thermogenesis of another animal; its most common form is huddling

Krebs cycle a biochemical pathway that requires oxygen and takes place in the mitochondria as part of cellular respiration; the second stage of aerobic cellular respiration

L

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

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

leucoplast a colourless plastid that does not contain pigments

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; carbon dioxide, hydrogen ions and ATP produce carbohydrate through a series of reactions

lipopolysaccharide a lipid-sugar compound that forms the outer surface of some types of bacteria

lock-and-key model a model suggesting that the shape of a substrate molecule is an exact fit to the shape of an enzyme's active site

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

lower critical temperature the external temperature at which metabolic activity begins to rise, thereby increasing the output of heat

lymph vessel a thin-walled tube forming part of the lymphatic system, which collects and transports lymph, a plasma-like fluid, containing cell debris and bacteria, and returns it to the circulatory system

lymphocyte a type of leukocyte involved in adaptive immune responses

lyse to burst

lysis the process of a cell bursting (verb: to lyse)

lysosome a cytoplasmic organelle that contains digestive enzymes

lysozyme an antibacterial enzyme found in tears, saliva and other body fluids

M

macromolecule a large molecule that has an important structural or functional role in cells

macrophage a large white blood cell in tissues that phagocytoses pathogens

mast cell a cell located in the tissues, which when activated releases granules containing histamine

mast ring a ring of paper with small circular 'offshoots' impregnated with different antibiotics

mechanical digestion the physical break down and/or mixing of ingested substances, with no chemical change occurring

mechanoreceptor a detector that detects a physical stimulus such as touch and sound

membrane attack complex (MAC) a complex of complement proteins that form pores in the membranes of target cells, disrupting the phospholipid bilayer

memory cell a lymphocyte that is stored in the lymph nodes long after infection and recognises a pathogen it has already been exposed to

mesophyll a chloroplast-containing cell in plant leaves that performs photosynthesis

mesophyte a plant that grows in an environment with medium conditions of moisture

metabolic heat the heat generated by chemical reactions of metabolism

metabolism the sum of chemical reactions that maintain life within an organism

metabolite a transitional molecule formed and modified during metabolic reactions

microflora a community of micro-organisms, including fungi and bacteria, that live in or on another living organism

mitochondrial matrix the gel-like substance enclosed by the inner membrane of a mitochondrion

mitochondrion an organelle within the cytoplasm that is the site of aerobic cellular respiration, which releases energy for the cell

mitosis a type of cell division in which a parent cell produces two daughter cells with the same genetic material as each other and as the parent cell

monocotyledon (monocot) a flowering plant with a number of characteristics, including a scattered arrangement of vascular bundles in the stem

monocyte a white blood cell that circulates in the blood and matures into a macrophage when it moves from the blood into the tissues

monomer a small molecule that acts as a building block for macromolecules

monosaccharide a simple sugar, such as glucose, which cannot be broken down into smaller sugar molecules

morbidity the impact of a disease within a population, measured by the number of people affected by that disease

mortality the impact of a disease within a population, measured by the number of deaths caused by that disease

motor neuron a cell that transmits nerve impulses from the central nervous system to the effector

multipotent stem cell a stem cell that can develop into a limited number of cell types

muscle tissue a type of tissue made up of thin, very long thread-like cells called muscle fibres that contract when stimulated

myelin sheath the fatty layers of insulation surrounding the axon of a neuron; made of Schwann cells

N

negative feedback a cyclic process where responses counteract disturbances to keep concentrations of substances within narrow limits for optimal cellular function

nephron a specialised structural and functional unit within the kidney where elimination of waste molecules from the blood and regulation of solute and water levels occurs

nervous tissue a type of tissue containing cells that are highly specialised for transmission of nerve impulses

neuron a nerve cell that transmits electrical impulses in the body

neurotoxin a toxin that disrupts the functioning of nerves

neurotransmitter a hormone that is used by neurons to carry a signal across the synapse

neutrophil a phagocytic leukocyte found in the blood and tissues

nociceptor a detector that detects only intense (painful) chemical, mechanical or thermal stimulation

node of Ranvier a small space between the Schwann cells along the axon of a neuron

non-competitive inhibitor a molecule that binds to an enzyme at a site other than the active site; this changes the shape of the enzyme so that the substrate can no longer bind to the active site

non-infectious disease a disease that is not transmitted from one organism to another

non-self an agent (for example, cells, organisms, substances) that is not recognised by the immune system as being part of the organism itself; it is foreign

non-shivering thermogenesis an increase in the cellular metabolic rate in skeletal muscle and other tissues to increase heat production

non-specific when the response is the same regardless of the type of pathogen

nosocomial infection an infection that is spread in a healthcare setting

notifiable disease a disease that, if diagnosed, is required to be reported to public health authorities

nucleotide an organic compound composed of a sugar, a phosphate group and a nitrogenous base

nucleus the organelle in a eukaryotic cell containing most of the DNA; its function is to coordinate cell activities

nutrient a substance required by living organisms that are not directly involved in energy production, such as dissolved salts and vitamins

O

operculum a protective covering over the gills in bony fish

opsonisation a process in which a pathogen is coated with antibodies and marked for ingestion and destruction by phagocytes

organ a collection of different types of tissues working together to perform a particular function

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

organic compound a substance made up of molecules containing carbon (and also usually hydrogen and oxygen)

osmoconformer an organism in which the internal solute concentration changes with the concentration of solutes in the external environment

osmoregulation the processes by which internal water and solute concentration are maintained despite fluctuations in the external environment

osmoregulator an organism that has specialised mechanisms for regulating internal water and solute concentrations, despite concentration changes in the external environment

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

osmotic concentration the measure of solute concentration

oxyhaemoglobin the molecule in red blood cells formed by the combination of oxygen and haemoglobin

P

palisade mesophyll a densely packed layer of elongated cells that have many chloroplasts for photosynthesis

pandemic an epidemic that has spread across multiple continents or worldwide

parasite an organism that lives on or in its host for all or part of its life, causing harm and gaining nutrition from the host

passive immunity immunity characterised by the transfer of antibodies from one individual to another; this type of immunity does not show memory

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

pathogen a disease-causing agent

pathogen-associated molecular pattern (PAMP) a broad molecular pattern commonly shared by a number of pathogens

pathogenicity the capacity of a pathogen to cause disease

pattern recognition receptor a cell receptor that recognises molecular patterns commonly shared by a number of pathogens

peritubular capillary a capillary in a network surrounding the tubules of the nephron

permeable able to be passed through

phagocyte a cell that is capable of phagocytosis; includes macrophages and neutrophils

phagocytosis the bulk transport of solids into a cell inside a vesicle

phagolysosome a membrane-bound vesicle formed from the fusion of a phagosome and lysosome

phagosome a membrane-bound vesicle formed around a particle during phagocytosis

phloem the vascular tissue in plants, consisting of living cells, responsible for the transport of sugars from leaves to the rest of the plant

phospholipid a type of lipid in which the head end is hydrophilic and the tail end is hydrophobic

phosphorylation the addition of a phosphate group to a protein or other organic molecule

photoreceptor a detector that detects light

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

phytosterol a type of plant-derived lipid compound that is similar to cholesterol in structure and function

pilus a surface appendage in some bacteria that functions in adherence

plasma cell an effector B cell that has differentiated to become highly specialised for producing antibodies

plasmid a small ring of DNA that is not a chromosome, most often found in prokaryotes

plasmodesma a tiny channel through plant cell walls that allows communication between cells by sharing cytoplasm

plasmolysis the process in which the cell membrane pulls away from the cell wall because of water loss

plastid a double-membrane bound organelle involved with the synthesis and storage of materials, found in plant cells

platelet a cell fragment in blood that helps blood to clot

pluripotent stem cell a stem cell that can develop into many, but not all, of the cell types necessary for foetal development

polar a molecule with an uneven distribution of charge, giving it distinct charged ends

polymer a large molecule built up from linking smaller molecules together

polyphenol a group of compounds formed by plants to protect them from attack by herbivores and pathogens

polysaccharide a complex carbohydrate that is made by linking together simple sugars

positive feedback a cyclic process where responses reinforce and strengthen disturbances to normal cellular function

postsynaptic neuron the neuron receiving the signal from the synapse

presynaptic neuron the neuron sending the signal across the synapse

primary response the response generated when an antigen is encountered for the first time

prion a small infectious protein

processing centre the organ or organ system, usually the central nervous system, that receives signals from receptors and sends appropriate responses to effectors

prokaryotic cell a simple type of cell that lacks a nucleus and membrane-bound organelles; a member of domains Archaea or Bacteria

prostaglandin a group of lipids that can cause vasodilation, fever and pain

protein channel a passageway formed across the membrane for the movement of specific substances

proximal tubule the section of the tubule in the nephron that leads from the Bowman's capsule to the loop of Henle

psychrophile an organism that can grow and reproduce at low temperatures, ranging from -20°C to $+10^{\circ}\text{C}$

pyrethrin a potent insecticide produced by chrysanthemum flowers

pyruvate the end product of glycolysis

Q

quarantine the enforced isolation of individuals at risk of carrying disease to prevent the spread of that disease into healthy populations

R

receptor a structure that detects or receives stimuli

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 each kidney

renal pelvis the section of the kidney where urine is collected and directed to the ureter

resistance the extent to which an organism is or is not affected by an agent such as a pathogen or chemical toxin

response the action resulting from a stimulus

resting potential the state of a neural cell membrane at rest, when outside the cell is more positive than inside

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 involved in protein synthesis

root hair a thin extension of a root epidermal cell that greatly increases the cell's surface area

root pressure the pressure, caused by the uptake of water in the roots, that forces water further up the stem

rough endoplasmic reticulum endoplasmic reticulum with ribosomes attached

S

sap the thick, sugary cytoplasm that fills the phloem of plants

Schwann cell a cell that wraps tightly around the axon of a neuron to form the myelin sheath

second messenger a small molecule that relays a signal from receptors on the cell surface to target molecules inside a cell

secondary response the response generated when the body encounters a pathogen to which it has previously generated an immune response

self an agent (for example, cells, organisms, substances) that is recognised by the immune system of an organism as being part of that organism

sensory neuron a cell that transmits nerve impulses from the receptor to the central nervous system

sieve plate the tough cellulose walls between sieve tube cells that contain pores to allow the cytoplasm to flow between cells

sieve tube cell a long, tubular plant cell without a nucleus that forms sieve tubes, the main component of the phloem

signal transduction the process by which a cell converts one kind of signal into

another; occurs when an extracellular signal binds to and activates a receptor, which, in turn, alters intracellular molecules to bring about a cell response

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

soma the main cell body of a neuron

specialise to develop specific features suited to a specific function

specific when the response is directed against a particular pathogen

spongy mesophyll a loosely arranged layer of irregularly shaped cells that have a few chloroplasts for photosynthesis and plenty of air spaces

sporadically refers to a disease that occurs infrequently and irregularly within a population

starch an important energy-storing polysaccharide in plants

stasis showing little or no change over time

stem cell an unspecialised, immature cell capable of differentiating into a specialised cell

steroid a hydrophobic signal molecule produced from cholesterol

stimulus a signal that causes a response

stimulus-response model a model that shows how organisms respond to stimuli

stoma a controlled opening in leaves and young stems that controls the movement of gases into and out of a plant

stroma the jelly-like, semifluid interior of a chloroplast

substrate a substance that enters a reaction; also called a reactant or precursor

succulent a plant with thick, fleshy, water-storing leaves or stems

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

susceptibility the likelihood of an organism being infected by a pathogen

symbiotic a type of relationship between two individuals where at least one organism benefits

symptom a characteristic effect of a pathogen on the body

synapse (synaptic cleft) the tiny space between an axon terminal and its target (neuron, muscle or gland)

system a collection of organs that work together to perform a particular function

T

tannin a type of polyphenol found in plants; used to tan leather

tannosome a plastid that produces tannins

taproot a large main root deep underground for stability and long-term water supply

temperature danger zone the range of temperatures at which harmful bacteria can grow and reproduce in food

thermogenesis the process of heat production in organisms

thermoreceptor a detector that detects changes in temperature

thylakoid membrane the interconnected, folded membranes within chloroplasts

thymus gland a gland sitting inside the rib cage that is involved in the development of mature T lymphocytes

thyroid gland a gland in the neck that secretes iodine-containing hormones, including thyroxine

thyroid-stimulating hormone (TSH) a hormone produced by the pituitary gland in response to signals from TRH; stimulates the thyroid gland to produce thyroxine; also called thyrotropin

thyrotropin-releasing hormone (TRH) a hormone produced by the hypothalamus that activates the anterior pituitary gland to release TSH

thyroxine a hormone produced by the thyroid gland that acts to increase metabolic rate and regulate growth

tissue a group of specialised cells working together to perform a specific function

tolerance limits the highest and lowest values of a particular factor (for example, temperature, blood glucose levels) that an organism can tolerate

tolerance range the range within which an organism can function

torpor a state of decreased physiological activity, usually by a reduced body temperature and metabolic rate

totipotent stem cell a stem cell that can develop into any of the types of cells necessary for embryonic development

toxin a poisonous substance produced by living organisms

tracheid a dead elongated cell that forms the unspecialised part of the xylem of plants

transcription factor a regulatory protein whose function is to activate or inhibit transcription of DNA by binding to specific DNA sequences

translocation the bulk movement of substances around an organism

transmission the passing of an infectious disease from an infected host to another individual

transpiration stream a continuous column of water that moves up 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 that draws water up the xylem

triglyceride a simple lipid formed by linking glycerol with three fatty acids

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

turgidity the state of being swollen with water, which usually causes the cell to become rigid

U

upper critical temperature the temperature at which the body's cooling mechanisms fail to keep the body temperature stable and above which the metabolic rate increases with rise in external temperature

upregulation when a cell is prompted to produce more of a particular cellular component, such as enzymes or receptors

urea a nitrogenous waste that is a less toxic breakdown product of ammonia in mammals; it is excreted in urine

uric acid a nitrogenous waste produced by desert animals, birds, reptiles and insects

urine a fluid containing water, urea and uric acid, which is expelled from the kidneys

V

vaccine an injected solution of antigens or pathogens that is designed to elicit

a primary response and promote the formation of memory cells

vascular describes vessels that conduct fluid

vasoconstriction the constriction of blood vessels by the surrounding smooth muscle cells, which increases blood pressure and redirects blood flow away from the constricted vessel

vasodilation dilation (widening) of blood vessels, particularly arterioles

vector a living organism that transmits pathogens from one host to another; a vehicle used to transfer DNA sequences from one organism to another

vein a blood vessel that carries blood to the heart

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

vessel element a dead cell that is perforated at each end and stacked vertically, forming the specialised part of the xylem in flowering plants

villus an elongated projection from the lining of the small intestine that hugely increases the surface area and thus the capacity for exchange of materials

virulence refers to the ability of a pathogen to cause severe disease within its host

virulence factor a characteristic that helps bacteria to invade the host, cause disease and evade host defences

W

wilting becoming limp and floppy in plants

X

xanthophyll a yellow pigment found in leaves and flowers

xerophyte a plant adapted to dry conditions

xylem the vascular tissue in plants, consisting of dead cells, responsible for the bulk transport of water and nutrients up the plant

Z

zoonotic a disease that animals pass to humans; infections that are naturally transmitted between vertebrate animals and humans

zygote a cell formed by the union of two sex cells; usually fertilisation of an egg cell by a sperm cell

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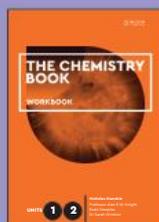
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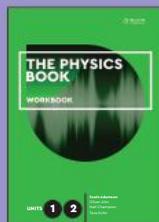
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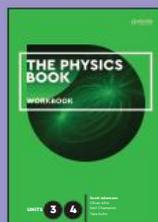
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